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Drainage and Environmental Sustainability

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Khuzestan Water and Power Authority

The International Commission on Irrigation and Drainage (ICID), established in 1950 is the leading scientific, technical and not-for-profit Non-Governmental Organization (NGO). ICID, through its network of professionals spread across more than a hundred countries, has facilitated sharing of experiences and transfer of water management technology for over half-a-century. ICID supports capacity development, stimulates research and innovation and strives to promote policies and programs to enhance sustainable development of irrigated agriculture through a comprehensive water management framework.

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Rahim Meydani
Deputy Minister of Energy for Water and Wastewater Affairs and Chairman of IRNCID

Dear Participants,
Having the honor to welcome all respectful delegates and accompanying persons from various countries around the world, I am very pleased to inform you that the 13th International Drainage Workshop (13th IDW) is currently being held in the beautiful city of Ahwaz, in Khuzestan Province as one of the main agricultural and economic hubs of Iran.
Indeed the event is a valuable opportunity for drainage scholars and experts from all over the world to bring together the technologies, experiences and the latest findings of drainage to be further investigated with the aim of coming up with new approaches and solutions towards better and efficient agriculture with due consideration to environmental aspects of drainage and promotion of drainage management for environmental sustainability
As we are all aware, the International Commission on Irrigation and Drainage (ICID) once every two years holds international drainage conferences in one of the member countries. The first International Drainage Conference (IDW) was held in Wageningen, The Netherlands in 1978, and the last one was held in St. Petersburg, Russia, June 2014. Now we are in the stage of hosting the 13th International Drainage Workshop in Ahvaz, with its pleasant weather at this time of the year. This event is organized by IRNCID and hosted by Khuzestan Water and Power Authority (KWPA).
Worth noting that, Khuzestan province is the birthplace of drainage in Iran. About 60 percent of drained area of the country is in Khuzestan. In addition, there are many ancient unique hydraulic structures in the region such as Chogha Zanbil Ziggurat, an ancient complex built around 1250 B.C. accompanied with water treatment facilities.
I hope the participants of the workshop will find the opportunity to visit modern drainage networks and enjoy the ancient hydraulic structures dating back to over 3000 years.
I would encourage your participation, appreciate your kind cooperation and look forward to reviewing the fruitful results of this fabulous event. Last but not least, I intend to submit the outcomes of this international event in the fourth coming official meetings I have with the Commission on Agriculture, Water and Environment of the Islamic Republic of Iran Parliament.
Wishing you a very pleasant and memorable stay.

M. R. Shamsaei
Chairman and Managing Director
Khuzestan Water and Power Authority

On behalf of the Khuzestan Water and Power Authority (KWPA), I have the pleasure to welcome all researchers, scholars and experts to participate in the 13th International Drainage Workshop (13IDW) which will be held in Ahwaz, Iran. Unique capacities in water, soil and climatic conditions has made Khuzestan plain an attractive place to different ethnic groups in years. Double cropping is possible here in Khuzestan province having two summers and mild winters, a unique characteristic throughout the country. Among other characteristics are salt affected heavy soils requiring drainage facilities. The Shavoor open drainage system was constructed back in 1956 followed by the development of sugarcane plantation covering 12,000 hectares of Haft Tappeh as the first subsurface drainage system in the 1970s. These developments shows the historic significant of the development of drainage systems in the south western Iran.

I am quite sure that being familiar with the technical tours in the province, along with the most interesting and tourist worthy cultural tours brings you unforgettable moments of your stay in Iran. During the workshop, you may enjoy visiting historical unique hydraulic structures in Khuzestan including Choqazanbil, the only remnant of an ancient city that was constructed approximately in 1300 BC. You should not miss the chance to visit Shushtar historical hydraulic system, a masterpiece of creative genius be traced back to Darius the Great in the 5th century B.C.

I hope that the workshop provides you with the chance to be familiar with KWPA's years of experience in irrigation and drainage network developments, adapting new design criteria, followed by finding the best practice managements in favor of the environment. We will do our best to take all the opportunities to provide all participants a memorable stay and a successful workshop.

Dr. Saeed Nairizi
President, ICID

Water and food security will continue to remain as the main global concerns for the years to come. The growing demand on food requires 60% increase in world food production by the year 2050 where this target would be achieved if such enhancement in developing countries doubles over the next 30 years. Irrigated agriculture is expected to play the major role in this ambitious goal and global endeavor. Higher yields and expansion of irrigated area supported by innovation in technology and irrigation revitalization appear to be the main potential options, particularly for developing countries, to meet their food security challenges.

However, irrigation development inhere adverse environmental consequences which should be managed appropriately. To minimize negative impacts of irrigation practices such as water logging and salinity and hence to maintain or improve the land productivity, drainage of agricultural land is essential and considered as a part of integrated land and water resources management approaches.

ICID through its Working Group on Sustainable Drainage and assisted by the Iranian National Committee on Irrigation and Drainage (IRNCID) and hosted by Khuzestan Water and Power Authority (KWPA) is organizing the 13th International Drainage Workshop, IDW 13, in Ahwaz, Iran 4-7 March 2017. Under the theme of "Drainage and Environmental Sustainability" the Workshop will focus on (i) Measures to lower volume of drainage water; (ii) Measures to improve drainage water quality; (iii) Adoption of new design criteria in favour of the environment; and (iv) Application of alternative drainage methods.

I am delighted to see the enthusiasm of the host to expect a large number of participants consisting of decision makers and officials, academician, scientists, and drainage system managers from different countries who are interested in sharing their experiences and being engaged in various technical deliberations.

The workshop program also consists of several side events and technical tours which definitely attract the participants with a variety of tastes. For instance two round tables on "Alternative Drainage Methods" and "Water Reuse" along with the second management board of ICID-International Research Program on Irrigation and Drainage (ICID-IRPID) - Iran Regional Node (IRPID- RN- I) and several side lectures in different universities such as "Role of Drainage in a Historical Perspective and Challenges for the Future" and many more are amongst the programs of this international event.

A fabulous exhibition is also being organized during these days with the attendance of around 25 companies demonstrating their products, activities and achievements in the field on Drainage.

I am quite confident that we will all benefit from the innovative methods and products presented in the exhibition.

I look forward to meeting you all in person during this important event.

International Drainage Workshop

The International Commission on Irrigation and Drainage has held technical and professional conventions on various topics related to irrigation and drainage during its active years.
The professional workshops includes, the International Drainage Workshop held in 1978, and ever since, it has taken place in one of the member countries. The upcoming convention is the 13th International Drainage Workshop, which will be held in Ahwaz, Iran, during the 4-7 March 2017.

Previous Workshops

12th IDW	St. Petersburg, Russia	June 2014 23-26
11th IDW	Cairo, Egypt	September 2012 23-27
10th IDW	Helsinki, Finland/ Tallinn, Estonia	July 2008 6-11
9th IDW	Utrecht, The Netherlands	September 2003 10-13
8th IDW	New Delhi, India	January - 4 February 2000 31
7th IDW	Penang, Malaysia	November 1997 21 – 17
6th IDW	Ljubljana, Slovenia	April 1996 23 – 21
5th IDW	Lahore, Pakistan	February 1992 15 – 8
4th IDW	Cairo, Egypt	February 1990 24 – 23
3rd IDW	Columbus, Ohio, USA	December 1987
2nd IDW	Washington, USA	December 1982 12 – 5
1st IDW	Wageningen, Netherlands	May 1978 17 – 16

Keynotes

VALUE ENGINEERING FOR UNBIASED DESIGN IN IRRIGATION AND DRAINAGE PROJECTS (CASE STUDY: RAMHORMOZ IRRIGATION AND DRAINAGE PROJECT IN IRAN)

Kamran Emami[1], Mojtaba Akram[2], Saeed Pourshahidi[3], Jafar Al-e-Tayeb[4]

Abstract

All designs are biased due to the expertise, experiences and orientations of the designers and clients. Value engineering is a proven technique for improving the value of projects, products and services. The value engineering methodology is based on the synergy and creativity of an independent team. The independence and outside perspective of the team would reduce and bias in the design and consequently would result in saving and enhanced benefits for the projects.

Value Engineering Change Proposals (VECP) are post-award value engineering proposals made by construction contractors during the course of construction under a value engineering clause in the contract. These proposals may improve the project's performance, value and/or quality, lower construction costs, or shorten the delivery time, while considering their impacts on the project's overall life-cycle cost and other applicable factors. The Ramhormoz project is medium size 5500 hectares on-farm project located in Khuzestan province in southwest of Iran. Value Engineering Change proposal submitted by the contractor in 2014 included 2 proposals on changing the orientation and geometry of drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project. This paper describes the procedure of the value engineering study and compares the benefits of the proposals to the base case specifications.

Introduction

Large and medium scale irrigation systems worldwide account for about 60 percent of the irrigated areas but are the ones that present the most severe gap between expected and actual performance. Efforts to improve the performance of these systems have been mixed because of a number of misconceptions of the problems. In this context, Value

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[2] KuritKara Consulting Engineers
[3] KuritKara Consulting Engineers
[4] KuritKara Consulting Engineers

Engineering (VE), has proved to be an effective and efficient methodology for recognizing and removing unnecessary costs in larges projects. The results of application of VE in 6297 highway projects in U.S. are shown in table 1. The total estimated cost of the projects studied is very close to 400 Billion USD. Consequently, the saving of $ 25.4 which is equal to 6.22% of the total cost, clearly indicates that all projects have unnecessary costs and can be improved.

Table1. Summary of Past VE Saving Federal-Aid Highway Projects (1997-2014) in U.S.A

YEAR	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Sum
Number of VE Studies	369	431	385	388	378	377	344	324	300	242	316	388	427	402	378	352	281	215	6297
Cost of VE Studies Plus Administrative Cost (Million $)	5	7	7	8	8	9	8	7	10	8	12	12	17	14	13	12	9.8	8.7	175.5
Estimated Costs of Projects Studied (Million $)	10093	17227	18837	16240	18882	20607	20480	18672	31576	21527	24810	29596	29160	34248	32257	30273	23000	2090	399575
Value of Approved Recommendations (Million $)	540	769	846	1128	865	1043	1016	1115	3180	1650	1970	2530	1700	1980	1010	1145	1150	1730	25367
Return on Investment	1:106	1:117	1:113	1:145	1:119	1:116	1:120	1:145	1:325	1:240	1:157	1:205	1:100	1:146	1:80	1:96	1:118	1:200	1:146
% of Project Costs Saved	8.35	4.47	4.49	6.94	4.58	5.06	5.42	5.97	10.09	8.29	7.95	8.53	5.84	5.79	3.12	3.78	5	8.32	6.22

The Reasons for unnecessary Costs in projects can be summarized as follows:

- ❑ Shortage of time
- ❑ Misleading information
- ❑ Ambiguous goals, objectives, scope etc.
- ❑ Hasty decisions based on false assumption
- ❑ Lack of ideas
- ❑ Lack of funds
- ❑ Resistance to Change
- ❑ Unrealistic temporary circumstances
- ❑ Politics
- ❑ Bad habits and attitudes, beliefs
- ❑ Over design & Unrealistic safety factors
- ❑ Continues changing in the owner requirements
- ❑ Lack of communication coordination
- ❑ Using unsuitable standards & specification
- ❑ No LCC estimate …… and more….

Many of the reasons presented are the results of biased thinking and design. All designs are biased due to the expertise, experiences and orientations of the designers and clients. The value engineering methodology is based on the synergy and creativity of an independent team. The independence and outside perspective of the team would reduce the bias in the design and consequently would result in saving and enhanced benefits for the projects. The main strengths of VE are shown in figure 1:

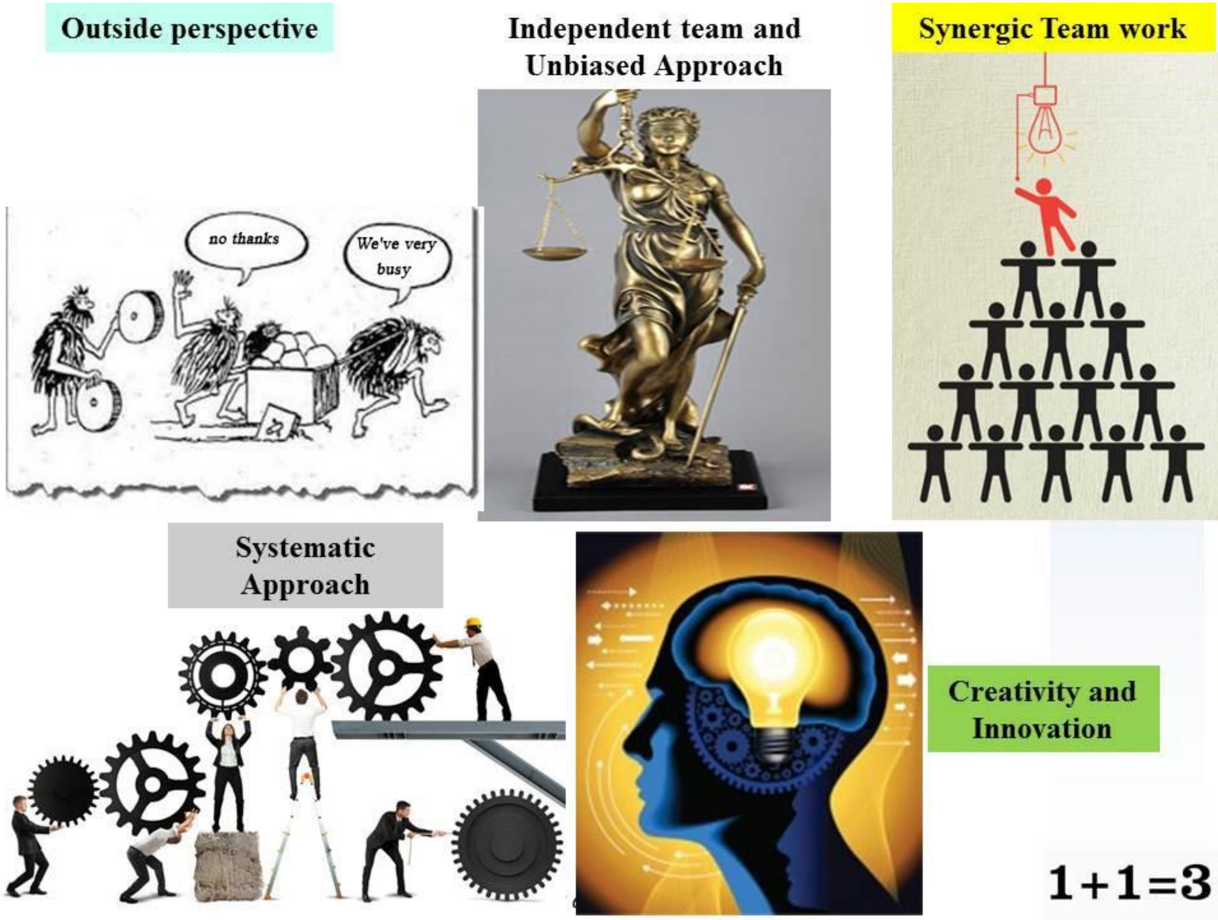


Figure 1. The main strengths of Value Engineering for removing unnecessary costs

In Bulletin 144 of ICOLD on "Cost Saving in dams", the biased design and the role of VE to the address it have been discussed:

"There can be a tendency to copy previous designs or arrangements. From the perspective of the designer and owner, this can give the comfort of previous acceptable behavior. However, given the variety of such standardized arrangement it is highly unlikely that they are at present the most economical solution in each case. In some cases, designs may have been developed to fulfill a particular set of needs, some of which may not apply elsewhere. Similarly a new requirement may be needed in a particular case when it is not addressed to previous design. VE is a useful technique to address such issues."

Consequently agencies adopted VE to:

- Save money and ensure cost-effectiveness,
- Improve quality,
- Eliminate unnecessary design elements, and
- Foster innovation and improve productivity

For example the U.S. Army Corps of Engineers have been using VE for more than 50 years and they have presented the main benefits of VE as follows:

- To shorten schedules significantly;
- To provide quality projects with reduced budgets;
- To ensure full project coordination with all stakeholders;
- To assist in preparing project scopes, negotiating environmental contracts, planning optimization, and project review;
- To provide planning assistance to states/communities;
- And to assist in program reviews.

Based on worldwide experiences, ICID has formed a Task Force on Application of Value Engineering for saving in Irrigation and Drainage Projects (TF-VE) to promote the application of Value Methodology (Value Engineering, Value Analysis, Value Planning, Value Management and Value Engineering Change Proposal (VECP)) in irrigation, drainage and flood management projects to increase benefits, reduce cost and ensure sustainable irrigated agriculture. A recent application of VE in Ramhormoz irrigation and drainage project in Iran is presented as a success story of VE in a drainage project.

Value Engineering study of irrigation and drainage project in Ramhormoz

The Ramhormoz project (third development block) is medium size 5500 hectares on-farm project located in Khuzestan province in southwest of Iran (Figure 2 and 3). The estimated cost of the project is approximately $10 m. To prepare Value Engineering Change proposal (VECP), a VE study was undertaken in 2014. Value Engineering Change proposal submitted by the contractor in 2014 included 2 proposals on changing the orientation and geometry of drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project.

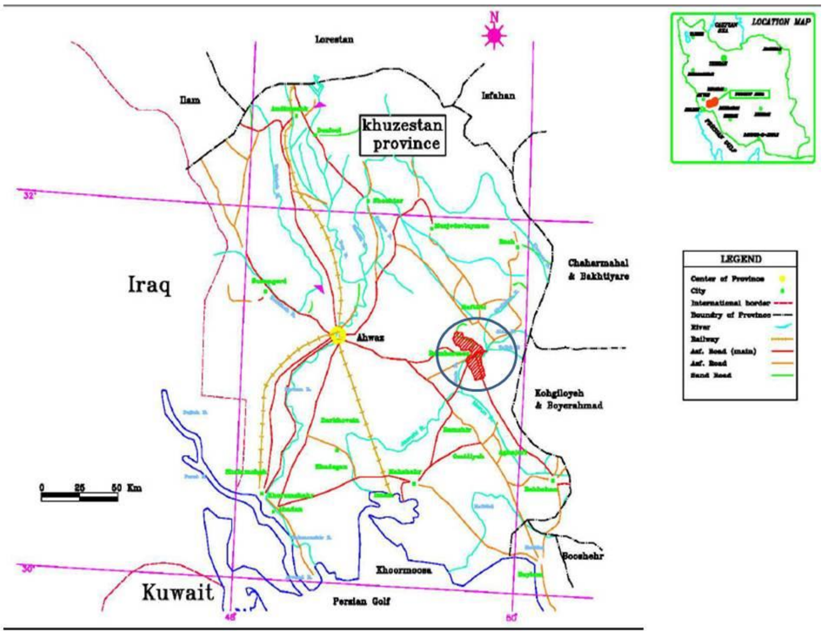


Figure 2. The location of Ramhormoz Project

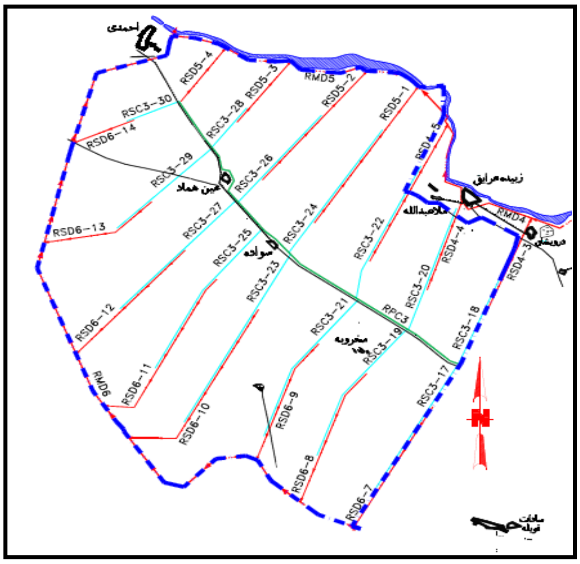


Figure 3. The general layout of Ramhormoz Project (third development block)

The members of the VE team were selected from Independent experts and engineers from the client, the consultant and the contractor. A few observers were also present in the workshops. The total professional experience of the team exceeded 400 years. The VE team is shown in Figure 4.

Figure 4. The VE Team of Ramhormoz Project ((Third development block)

The VE Job plan

The FHWA defines VE analysis as: A systematic process of review and analysis of a project, during the concept and design phases, by a multidiscipline team of persons not involved in the project. Simply stated, VE is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs in a project.

The "systematic application of recognized techniques," referred to in the above definition is embodied in the VE Job Plan. The Job Plan is a systematic and organized plan of action for conducting a VE analysis and assuring the implementation of the recommendations. The methodology utilized for any VE analysis shall follow widely recognized systematic problem-solving procedures that are used throughout private industry and governmental agencies.

The Job Plan contains seven phases. The first phase is completed prior to the commencement of the VE analysis, six of which are performed by the VE team and one that is conducted to "close out" the process. Each phase of the Job Plan includes several tasks. It is the melding of the various tasks and techniques, coupled with finesse in their application that makes the VE process work.

VE Job Plan consists of the following steps:

- Investigation (gathering of information)
- Function Analysis (analyzing functions, worth, cost, performance and quality)
- Creative (speculating using creative techniques to identify alternatives that can provide the required functions)
- Evaluation (evaluating the best and lowest life-cycle cost alternatives)

- Development (developing alternatives into fully supported recommendations)
- Presentation (presenting VE recommendations for review, approval, reporting and implementation)
- Close Out (Implementing and evaluating of the outcomes of the approved recommendations)

The 3-day workshop was conducted according to formal phases of the VE Job plan (above). After Information phase, the team prepared the FAST diagram shown in Fig 5. The diagram would improve creativity and help the team using Pareto principle (also known as the 80/20 rule or the law of the vital few) which help team to focus on the most important functions of the project.

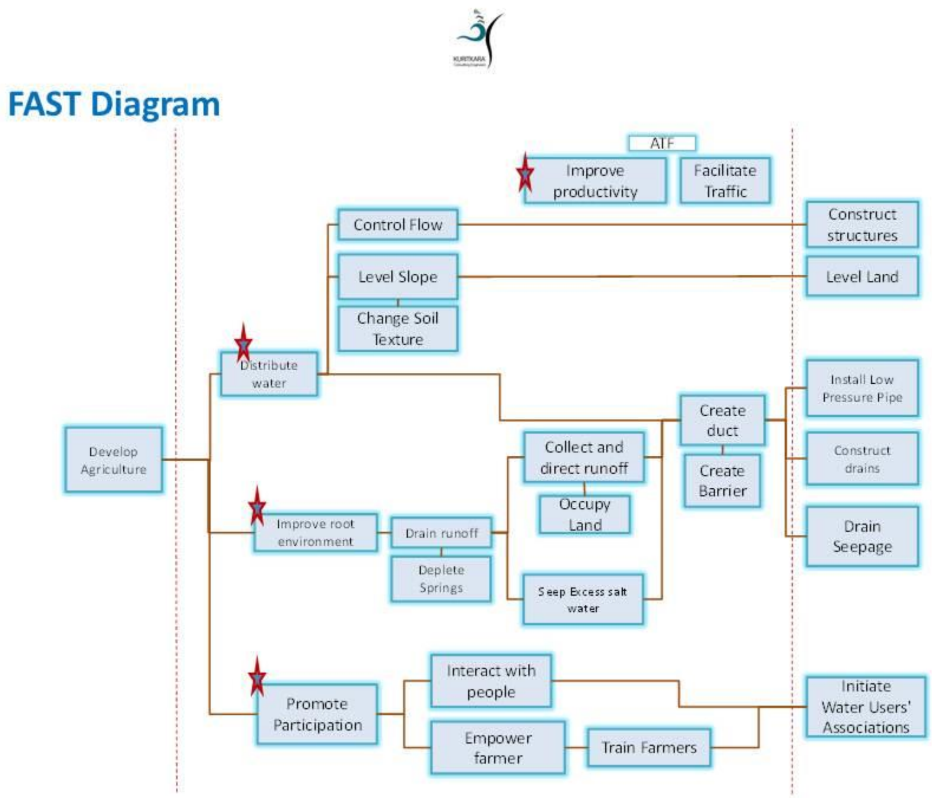


Figure 5. The Fast Diagram of Ramhormoz Project ((third development block)

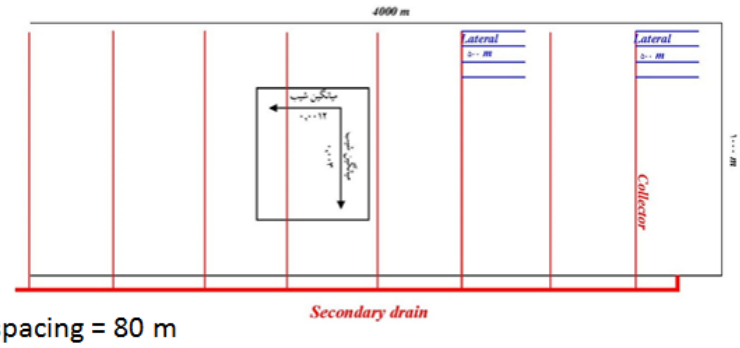
Results and discussion

In Creative phase, the team generated ideas for improving the Value of the project. After screening the ideas, the selected ideas were developed and presented to the senior managers of the client. The approved proposals of the VE study are as follows:

1) Change in lateral alignment according to the natural slope

The base case is shown in figure 4.

Layout of subsurface drains (Base Case)



Lateral spacing = 80 m

Lateral length = 500 m

Pipe collector spacing = 80 m

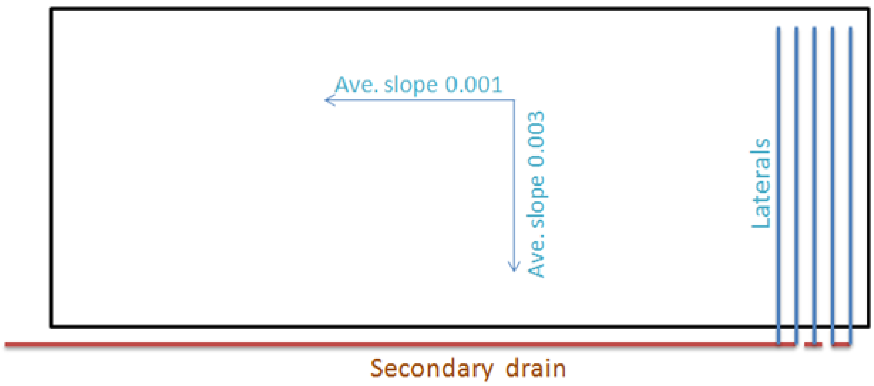
Number of collectors = 8

Lateral diameter = 100 and 125 mm

Collector diameter = 160 and 300 mm

Figure 5. The base case for layout of subsurface drain

Layout of subsurface drains (Proposed Case)



Lateral spacing = 100 m

Lateral length = 1000 m

Pipe collector : no needed

Lateral diameter = 100 and 125 mm

Figure 6. The VE proposal for Layout of subsurface drains

In original design, the laterals are connected to the collectors and the collectors to the secondary drain (Figure 5). In VE proposal, the laterals are directly connected to the secondary drain by the virtue of higher slopes. The seepage analysis has validated that the proposed design of the VE team was adequate for drainage purposes. Benefits of alteration of the direction of lateral drains were:

- Cost Saving equivalent to 0.9 million USD;
- No need for any type of collector drains;
- Constant depth of the laterals;
- Lower sedimentation risk in the drains because of higher water velocity; and
- Easier maintenance.

2) Change distance between the laterals and their depth

By changing the general layout of the laterals, the slope of the laterals would increase and consequently the distance between laterals can be increased. On the other hand, the depth of the laterals can be reduced by 20% considering the ground conditions and recommendations of drainage experts. Apart from cost saving equivalent to 2.3 million USD, these modifications would result in:

- Better adaptation to the natural slope;
- Constant drain depth along the lateral;
- Less sedimentation because of steeper slope;
- No need for any type of collectors;
- Less land loss in comparison to the base case.

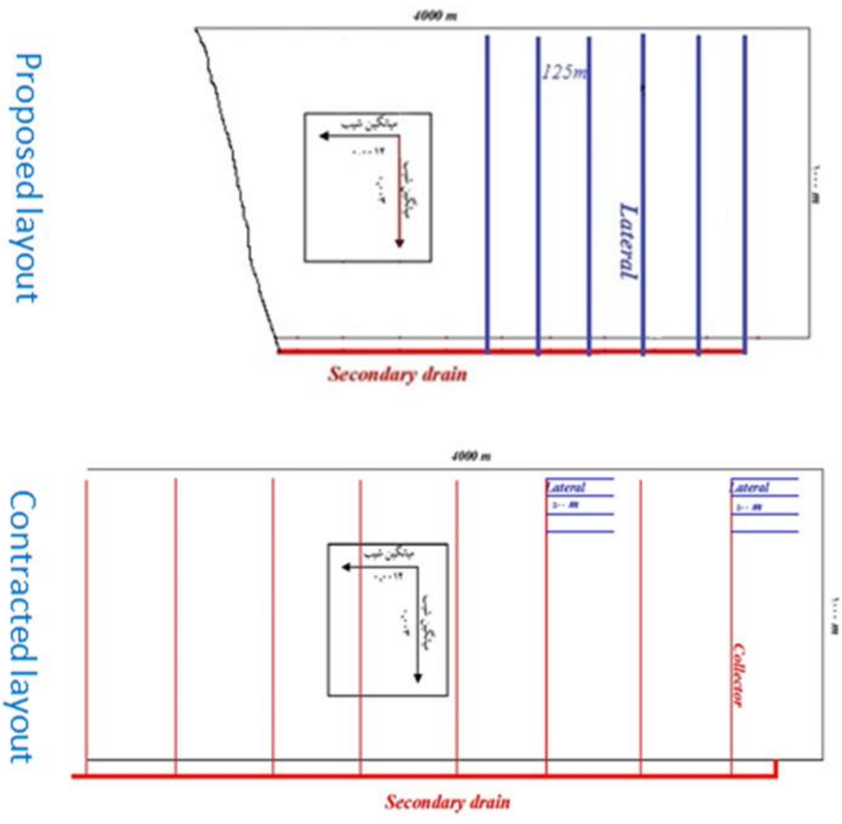


Figure 7

Conclusions

VE is a proven technique for improving the value of any projects especially larger ones. While "Food security" is one of the greatest challenges of 21st century, VE can have many benefits in large water projects:

- To shorten schedules significantly;
- To provide quality projects with reduced budgets;
- To ensure full project coordination with all stakeholders;
- To assist in preparing project scopes, negotiating environmental contracts, planning optimization, and project review;
- To provide planning assistance to states/communities;
- And to assist in project reviews.

The VE team of Ramhormoz project developed 2 proposals on changing the orientation and geometry of the drainage laterals. The approved savings by the client was estimated to be about 3.2 million USD (16% of the total cost). The proposals would also improve the schedule of the project.

Acknowledgement

The authors wish to thank all the members of Ramhormoz VE team whose expertise, engineering ethics and synergy have improved the Value of Ramhormoz project drastically.

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TRANSPORT OF VIRUSES AND COLLOIDS IN PARTIALLY-SATURATED SOIL AND GROUNDWATER

Seyed Majid Hassanizadeh[1,*], Gholamreza Sadeghi[2], Zhang Qiulan[3], Jack Schijven[4]

Abstract

Surface water is often used for the recharge of aquifers used in drinking-water production. Surface water is often contaminated with pathogenic micro-organisms and viruses. These pathogens have to be removed to produce safe drinking water. One effective way is the passage of surface water through soil, as is the case in bank filtration, dune recharge, and deep-well injection. Dune recharge is widely applied in The Netherlands, where surface water, after some pretreatment, is fed into canals in protected dune sands. Then, water is abstracted after 50 to 60m of passage through the soil. To assure production of safe drinking water from surface water, adequate travel times and travel distances are needed. In this regard, it is important to determine various factors that affect the rate of removal of pathogenic viruses during soil passage. These factors include hydraulic conditions (such as flow velocity and saturation) and geochemical conditions (pH, ionic strength, concentration of calcium, etc.).

In some parts of the world, use of grey water (e.g. kitchen/shower wastewater or treated wastewater) for agricultural purpose is practiced or is being considered. In such cases, it is essential to determine whether the infiltrating water will be droid pathogenic micro-organisms when it reaches groundwater.

In this lecture, we present results of a large number of laboratory and field experiments for the study of movement of bacteriophages (these are harmless viruses that are used as surrogates for pathogenic viruses) through soil and colloids through a micro-model (an artificial porous medium). Experiments are carried out under a variety of conditions: a range of pH values, a range of ionic strength values, different Ca concentrations, and

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different water saturations; all under steady-state flow conditions. This data are used to derive (empirical) relationships between removal rate coefficients and geochemical conditions as well as soil moisture content. In the case of unsaturated flow, the role of air-water interfaces in the removal of viruses has been also investigated.

We have also performed experiments under transient flow conditions both in sand columns and in micro-models, where water content has been changed significantly. Our experiments as well as other researchers' results have shown that both drainage and imbibition fronts cause a remobilization of adsorbed viruses. We discuss the mechanisms behind this remobilization and provide evidence from pore-scale visualization experiments. Such a remobilization was also observed when the calcium concentration was changed significantly.

DRAINAGE MANAGEMENT FOR CROP PRODUCTION AND WATER QUALITY BENEFITS

Ali Madani[1]

Abstract

Nearly all agricultural soils require drainage. Artificial or improved drainage is essential to produce crops on most agricultural soils. Subsurface (tile) drainage systems are designed and installed to remove excess water from the soil profile to improve traffic ability and to facilitate timely seedbed preparation, planting, and harvesting. In dry regions, where irrigation is practiced, drainage systems may be required to maintain a suitable salinity level in the soil profile.

While some of the most productive agricultural soils are artificially drained, artificial drainage is blamed as a major contributor to water pollution. Results of numerous studies throughout the world have shown concentrations of agri-chemicals, pathogens, and other detrimental pollutants in subsurface water as well as groundwater.

Research has shown that management strategies can be used to reduce pollutant loads from agricultural drained lands. These strategies range from agricultural drainage water management to cultural and structural measures. A number of approaches have been identified as cultural and structural practices. These practices include routing of drainage water through constructed wetlands, precision agriculture, and nutrient management. This presentation will focus on these strategies as well as the use of simulation modeling on a watershed scale.

[1] Nova Scotia Institute of Agrologists, Nova Scotia, NS, Canada

IMPROVING IRRIGATION AND DRAINAGE EFFICIENCY USING EDDY COVARIANCE, SCINTILLOMETERY AND COSMOS TECHNOLOGIES

Ragab Ragab[1]

Abstract

In the context of increased pressure on water resources for food production, where globally some regions are already in water crisis, it is necessary to maximize yield for a given water resource. For irrigated crops, this means not only more efficient application of water, but also an improved understanding of crop water requirement.

Modern technologies to measure actual evapotranspiration (ETa) such as Large Aperture Scintillometer (LAS) and Eddy Covariance (EC) instruments can offer alternatives to the widely used potential evaporation equations such as those of FAO. Potential Evapotranspiration, ETp based on equations represent the atmospheric demand for water rather than the actual crop demand for water. Actual evaporation Eta represents the crop water requirement and is expected to be lower than the potential evapotranspiration, ETp.

The very recent field experiment results showed significant differences between actual evaporation values measured by the Eddy Covariance and Scintillometer when compared with the worldwide used potential reference evaporation, ETo, calculated from meteorological data using Penman-Monteith equation and the crop potential evaporation, ETc, which is based on the ETo and the crop coefficient, Kc. The ETc and ETo showed higher values than those of ETa obtained by Eddy and Scintillometer. On average the actual evaporation measured by Eddy Covariance and Scintillometers represented nearly 50% of the ETo. These are quite significant differences.

These results indicated that there is a potential for water saving in irrigation, should the crop water requirement be based on actual measured evapotranspiration rather than on the calculation based on the widely used Penman–Monteith equation and possibly other

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methods of calculating potential evaporation, not the actual evaporation. This proves that for realistic crop water requirement estimation, one should consider methods based on crop demand rather than the atmospheric demand for water.

The exact percentage of water saving by using these modern technologies, will differ between seasons and crops but will always be actual irrigation water requirement. Another benefit is that these modern technologies of measuring the actual evaporation do not need the crop coefficient Kc, which for many irrigation practitioners is difficult to obtain.

The field results showed that soil moisture obtained by COSMOS was comparable with those obtained for the top 50-60 cm soil layer soil moisture measured by sensors, soil cores and profile probes and simulated by the SALTMED model. This indicates that there is a possibility that COSMOS probe's effective depth could be within the top 50-60 cm of the irrigated lands particularly during the summer crop seasons. In such case, knowing that almost 80% of the crop root system is accommodated within the top 50-60 cm, the COSMOS measurement could be useful for monitoring the soil water status and subsequently soil moisture deficit in the root zone. The Cosmos results could be made operational for irrigation managers to determine when and how much to irrigate to avoid harmful water stress. The COSMOS technology is one step in the right direction as it provides continuous, integrated, area based values and solves the problem of spatial variability often found in point measurements in relation to the soil spatial heterogeneity. This method could also be used to determine the soil moisture deficit, hence determine when and how much to irrigate.

The above modern technologies, Eddy Covariance, Scintillometer and COSMOS proved their suitability for use in agricultural water management. They can improve water use efficiency, save water, reduce drainage volume, and reduce water logging and salinity.

AGRICULTURAL WATER MANAGEMENT AND FOOD SECURITY IN A SUSTAINABLE ENVIRONMENT

Bart Schultz[1]

Abstract

The Worlds' population is expected to grow from 7.4 billion at present to 10.0 billion by 2055. Combined with the expected rise of living standards, improvement in life expectancy, urbanisation and growing demands for animal feed and energy from crops this requires, among others, a substantial increase in cereal production to ensure food security. Overall, global cereal production meets the current demand and the global cereal stock is stable. Achieving the required increase in cereal production in a sustainable way seems to be possible.

In the framework of rural reconstruction irrigation and drainage will have to play a major role in achieving the required increase in cereal production, while most of the increase will have to be realised at already cultivated land and land reclamation can only result in a relatively small contribution. This implies a focus on approaches and solutions that on the one hand will result in the required increase and on the other hand are environmentally sustainable. In light of this upgrading, modernisation and expansion options for irrigation and drainage schemes will be presented with special attention to the role of drainage. This will be done with due attention for the Sustainable Development Goals (SDG) and the draft Action Plan 2030 of the International Commission on Irrigation and Drainage (ICID).

Introduction

The Worlds' population is expected to grow from 7.4 billion at present to 10.0 billion by 2055. Combined with the expected rise of living standards, improvement in life expectancy, urbanisation and growing demands for animal feed and energy from crops

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this requires, among others, a substantial increase in cereal production to ensure food security. In the framework of rural reconstruction irrigation and drainage will have to play a major role in achieving the required increase in cereal production. This implies a focus on approaches and solutions that on the one hand will result in the required increase in cereal production and on the other hand are environmentally sustainable. In light of this upgrading, modernisation and expansion options for irrigation and drainage schemes will be presented with special attention to the role of drainage in the arid and semi-arid zone. This will be done with due attention for the Sustainable Development Goals (SDG) and the draft *ICID Action Plan 2030* of the International Commission on Irrigation and Drainage (ICID).

Population, population growth and urbanisation

The World population is expected to grow from 7.4 billion at present to 10.0 billion by 2055, with thereafter a limited further growth till 11.2 billion by the end of the Century (Figure 1). The growth is especially expected in urban areas of countries with a low, medium and high Human Development Index (HDI) in Asia as well as in sub-Saharan Africa (Figure 2).[1] In addition the standard of living in countries with a medium and high HDI - almost 75% of the World population - is rapidly rising, among others resulting in changes in diets that require more and diversified food per person and in general more water to be produced. A third development is the significant improvement in life expectancy from 46 years in the 1950s to 71.4 years by 2015 (World Health Organisation (WHO), 2014 and 2017).

[1] Low Human Development Index. Most of the countries in Africa, five countries in Asia, one country in Central America and one in Oceania;

Medium and High Human Development Index. Most of the Eastern European countries (including Russia), most of the countries in Central and South America and in Asia (including China, India, Indonesia and Bangladesh) and several countries in Africa;

Very High Human Development Index. Most of the countries in Western and Central Europe, North America, several countries in Central and South America and in Asia, and the larger countries in Oceania.

World food situation and prospectives

Up to present cereal production has been in line with the increase in utilisation and the global cereal stock even increased in the past years (Figures 3 and 4).

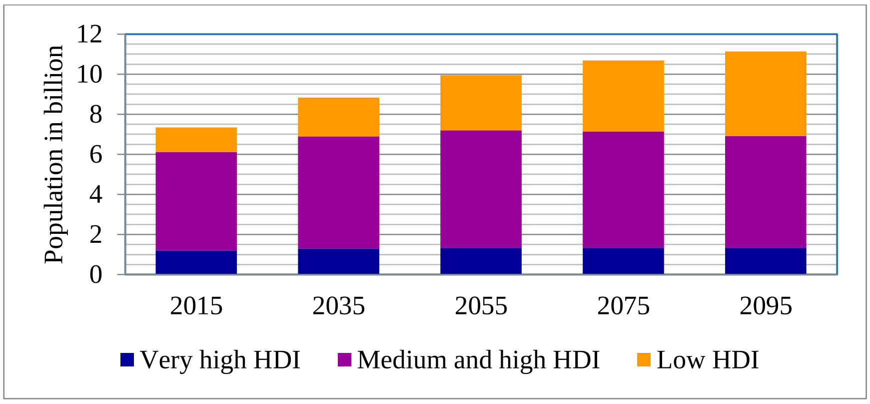
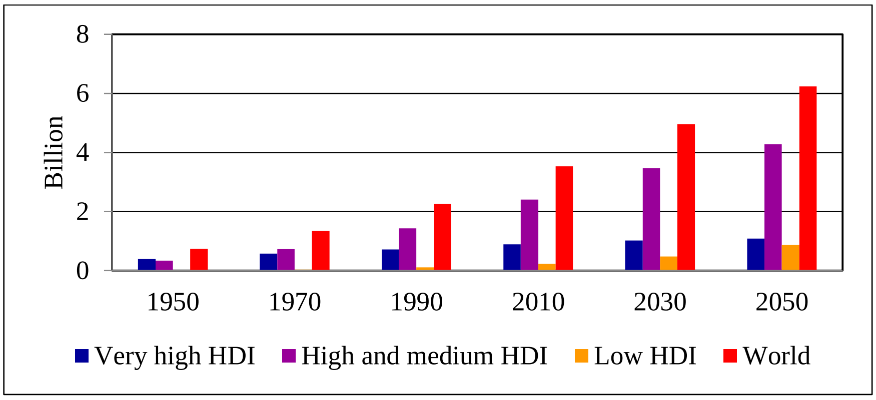
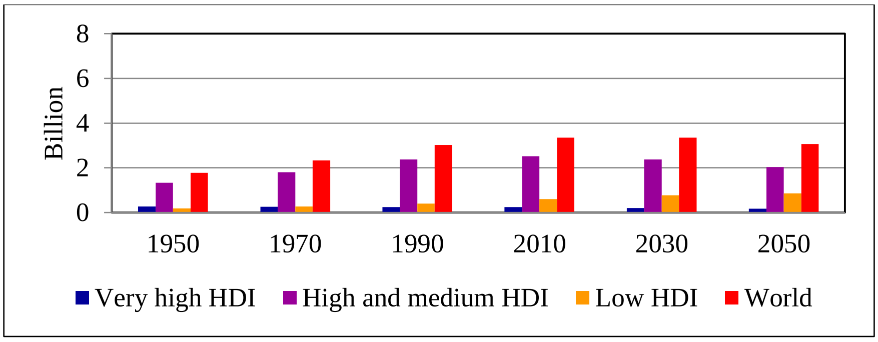


Figure 1. Population and population growth (updated after Schultz, 2012; based on data of the United Nations Department of Economic and Social Affairs, Population Division, 2015)



(a)



(b)

Figure 2. Development from 1950 - 2050 of urban (a) and rural (b) population in the three different groups of countries and at the global scale (updated after Schultz, 2012; UN Population Division, 2014)

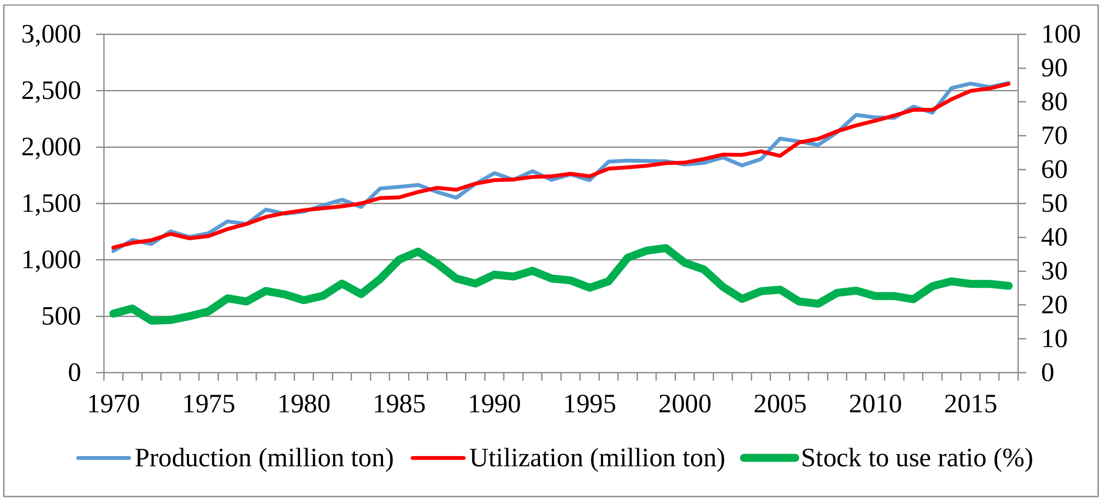


Figure 3. Development in World cereal supply and demand (Data Food and Agriculture Organisation of the United Nations (FAO), 2010 - 2016)

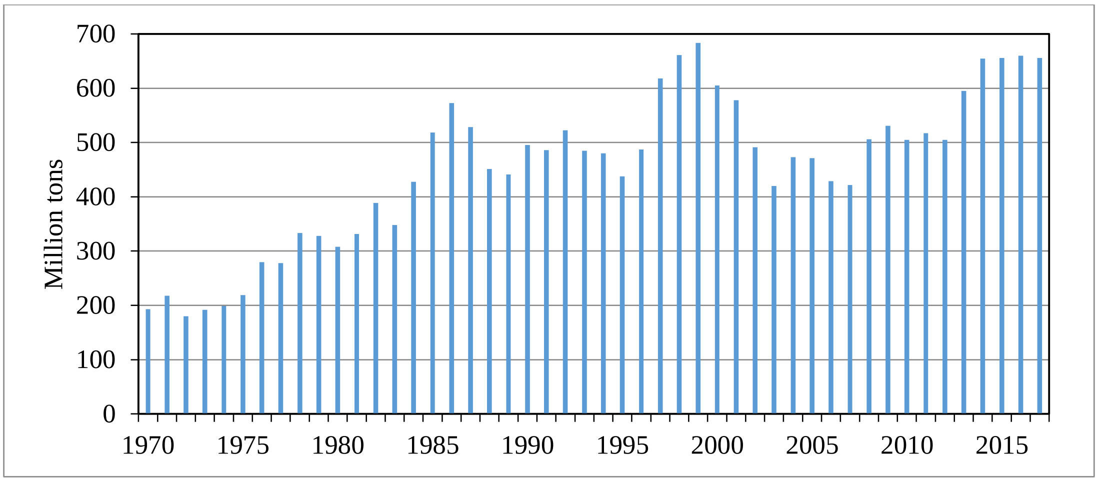


Figure 4. Development of the Global cereal stock since 1970, including forecast for 2017 (Data FAO, 2010 - 2016)

The long downward trend in cereal prices made a turnaround in the period 2000 - 2002 and prices rapidly increased in the period 2007 - 2008 (Figure 5). However, since 2008 prices did not show further increase and even went down for the most important cereals. With respect to farming the on-going urbanisation in countries with a medium and high HDI and to a certain extent in countries with a low HDI will have its impact. In countries with a very high HDI farming has gone through a significant up-scaling. For example in my country, the Netherlands, a farmer could have a living from 5 hectares at the beginning of the 20th century and from 50 hectares by the end. Similar processes can be observed in several countries with a medium and high HDI and to a certain extent already as well in some countries with a low HDI. In several other countries, especially in Africa, where despite rapid urbanisation the agricultural population is not decreasing and may even continue to increase, smallholder agriculture will retain an important place. However, the overall consequence will be that farmers will have to produce significantly more food for urban people in a competitive environment (Figure 6). This will require an increase in farm sizes, transfer to higher value crops and mechanisation. Especially in the countries with a low HDI it also implies that infrastructures have to be strengthened in order to secure the transport of food to the necessary places. Such trends will have to play an important role in measures with respect to food security at affordable prices.

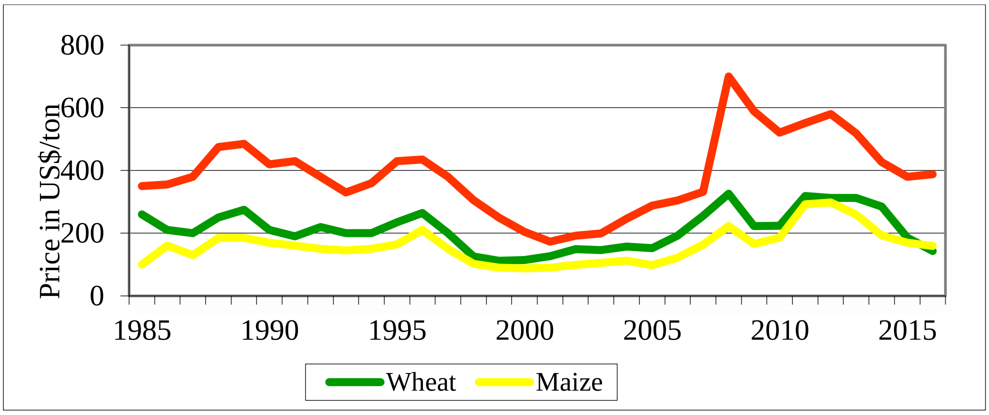


Figure 5. World market prices for wheat, maize and rice. Prices not corrected for inflation (data International Monetary Fund (IMF))

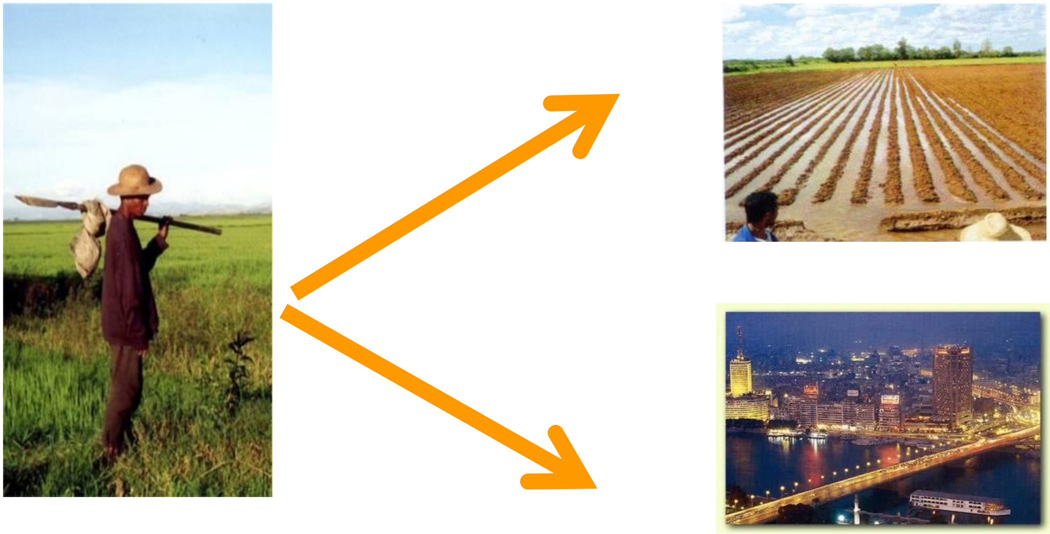


Figure 6. Increase in farm size to produce food for urban people at affordable prices (source: H. Tardieu)

There are different ways to achieve the required increase in cereal production. It can be increase in yield at the existing cultivated area, expansion of arable land, or increase in cropping intensity. There is a common understanding that 80 - 90% of the increase in production will have to be realised at the existing cultivated land and only 10 - 20% by expansion of agricultural land (FAO and ICID, 2014). This can, for example, for several regions be clarified by a study of FAO (2011) as shown in Figure 7.

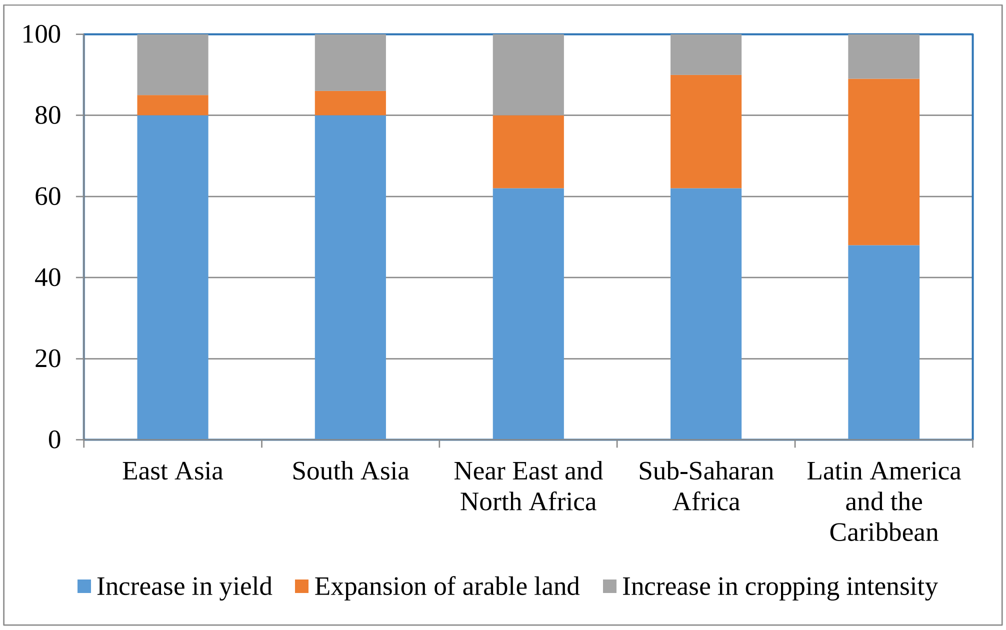


Figure 7. Anticipated sources of growth in crop production 1997 - 2030 (based on FAO, 2011)

Agricultural water management

In the last fifty years, agricultural water management has helped to meet the rapidly rising demand for food (Figures 3 and 4), and has contributed to the growth of farm profitability and poverty reduction as well as to regional development and environmental protection. The Green Revolution has enabled many countries with a medium and high HDI to transform from agrarian to industrializing economies. The technology of high inputs of nitrogen fertilizer, applied to responsive short-strawed, short-season varieties of rice and wheat, often required irrigation to realize its potential (FAO and ICID, 2014). In principle developments can be based on the various options of water management as shown in Figure 8.

When growing food crops, the timing and reliability of water supply and drainage is crucial. In the arid and semi-arid zone, as well as in the humid tropical zone irrigation allows cultivation of crops when rainfall is erratic or insufficient. In the temperate humid and the humid tropical zones drainage is generally required to prevent waterlogging during the winter or monsoon seasons. In the arid and semi-arid zone drainage may be required to prevent waterlogging and salinisation, especially in irrigated areas (Schultz, 1997). For the three groups of countries Table I shows the areas with and without a water management system. Table II shows these data for the different Continents. The data in the two Tables have been determined as good as possible, but have to be considered as rough estimates, while in quite some cases data are not available.

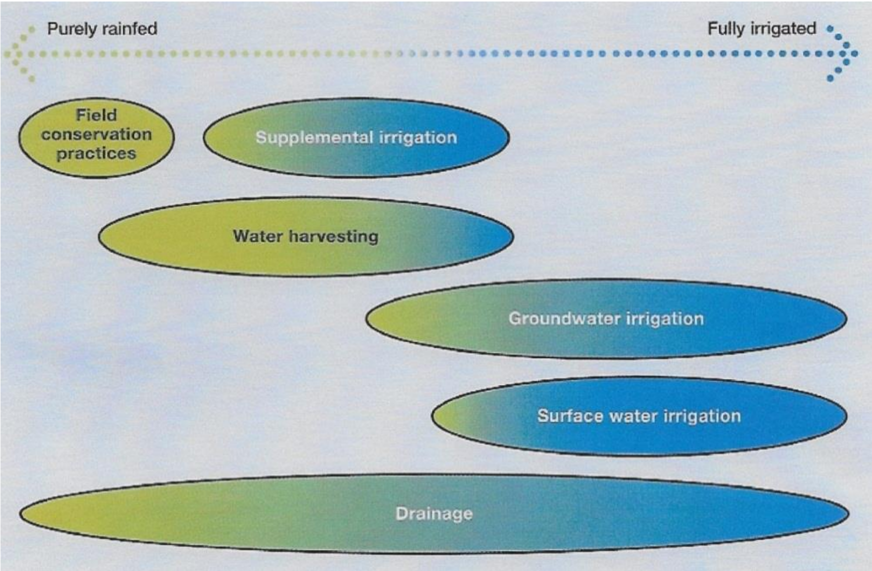


Figure 8. Diverse options for agricultural water management (International Water Management Institute (IWMI - CGIAR), 2007)

The irrigated area of the World increased significantly during the early and middle parts of the 20th century. Production and average yields of irrigated crops in these countries have responded to this demand by increasing two- to fourfold. Irrigated agriculture now provides approximately 45% of the Worlds' food, including most of its horticultural output, from an estimated 20% of the agricultural land. Irrigated agriculture accounts for about 70% (2,850 km^3 per year) of the freshwater withdrawals in the World, and up to 85% in countries with a low, medium and high HDI. In addition rainfed agriculture uses 6,400 km^3 per year. In the 20th century global water use has been growing at more than twice the rate of population increase (FAO and ICID, 2014).

Table I. Cultivated area with and without a water management system in the three groups of countries in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Countries with a very high HDI	436	33	23	56	99	10	109	271
Countries with a medium or high HDI	828	182	78	260	51	24	75	493
Countries with a low HDI	260	28	6	34	2	16	18	208
Total	1532	242	107	349	153	49	202	972

Table II. Cultivated area with and without a water management system in the different Continents in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Asia	530	184	79	262	68	31	69	199
Africa	239	12	3	14	1	4	5	220
Europe	303	18	3	21	54	3	57	225
Americas	400	27	22	48	57	11	68	284
Oceania	49	3	0	3	1	1	2	44
Total	1532	242	107	349	96	49	202	972

The challenge is how to meet the ever-rising demand for food in the context of the above mentioned processes and expected developments, while at the same time increasing farmer incomes, reducing poverty and protecting the environment (FAO and ICID, 2014). While the major part of the increase in food production will have to be achieved at the existing cultivated area the focus will have to be on a higher yield per hectare, and where possible on double or triple cropping. A significant part of the increase can already be achieved by improved operation and maintenance of existing schemes. As far as the contribution of improvement options of water management schemes is concerned the increase can be achieved by (Schultz *et al*., 2005 and 2009):

- modernization of existing irrigation and drainage systems;
- installation of drainage in irrigated areas;
- installation of irrigation in rainfed areas with drainage;
- installation of irrigation and/or drainage systems in areas without a system.

In light of this it is expected that the amount of water withdrawn by irrigated agriculture will have to be increased by 11% by 2050 (FAO, 2010; FAO and ICID, 2014). This will be a considerable challenge in water-constrained areas. An increasing number of regions are already reaching the limit at which reliable water services can be delivered (Figure 9). The situation will be exacerbated as demands of fast growing urban areas place increased pressure on the quality and quantity of local water and land resources.

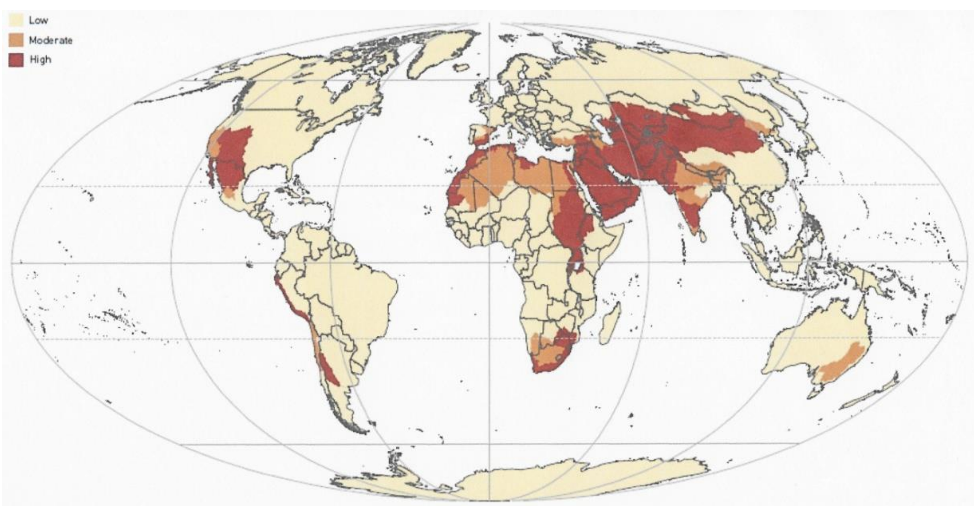


Figure 9. Global distribution of water scarcity by major river systems (FAO, 2011).

Another important point is who are really the actors in agricultural water management. This is shown in Figure 10. A distinction has been made in those who are responsible and those who are contributing. Key issue in this simple scheme is that when the three parties that are responsible have an agreement on their roles and responsibilities, the water management schemes will generally be operated and maintained in a proper way. If they cannot reach such an agreement there will generally be under performance of the water management scheme, resulting in lower yields.

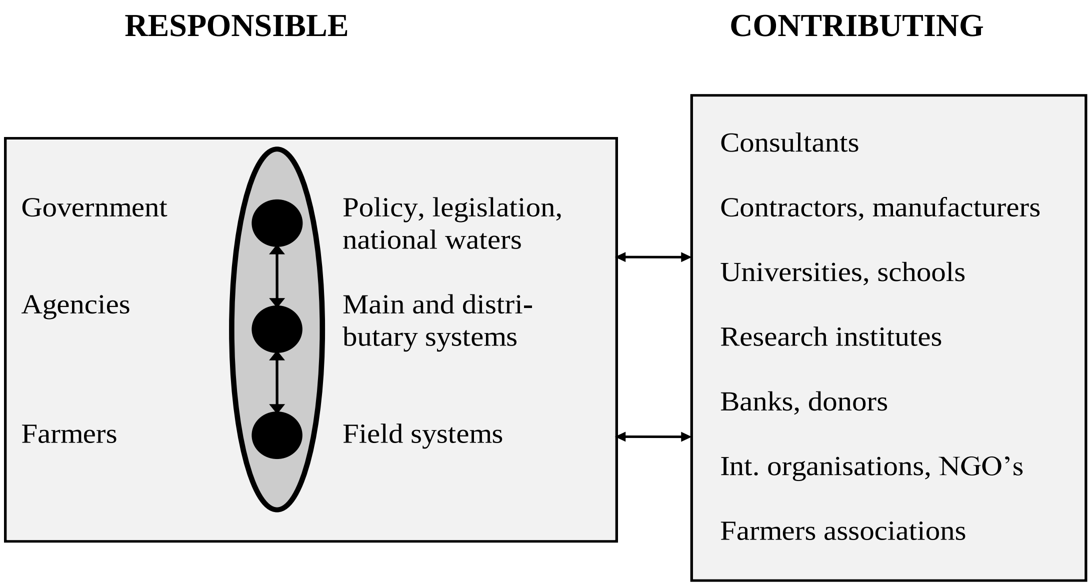


Figure 10. Actors in agricultural water management (Schultz, 2001)

With respect to modernisation of schemes in countries with a low, medium and high HDI it is important to point out that the Governments developed most schemes. These Governments can or will generally not continue to take full responsibility for operation and maintenance. Due to this transfer of responsibilities and/or of ownership of schemes to farmers, or companies is an on-going process. The sustainability of schemes through shared cost-recovery, for which the sustainability cost may be expected from the farmers, is essential (Tardieu, 2005). In parallel to such processes there will be an important role for innovation by better implementation of available research results in practice and by linking research projects and programmes to improved applications in practice. In addition to surface water also groundwater provides a resource and helps maintain the pace of, mostly private, irrigation expansion (Tables I and II). However, in many river basins groundwater is being mined and environmental stress is growing. In such cases measures will be required to assure sustainable exploitation of groundwater resources. An important issue in the arid and semi-arid zone is how to lessen the pressure on agricultural water by bringing in low quality water and reuse of wastewater in agriculture.

Role of drainage

The objective of drainage in agriculture is such that excess water, and may be salts will be removed from the fields in such a way that a good growth of the crops can be assured. With respect to the objectives of drainage different situations can be applicable:

- *prevention of waterlogging outside the main growing season*. Its effect on crops will be indirect. It is referred to as 'off-season drainage';
- *prevention of waterlogging during the main growing season.* This will have a direct effect on crop growth. It is referred to as 'crop-season drainage';
- *prevention of salinization of the soil by irrigation or by capillary rise of groundwater.* It is referred to as 'salt drainage'.

The drain depth and spacing determine the capacity of the system. The best capacity can be formulated in economic terms as that capacity where the net benefits of drainage are maximal. This economic criterion for design purposes is to be translated into hydrological criteria: the design discharge which is the quantity of water the system should be able to discharge during peak periods and the depth at which the groundwater table is to be controlled in those periods. The design discharge is commonly expressed as the required discharge rate in mm/day or l/s/ha. The criteria are different for: off season, crop season and salt drainage.

In many cases drainage systems are installed in lowland areas. This implies that the discharge of drainage water by outlet structures, or pumping stations and flood protection provisions may be of importance as well. In such cases the possible impacts of changes in land use, land subsidence and climate change will have to be taken into account (Schultz, 2000, 2008 and 2016).

As outlined above a significant part of the increase in cereal production has to be achieved at existing cultivated land. As described above this generally implies modernisation of existing irrigation and/or drainage systems, or installation of new systems. It may also apply to increased application of fertilisers and/or pesticides. Here is a very critical point with respect to environmental sustainability, while dependent on the application and the conditions a certain part of the fertilisers and/or pesticides cannot be absorbed by the plants, but will be discharged with the drainage water. In that case pollution of the receiving water body may become a problem. Therefore such applications have to be controlled in a strict way. A good example for this may be the development of environmental legislation in the European Union, among others by the European Water Framework Directive (European Commission, 2000). By this legislation the application by the farmers is being controlled in such a way that the discharge through the drains is at an acceptable level. In order to determine the criteria at several places research has been done. Figure 11 shows field research on the discharge of chemicals in relation to the application through drains under apple trees. Based on results of such researches quality criteria for surface waters have been developed that are applicable to all the member countries. These criteria are binding and have to be fulfilled when developing new projects.

Figure 11. Field research on the discharge of chemicals through subsurface drains under apple trees in relation to the application

Role of drainage in the arid and semi-arid zone

In quite some countries with a low, medium and high HDI drainage has been neglected in irrigated areas. This is especially the case in the arid and semi-arid zone, where the drains only may have a role in the control of waterlogging and salinity development. When in such regions irrigation systems are installed, sooner or later a certain amount of leaching will become required in order to prevent the development of waterlogging and salinity in the root zone. Generally in such cases subsurface drainage at a relatively deep level becomes required. There has been quite some discussion on the preferred depth of such drains. Smedema has made an analysis on the optimal depth that can well be used as a reference (Smedema, 2007). He found that in quite some cases the drains were located at a greater depth than required.

All in all agricultural water management has played and will play a central role in reducing the risk of food insecurity in countries with a Low, Medium and High HDI. To a large extent solutions to facilitate expansion of efficient irrigation and drainage through improved infrastructure and increased water productivity are known and available. Crucial question is what is best applicable under the local conditions (Figure 8).

Sustainable development goals and the draft icid action plan

In January 2016, the sustainable development goals (SDG) as adopted by the United Nations in September 2015 came into force. Six of the seventeen SDGs are of special importance for agricultural water management. These are:

- *Goal 1*. End poverty in all its forms everywhere;
- *Goal 2*. End hunger, achieve food security and improved nutrition and promote sustainable agriculture;
- *Goal 6*. Ensure access to water and sanitation for all;
- *Goal 12*. Ensure sustainable consumption and production patterns;
- *Goal 13*. Take urgent action to combat climate change and its impacts;
- *Goal 15*. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss;
- *Goal 17*. Revitalize the global partnership for sustainable development.

In this context, ICID is developing its *ICID Action Plan 2030.* The intention of the plan is to show the results of reviews and to propose planning principles, design criteria, operating rules, contingency plans and management policies for new water management systems.

Challenges

In the discussions on the draft *ICID Action Plan 2030* Prof. Daniele de Wrachien has formulated the following key challenges on agricultural water management (Editorial Board, 2016).

Despite the enormous advances in our ability to understand, interpret and ultimately manage the natural world we have reached the 21st century in awesome ignorance of what is likely to unfold in terms of both the natural changes and the human activities that affect the environment and the responses of the Earth to those stimuli. One certain fact is that the planet will be subjected to pressures hitherto unprecedented in its recent evolutionary history. The "tomorrow's world" will not simply be an inflated version of the "today's world", with more people, more energy consumption, more industry, rather it will be qualitatively different from today in at least three important respects:

- *first*, new technology will transform the relationship between man and the natural world. An example is the gradual transition from agriculture that is heavily dependent on chemicals to one that is essentially biologically intensive through the application of bio-technologies. Consequently, the release of bio-engineered organisms is likely to pose new kinds of risks if the development and use of such organisms are not carefully controlled.
- *second*, society will be moving beyond the era of localized environmental problems. What were once local incidents of natural resource impairment shared throughout a common watershed or basin, now involve many neighboring countries. What were once acute, short-lived episodes of reversible damage now affect many generations. What were once straightforward questions of conservation versus development now reflect more complex linkages;
- *third*, climate variations. It is nowadays widely accepted that the increasing concentration of the so-called greenhouse gases in the atmosphere is altering the Earth's radiation balance and causing the temperature to rise. This process in turn provides the context for a chain of events which leads to changes in the different components of the hydrological cycle, such as evapotranspiration rate, intensity and frequency of precipitation, river flows, soil moisture and groundwater recharge. Mankind is expected to respond to these effects by taking adaptive measures including changing patterns of land use, adopting new strategies for soil

and water management and looking for non-conventional water resources (e.g. saline/brackish waters, desalinated water, treated wastewater, hydroponics and aeroponics).

While the draft *ICID Action Plan 2030* is still under preparation input and comments have been requested from the ICID National Committees and Work Bodies. All this information is expected to be included in the revised Action Plan that will be presented, discussed and hopefully approved during the forthcoming ICID Congress in October this year in Mexico City. For the draft Action Plan six operational goals have been identified. These are:

- *Goal 1*. Enable higher crop productivity with less water and energy;
- *Goal 2*. Be a catalyst for change in policies and practices;
- *Goal 3*. Facilitate exchange of information, knowledge and technology;
- *Goal 4*. Enable cross disciplinary and inter-sectoral engagement;
- *Goal 5*. Encourage research and support development of tools to extend innovation into field practices;
- *Goal 6*. Facilitate capacity development.

These operational goals have been detailed in strategies, targets and indicators that will be further refined in the coming months.

Conclusion

Global food production is sufficient to feed the Worlds' population; shortages are of a regional and local nature. Although they may be caused by drought or other climatologic phenomena they can be prevented when sufficient action is being taken. First responsibility rests with the National and/or Regional Governments and the farmers or agricultural producers.

Over the past years an impressive increase in food production has been achieved. However, population growth and increase in standard of living, especially in countries with a medium and high HDI, require that food production will have to be doubled over the next 25 – 30 years. It is therefore required that governments have a clear policy on the level of food self sufficiency and on the measures that would be required to achieve this. In addition it will be of importance that they enable that the remaining food can be imported and sold at affordable prices. Based on the common understanding that 80 - 90% of to increase in food production will have to come from existing cultivated land and that the remaining has to come from land reclamation this will require a significant improvement in water management measures and their operation, maintenance and management. In principle this can be achieved.

The Sustainable Development Goals and the goals, strategies and activities as formulated in the draft *ICID Action Plan 2030* create a good frame in which the actual activities in the field of irrigation, drainage and flood control can be developed. However, we have to realise that the problems and activities will become more pronounced in the years to come, as society enters an era of increasingly complex paths towards the global economy. It will require wisdom, spirit, innovation and intense cooperation of all involved to achieve in the coming decades that agricultural water management will be further developed, operated and maintained to assure food security in a sustainable environment.

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BEYOND MODERN LAND DRAINAGE

Willem F. Vlotman[1]

Abstract

Modern Land Drainage implies making drainage environmentally sustainable which includes enhanced water balance assessments at regional and field scale (incl. a detailed look at water movement on the root-zone), prevent excess water except for leaching salts, support ecological water requirements, and then if any access water remains design a drainage system. The less water is mobilised thorough our agricultural lands, the better the quality of water will remain. No matter how efficiently our crops are watered, sooner or later we need to have a well-functioning drainage system for complete in-field water management. Under natural conditions, i.e. in areas with rainfall surplus and no irrigation system, drainage is considered when causing waterlogging that restricts crop growth. Salinisation of the land, i.e. the accumulation of salts in the upper layers of the soil occurs naturally in coastal areas but can be a secondary effect of waterlogging. In all cases the absence of a sustained seasonal net downward water movement through the root-zone is generally the reason for salinisation. Beyond modern land drainage includes various approaches to assessment, prevention of waterlogging an salinity problems, considers the water-food-energy nexus approach and gives due attention to ecological considerations for more sustainable results. Theories of drainage design have been well developed and with powerful computing now available at the desktop at affordable prices, many solutions to a drainage issue can be considered that include controlling the amount of water drained, reuse and how best to control drainage water quality. Ready access to satellite imagery, new and enhanced existing computer models to simulate land inundation and the recent advance in the use of drones with cameras (quad copters and the like) provide an opportunity to enhance integrated water resource imbedded drainage design. Regardless of these technological advances nothing beats going out when it rains to assess what is really happening in the field. A holistic approach to drainage is describes that includes steps to successful stakeholder involvement from beginning to end, from farm to fork and from minister to manager.

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Introduction

Modern Land Drainage (MLD) is an extended approach to the traditional drainage design methods for rain fed agriculture in the humid temperate zone. It includes and extensive consideration of salinity control of irrigated land in (semi-) arid zones, drainage of rice land in the humid tropics and advocates controlled drainage in the framework of integrated water resources management (IWRM). Institutional, management and maintenance are included as well as the mitigation of adverse impacts of drainage interventions on the environment. Beyond Modern Land Drainage considers the Triple Bottom Line (TBL), the triangle that considers interactions between social, environmental (or ecological) and financial aspects and extents it to consideration of drainage within the Water-Food-Energy Nexus (Vlotman 2014).

At the ninth International Drainage Workshop (IDW9, 2003) in Utrecht, the Netherlands, drainage was placed firmly in the realm of Integrated Water Resources Management (IWRM). At IDW10 held in Finland and Latvia in 2008 it was mentioned that drainage is an important driver for sustainable outcomes and the three main areas of indicators for the need for drainage in the framework of sustainable IWRM were given as (Vlotman 2008):

1. an aging water supply system and infrastructure that supports economic development,
2. the perceived changes in regional climates (i.e. the Climate Change bandwagon), whether caused by anthropogenic influence or whether part of a natural cycle, and
3. the increased attention for sustainable physical environments.

At the 11th ICID International Drainage Workshop on Agricultural Drainage Needs and Future Priorities in Cairo, Egypt from September 23 to 27, 2012, the discussions centred around how to make agricultural production possible and more profitable. Agricultural drainage is part of integrated land and water resources management where environmental aspects play an important role; the impact of agricultural drainage on crop productivity and environmental aspects and advances to address these issue were elaborated (IDW11 2012).

The theme of the12th International Drainage Workshop (IDW), 23-26 June 2014, St. Petersburg, Russia was: Drainage on Waterlogged Agricultural Areas. Sub-topics were: (a) New equipment and modern technology drainage construction in wetlands; (b) Efficiency of the use of reclaimed land and socio-economic aspects of the use of reclaimed land; (c) Drainage design and methods of calculating; (d) Advanced training of specialists: constructors and engineers in the field of drainage systems management and operation; (e) An integrated approach to the management of drainage and environmental protection; (f) Using reclaimed land for agricultural purposes; and (g) History of the drainage system development. The proceedings do not contain a summary of the discussions of each section.

At IDW13, a new paradigm for sustainable, integrated, water resources management is presented that has been emerging from international conferences around the world. Its most succinct description is 'the water-food-energy nexus (WFEN) for a green economy'. The water, food and energy nexus aims at the most efficient, best practice principles applied throughout the full food supply chain. This includes consideration of reducing wastage of the food for various reasons in the supply chain. Food wastage equates on average to 243 litres of water a day/person in the food they throw away, which is 1.5 times the daily water use per person (Vlotman and Ballard, 2014). The concepts of virtual water and water footprint can help in identifying opportunities to save water by targeting reduction of wastage of food that has the highest virtual water content. Energy efficiency occurs when we consume where we grow, so do not transport food unnecessarily. Green economy aims at achieving the optimised supply chain objectives in a manner that espouses the sustainability principle, gives due attention to environmental concerns and helps with eradication of poverty and hunger.

Artificial and natural drainage systems are an essential part of the water management system; in fact many systems would not be sustainable without it. For instance, managing salinity and waterlogging requires artificial or natural drainage to be in place. However, it is probably needed only a few times per year if irrigation is applied efficiently resulting in minimum leaching requirements.

Over the years it has become clear from worldwide experiences that economics and technical expertise are not the only key drivers of drainage development and that care for the natural physical and social/cultural environment will enhance the likelihood of sustainable water management and sustainable drainage systems.

The drivers of sustainable environments are, amongst others, the Key Performance Indicators (KPIs) of Triple Bottom Line (TBL) frameworks that inform us how well we are doing. These KPIs are either oriented towards internal business performance or towards external impacts of water management organisations, incl. business by government departments. It is important to keep the internal and external KPIs separate such that mission, strategies and operational objectives of the organisation that is responsible for the drainage system are clear in the mind of all stakeholders. Drainage environmental KPIs are related to salinity, waterlogging and water quality while many others relate to the IWRM more generally.

The drainage system design process

The steps in traditional land drainage design are identification of the problem, reconnaissance or a pre-feasibility stage, then the actual feasibility stage followed by the detailed design stage (Smedema et al. 2004). Operation and Maintenance processes come into play after the construction and commissioning of the drainage system. Beyond modern land drainage design includes considerable stakeholder involvement right from inception to eventual ownership of the systems, and also includes remote sensing technologies in the early stages and post construction with due regard to economics and environmental/ecological considerations.

Beyond Modern Land Drainage starts with a process of stakeholder involvement. The process was elaborated in a background paper at the ICID meetings in Chiang Mia, Thailand and the following are suggested (after Ardakanian et al. 2016):

- Carry-out an assessment of existing institutional arrangements with all potential stakeholders of the area under consideration for water management interventions
- Ask stakeholders what needs to be established in order to become more involved (gap analysis)
- Identify the challenges & demands of the stakeholders
- Identify the need for continuity of participation and support capacity building keeping in mind the operation, management and maintenance needs of the future
- Identify the need for political commitment, innovation and advocacy for involvement.

Vlotman and Ballard (2014, 2016) included two more aspects:

- Energy efficiency. This includes considerations such as switching from high pressure sprinkler systems to low sprinkler pressures systems, gravity drainage instead of pumped drainage, consume food where it is produced, avoid growing food at location A, transport it to B for wholesale and then back again to A for retail; this will safe oil (truck and rail transport), gas (heating and cooling) and electricity (electric train transport, cooling needs), re-introduce seasonality in the availability of foods, and
- Reduce food wastage, i.e. reduce the loss of imbedded or virtual water. Do not buy more food than needed, recycle food via Foodshare (Foodbank, 2013), Fareshare (2013) and retail at farmer markets (Vlotman and Ballard 2014). This will use food more effectively and efficiently without wasting it and at the same time save virtual water which then allows it to be an actual water savings higher up in the food and water supply chains.

These latter two aspects were cast in the water-food energy nexus to assist the balancing of these elements in the triple bottom line framework with irrigation and drainage systems, Vlotman and Ballard (2014).

To achieve active stakeholder involvement a planned process will need to be executed (MDBA 2015):

- Assessment of state of institutional development at all levels;
- Needs assessment;
- Plan development reflecting:
    - Who you will engage with;
    - Why you will engage them;
    - Why they will want to engage with you;
    - How you will engage them;
    - When you will engage them, and how you will monitor and evaluate your engagement approach?

The key for involvement of stakeholders in irrigation and drainage system operation, management and maintenance (OMM) is the central question: what is in it for me? Incentives do not necessarily need to be economic in nature. They can be improvement in lifestyle, improvements in physical environment and in general improvement in social well-being. Hence, in order to involve stakeholders in water management, incl. irrigation, drainage and environmental watering, it is essential to find out first in what type of TBL environment they operate and what their needs are. It is not just involvement in water management but consideration of all aspects of being successful (i.e. all TBL elements and all water-food-energy nexus considerations, WFEN).

All stakeholders from farmer to system operator to top level regional and national government staff need to have a clear understanding of the potential benefits of being involved and they need assurance that those benefits are sustainable. Stakeholder engagement is a planned process with the specific purpose of working across organisations, stakeholders and communities to shape the decisions and actions of the members of the community, the stakeholders and the organisations involved. Typical questions to be asked in planning for the involvement of water managers at all levels, including foremost farmers, are:

- What issues do you face in being successful in your (water operation, management and maintenance) enterprise/organisation?
- Do you consider all TBL aspects for the design and future operations?

- Are you willing to share water with the environment/ecology?
- What additional knowledge, skills and information do you need to make an informed decision?

These questions will generate discussions, anger, trepidation, excitement and raise a range of socio-economic issues that should not be ignored and are essential to consider for successful involvement of stakeholders in the design process of drainage system and the eventual successful OMM of the system.

Design

Although traditionally drainage design evolves around rainfall intensities, in particularly in the temperate climate zones, this is not always the case and it is changing rapidly. In irrigated areas the efficiency of the water delivery system determines the need for drainage (Table 1). In drier climate zones flooding is caused by runoff from upstream areas congregating in the lower reaches of the catchment. The fact that the "problem" is caused upstream suggests a closer look at what is happening upstream. Should we re-forest certain areas, should we change land use (Baoa et al. 2017), should we built water and salt interception schemes? Fortunately recent advances in aerial photography with drones and advances in the use of satellite remote sensing applications will allow us to determine the need for drainage in more holistic ways than before. This will be described in further detail in the section on remote and robot reconnaissance.

Table 1 Efficiency of various irrigation methods

Method	Efficiency (%)	Remarks
Flood irrigation	50 - 85	New water management control technologies
Sprinkler irrigation	65 - 90	From high pressure to low pressure application
Trickle irrigation	75 - 95	Reliability, durability and water management
Sub-surface irrigation	50 - 95	Shallow soil management
Controlled drainage	50 - 85	Maintain and manage high water table as appropriate
State of the art water management	85 - 100	Soil moisture management and delivery system management combined

Traditionally (or, almost traditionally), design of drainage systems is supported by using a variety of water resource models (MIKE21, SWATRE, HEC-RAS, DUFLOW to name a few) and dedicated drainage models such as the various versions of DRAINMOD (Box 1), to investigate a variety of drainage rates under different weather and design arrangements (i.e. depth and spacing of drains). Modern Land Drainage (Smedema et al. 2004) gives a listing of websites to access these models which was current in 2003 and is a good starting point to investigate the latest in computer aided design. The models can include salinity levels and levels of other potentially toxic elements such as nitrogen, Biological and Chemical Oxygen Demand (BOD & COD), a variety of micro-organism, pesticides, etc. Many dedicated computer models exist for these situations.

Obtaining good topographical maps is essential for detailed design. A viable alternative during the reconnaissance stage of projects under consideration is the use of Google Earth, which now includes generation of surface elevations along selected lines, which could be proposed surface and sub-surface drains rather than the streams shown in Figure 1. Spatial software applications based on satellite imagery, aerial photography or drone imagery can also provide the exact extent of flooding, waterlogging (indirectly through observing the status of the vegetation) and salinity.

Box 1 Overview of the state of DRAINMOD models.

DRAINMOD based field and watershed scale models

http://www.bae.ncsu.edu/soil_water/drainmod/models.html accessed 5/11/16.

For details of references see the website.

The original DRAINMOD hydrology model has been modified to include sub-models on the fate and transport of nitrogen in the soil and salinity. The field hydrology and water quality models were also coupled with drainage network routing sub-models for watershed scale applications. Below are the models developed at the Biological and Agricultural Engineering Department at NCSU.

FLD&STRM (Konyha, 1989) - DRAINMOD based watershed scale Agricultural water management model.

DRAINLOB (McCarthy, 1990)- DRAINMOD based field scale forest hydrologic model.

DRAINMOD-S (Kandil, 1992)- DRAINMOD based field scale model for predicting salinity on arid/semi-arid lands.

DRAINWAT (Amatya, 1993) - DRAINLOB/FLD&STRM based watershed scale forest hydrologic model.

The FAO Irrigation and Drainage Paper no 62 (van der Molen et al. 2007) on guidelines and computer programs for the planning and design of land drainage system is one of the latest readily available publications on land drainage design but considers minimal attention to stakeholders (farmers only) and environment is described in an eleven line paragraph. For the latest in environmental design and for examples of the use of the web to view live river data see the Murray-Darling Basin Authority website (http://www.mdba.gov.au) and navigate to the "publications" and "live river data" sections (http://livedata.mdba.gov.au/system-view). For selected locations in the system overview data such as water levels, river and channel flows, reservoir storage levels and reservoir releases, rainfall, water temperature, dissolved oxygen levels and salinity levels are given. This type of information will be very helpful during the reconnaissance and OMM stages in the life cycle of drainage systems and how they interact in the broader integrated water resource management system.

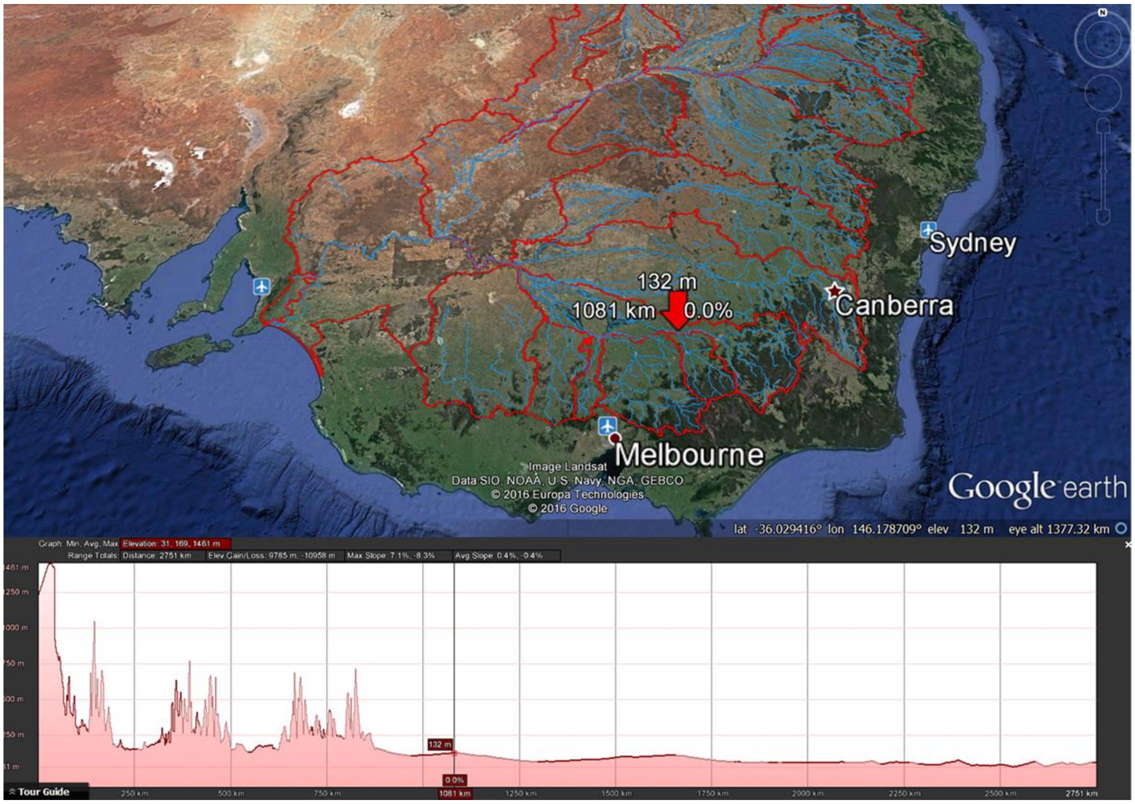

Figure 1 Screen dump of Google Earth map with basin regions boundaries (in red; i.e. catchment boundaries) and rivers in blue.

A right-hand click on top of a river line will produce an elevation profile as shown. Naturally the river will not go uphill as is shown in the profile here; this however is a scale and location of the line representing the stream on top of the Google Earth map which at this scale is highly inaccurate (accessed December 2016). The red arrow in the map will move along the river line when the vertical line in the elevation profile is moved. The elevation heights are in meter, but care should be taken to check the datum of the elevation used.

A rather interesting design process is proposed by Tuohy et al. 2016. The method is based on a new visual soil assessment method whereby an approximation of the permeability of specific soil horizons is made using seven indicators (water seepage, pan layers, texture, porosity, consistence, stone content and root development) to provide a basis for the design of a site-specific drainage system. The incentive was the ability to design a suitable system for each of the stakeholders at the lowest possible costs.

In the next section additional innovations are described that are considered beyond MLD in the reconnaissance, analysis, and design stages of drainage systems, including consideration of new materials and equipment available in today's environments and markets.

Remote and Robot Reconnaissance

Similar to involving stakeholders from the beginning to the end, a thorough technical analysis of the condition at, up and downstream of the intended drainage system is essential. The advances in remote sensing techniques and the availability of these services as well as the skills of our stakeholders allow a sophisticated process to be included in the reconnaissance stage of the design process. These processes may actually lead to the conclusion that drainage is not necessary if other, potential cheaper solutions high or lower in the water management system show promise that will negate the need for drainage, or, show means of controlling water quality at downstream locations.

The continued advances in remote sensing in the last couple of decades (Figure 2) have been significant and will continue to evolve at a rapid pace when more satellites are launched (Landsat, IKONOS, MODIS, SPOT, QuickBird, WorldView, RapidEye, etc.). Access to the raw outputs of Landsat imagery is easy via the web. More advanced outputs are commercially available and can include those from other platforms such as aerial photography and drones. Many government agencies and private companies are developing tools to help with accessing and assessing the data available via the web and internal computer network systems. This is a far cry from the good old days when draftsmen prepared drawings on tracing paper; then to be printed; the smells of ammonia filling your nose; something un-imaginable with today's attention to Occupation Health and Safety procedures (OHS).

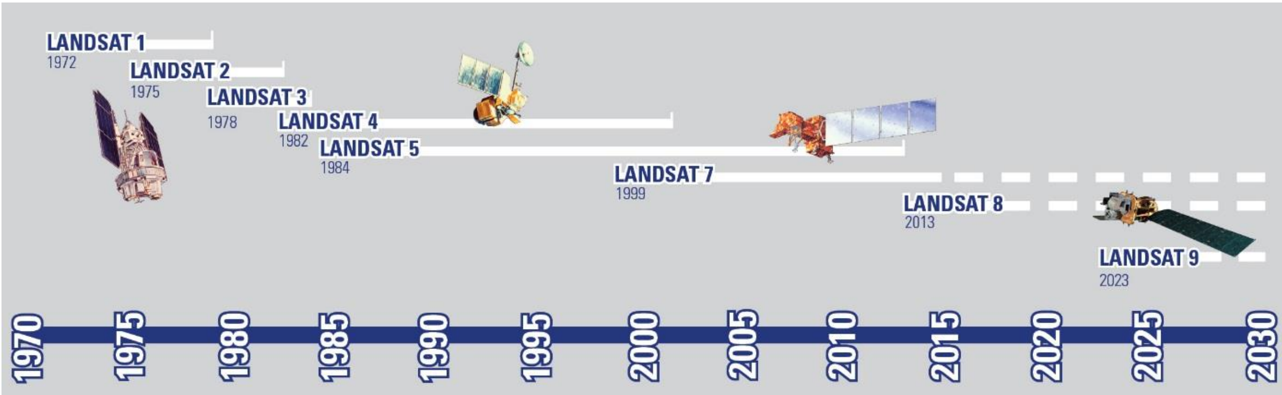

Figure 2 Overview of Landsat satellites past, present and future.

Agencies in the US and Australia now make water observation from space (WOfS) maps available (US Landsat web, http://landsat.usgs.gov, and WOfS web from Geoscience Australia, www.ga.gov.au). These maps are used to inform flood inundation modelling and mapping which allows us to assess the extent and duration of flooding at certain flow rates from low overbank flows (Figure 3) that occur on a regular basis (several times a year) to events that occur only 1 in 50 or 1 in 100 years. As Figure 2 shows the remote sensing information is readily available from 1972 and one will find that in these last 40 years there is a good likelihood that events that occur 1 in every 50 or more years are covered.

The emergence of drones with cameras at retail outlets, rather than the sophisticated multi-million dollar drones used by the military has opened a whole new avenue of reconnaissance. Combined with traditional aerial surveys, albeit with far more sophisticated equipment such as cameras used on satellites with various band widths that identify plant health and water in the landscape than in the past, we now can study flood events as they occur.

Reconnaissance during operation, management and maintenance (OMM) stage of the life cycle of a drainage system could be with the use of swarm farm robots for precision application and control of drainage water quality (Figure 4). The idea is that farmers instead of large tractors and sprayers use a swarm of autonomous, collision-avoiding robots that can spray with accuracy and in the right quantity when via GPS and satellite linkage other farm inputs such as soil type, moisture content, etc. are fed into the software controlling the swarm bots and adjusting the intensity and concentration of the spraying. Clearly a variety of sensors can be added or built-in the swarm bot and salinity (think of EM38 salinity survey technologies, Vlotman 2000), soil moisture, temperature of the soil and a variety of chemical assessments with probes drawn through the top layers of the root zone can be performed.

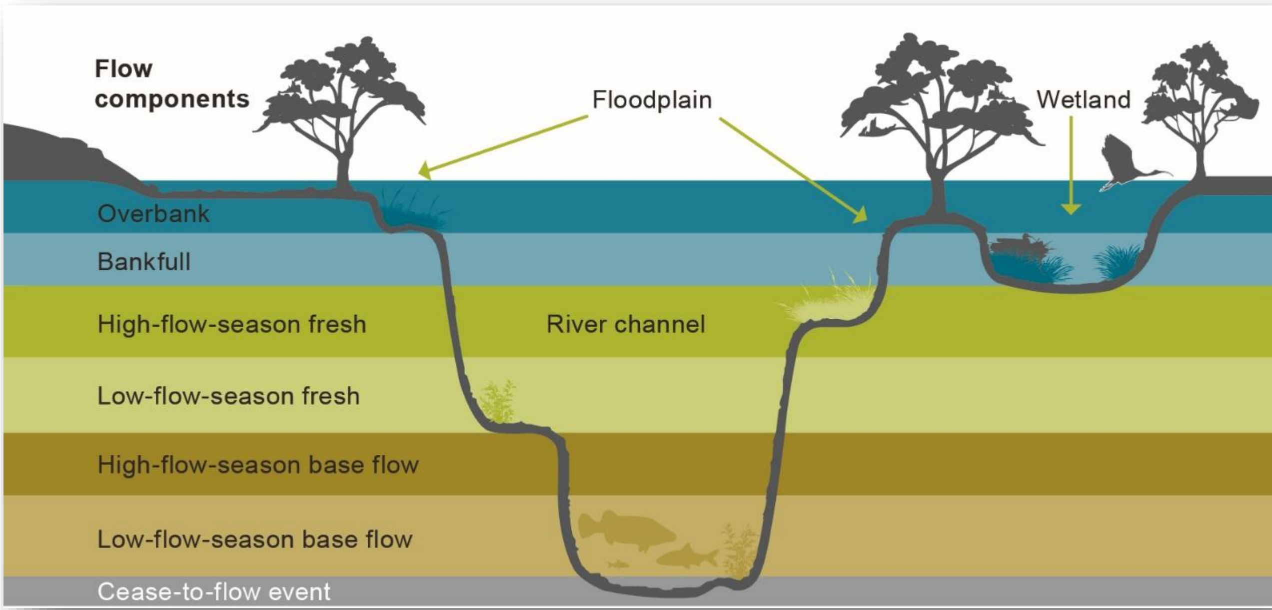

Figure 3 Schematic of flow types, incl. overbank flow (MDBA 2011)

Figure 4 Swarmfarm robots in action (www.swarmfarm.com).

Linking hydrological data with remote sensing data, whether flood extent, vegetation type or biological occurrence (bird surveys, fish numbers) can result in outputs such as shown in Figure 5 showing the area of flood plain grassland covered for a range of flow rates and Figure 6 showing aerial survey of the number of birds observed in various wetlands and the area of wetland at the time of fly-over. Data collected as shown in Figure 4 and 5 can be used in design and OMM processes to determine the amount of irrigation water needed, drainage water to be removed or localised leaching of salts to be planned. Bird breeding events can be analysed in more detail and may actually be planned by giving additional water to certain wetlands.

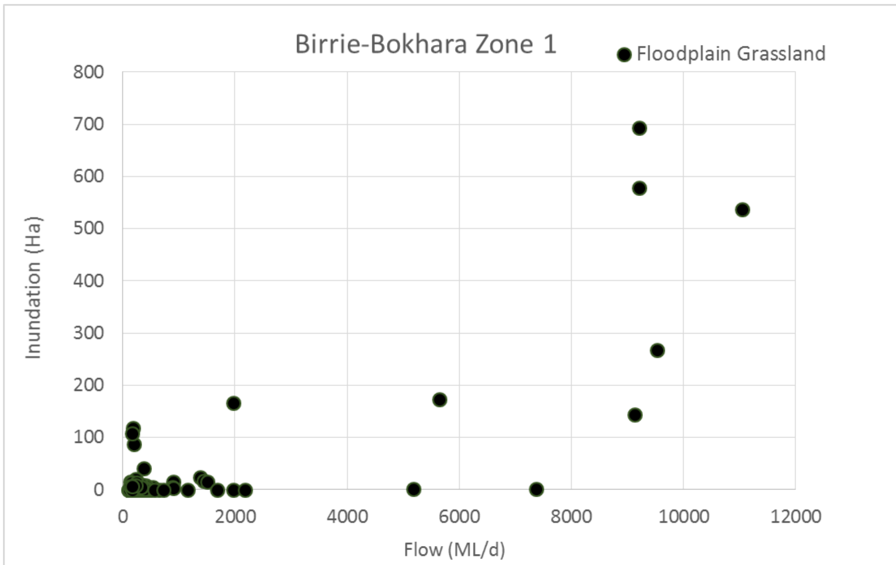

Figure 5 Example of relating a vegetation type to flood extent (Weldrake et al. 2016).

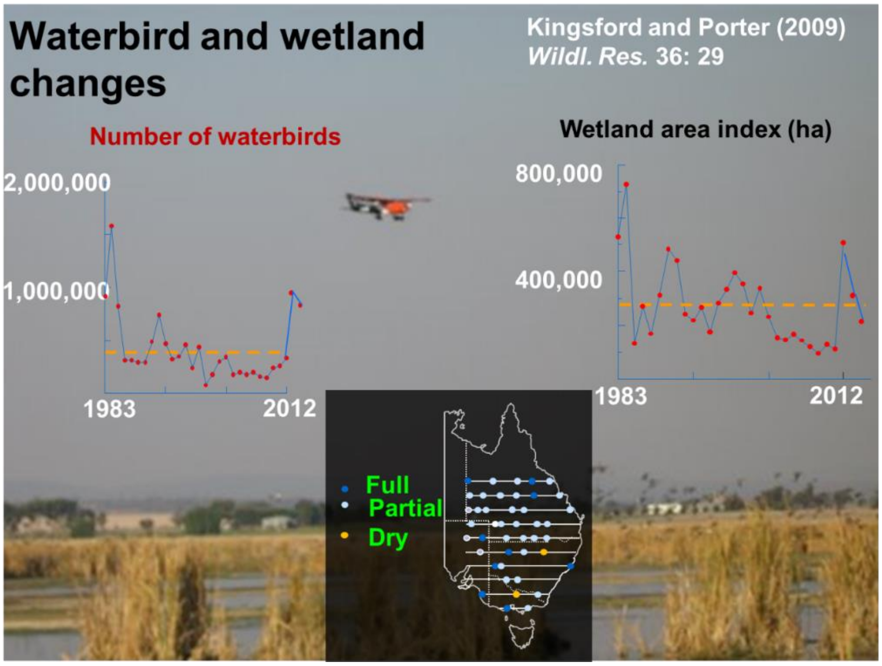

Figure 6 Number of Water birds and Wetland area index (Kingsford and Porter, 2009).

The applications of remote reconnaissance described above are only the tip of the proverbial iceberg of possibilities and opportunities to develop and advance these technologies further.

Final comments and conclusions

Beyond Modern Land Drainage espouses the use of new materials. For instance the Capiphone drain (www.greenability.com.au) uses the capillary action of the drain to both drain and supply water to the root zone; a new form of controlled drainage and irrigation. This type of drainage is also known as wick drainage although this is different in its applications and configurations (Koerner 1994, Vlotman et al. 2000).

For water quality control prevention is the best solution and precision agriculture, including the type of application such as advocated by swarm farm robots are exiting new developments.

For salinity control we need to become a bit more innovative and think out of the box. For instance the farmer which sees his land becoming increasing saline over time and looks at the government to provide him with solution can actually do something himself. By taking part of his farm out of production and assuming has access to the same an=mount of water as before, he can irrigate the remainder of his fields with adequate water, including meeting leaching requirements. It is important that in fields affected by salinity a net downward water movement through the root zone is maintained on seasonal basis! This assumes that the government cannot give him more water due to a number of constraints, and assumes that he can still make a living of the remainder of the farm. It may be that the farmer needs some financial support in the form of government guarantees of income, while he or she experiments with concentrating the water available to recover sections of the farm and make them salinity free.

Consider solutions that reduce the upward movement of water (and salts) in the root zone; can we cover the ground with plastic during part of the growing season and thus minimise direct soil water evaporation? Unfortunately in areas where plastic has been used in agriculture, the OMM is not very effective in removal of the plastic afterwards and severe visual and possibly ecological damage results.

A major change in paradigm in Modern Land Drainage design, construction and operation is that we not only concentrate on technical solutions, and not only consider the location of the problem, but take a much wider perspective in time, space, environment, ecology and stakeholder involvement. Look what can be done upstream of the location, look how a change in water management upstream can prevent the problem occurring downstream, look what alternatives there are for the farmer such as re-locate, train, re-skill and change job. If the solution is not found upstream look at minimising or eradicating the negative downstream impacts and turn them into opportunities to enhance water schemes elsewhere.

Finally, in the foregoing a number of solutions were described to use the advances in science and technology combined with active stakeholder involvement from top to bottom and from beginning to … no not the end, but to the stage of Operation, Management and Maintenance (OMM). This is intended to make drainage design more effective and sustainable in the long-term. It is suggested that prevention is the solution to many problems and that a holistic approach such as advocated by Vlotman and Ballard (2014) in describing the water-food-energy nexus for a green economy is necessary for a sustainable triple bottom line development. It is also imperative that the scale of intervention is extended beyond the mere location of the drainage system and that by considering carefully what is happening upstream and downstream of the location, it may be concluded that other solutions to the problem are more effective and guarantee long-term success. There are many opportunities to save water, energy and food beyond the realm of consideration of a drainage system in isolation. The involvement of stakeholders from beginning to end, from farm to fork, from minister to manager, and from preserving and maintaining ecological environments in conjunction with food production is essential in the success of any endeavour including modern land drainage design.

Beyond Modern Land Drainage design is using the latest science, technology and socio-economic insights and considering the interaction between water, food and energy for the best outcomes for all stakeholders in a green economy.

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1

Topic 1:
Measures to Lower Volume of Drainage Water

EFFECTS OF AGRICULTURAL DRAIN WATER CONSUMPTION ON THE GROWTH OF JUVENILE DATE PALM

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Abstract

The efficient use of irrigation water is one of the important issues and programs of the agricultural sector in Iran. The purpose of this study is the exploring of the possibility of juvenile date palms irrigation utilizing agricultural drain water. This experiment was carried out using acomplete block design with three irrigation water salinities of 2.5, 8 and 12 dS m^{-1} in four replications. Saline water with 8 and 12 dS m^{-1} were obtained from a mix of agricultural drain water and water abstracted from the Karun River. The results show that the salinity of irrigation water had a significant effect on soil salinity, the number of leaves, leaf length, leaf width, number of leaflets and truck perimeter at 5% level of probability. The maximum and minimum of plant vegetative characteristics except for leaf chlorophyll and leaflet width were obtained from water with 2.5 dS m^{-1} and 12 dS m^{-1}, respectively. There was a significant difference between the water with 2.5 dS m^{-1} and 8 dS m^{-1} in terms of leaf number, leaf width, number of leaflets and truck perimeter. Therefore, saline water (EC ≥8 dS m^{-1}) cannot be used for irrigation of juvenile date palms.

KEY WORDS: Irrigation, Lysimeter, Saline water, Salt, Soil salinity.

Introduction

Water salinity is one of the most important problems in many countries in the world, especially in arid and semi-arid regions. The lack of fresh water resources has resulted into the use of non-conventional water resources such as brackish and saline water and has received greater attentions in the agriculture sector in recent years. Iran has large salt water sources that have different levels of salinity. These sources can have a great impact on the country's agricultural development (Shiati, 1998). The use of these resources requires special management practices for the reduction

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of their negative environmental impacts. The use of saline drainage waters, generated by irrigated agriculture, seems inevitable for plants irrigation (Qadir and Oster, 2004).

The Date palm is an important horticultural crop in Iran. According to the Food and Agriculture Organization of the United Nations (FAO) report in 2013, Iran with a harvested area of 163000 hectares and 1100000 tons production of date fruit is ranked third and second in the world, respectively. The salinity threshold in date palms, based on water salinity and soil saturated extract salinity are 2.7 dS m^{-1} and 4 dS m^{-1}, respectively. The reduction of 50% in fruit yield is at a water salinity of 12 dS m^{-1} and a soil salinity of 18 dS m^{-1} (Ayers and Westcot, 1994). The date palm cultivars have different tolerance levels to water and soil salinity.

Akhlas and *Ruzaiz* are two of the most common and well-known date varieties in the Al-Hassa oasis of Saudi Arabia. Abderrahman and Abdelhadi (1990) reported that the *Akhlas* variety has a low tolerance level while the *Ruzaiz* variety has a high tolerance level for soil salinity. Al-Rokibah et al. (1998) compared six months old seedlings growth of ten palm date cultivars. Irrigation water salinity of 12.9 dS m^{-1} reduced seedlings length and fresh weight rate to salinity 1.4 dS m^{-1} for most date cultivars. However, seedlings length and the fresh weight of one date cultivar increased with irrigation water salinity.

Aljuburi and Maroff (2007) investigated the effect of diluted sea water when used for irrigation on date palm seedlings. This study was carried out on four levels of sea water (SW) 0.0%, 20%, 40% and 60% on two year old uniform date palm seedlings of the *Hatamy* variety at the experimental station of the University of Qatar. Salinity treatments were imposed by irrigating each seedling once every 20 days with 300 ml of different concentrations of sea water. The number of roots and leaves per seedling significantly increased with the application of 40 or 60% sea water as compared to untreated control plants. Shoot dry weight matter percentages significantly increased with sea water. The Irrigation of *Hatamy* seedlings with sea water did not affect root dry matter percentage. The addition of 40 or 60% sea water to irrigation water significantly increased leaf Na concentrations, where as 20% sea water reduced leaf Na concentrations as compared to untreated seedlings. While, Leaf K^{+} and Ca^{2+} concentrations significantly decreased with 60% sea water and different sea water concentrations, respectively.

Tripler et al. (2007) investigated the growth characteristics, transpiration and ion uptake in juvenile date palms (cv. *Medjool*) under conditions of increasing salinity and B concentrations. Irrigation water salinity levels included EC=0.5, 4, 8, and 12 dS m^{-1}. Boron concentrations in irrigation water were 0.028, 0.185, 0.4625, 1.850, and 3.700 mmol l^{-1}. The salinity levels were a result of additions of concentrations of NaCl and $CaCl_2$. The negative effects of salinity were evident as early as the first months of treatments, manifesting themselves as a drastic decrease in evapotranspiration which appeared during the 12 dS m^{-1} treatment. Elevated root concentrations of Cl and Na were found with increasing irrigation salinity. For salinity treatments of 4, 8 and 12 dS m^{-1}, root Na was two times greater than that in the leaves, while Cl was up to eight fold greater in roots than in leaves.

Four date palm varieties offshoots were irrigated with saline water commencing with 7.8 dS m^{-1} and slowly increasing the concentration of salt to 11.7, 15.6, 19.5, 23.4 and 27.3 dS m^{-1} at regular intervals of three months duration (Kurup et al., 2009). The varieties response was different to the increasing salt concentration. The plant height, collar girth and number of leaves of *Mesalli* and

Razez variety cultivars reduced with the increasing of water salinity from 7.8 to 27.3 dS m^{-1}, while water salinity increased vegetative growth of *Bugal White* and *Khashkar* cultivars.

The overall objective of this research was to evaluate the effect of irrigation water salinity on the survival and growth characters of Barhee juvenile date palms. The *Barhee* date palm is one of most important date palm cultivars in Iran.

Materials and Methods

This field study was conducted in the Date Palm and Tropical Fruits Research Center (N 31°15′ E 48°30′ and22.5 m a.s.l.) in the city of Ahwaz, Iran. The research was carried out as a randomized complete block design with three treatments and four replications on *Barhee* juvenile date palm. The treatments were:

WS1: Water salinity of 2.5 dS m^{-1} (Karoun River).

WS2: Water salinity of 8 dS m^{-1}.

WS3: Water salinity of 12 dS m^{-1}.

12 polyethylene drainage lysimeters of 0.6 m diameter and 0.9 m depth were installed for the performing of this experiment. The lysimeters were filled with sandy loam soil (Table 1).

Table 1. Composition of lysimeter soil.

Sand	Silt	Clay	Texture	EC (dS m^{-1})	SAR	pH	Na^+ (meq/lit)	Ca^{2+} (meq/lit)	Mg^{2+} (meq/lit)
69	17	14	Sandy loam	3.9	4.9	7.8	17.7	12.2	13.5

A *Barhee* juvenile date palm was planted in each lysimeter (February 2015). The juvenile date palms were irrigated via a bubbler system. The lysimeters soil surface was covered with date palm leaf particles (1 kg/m^2) as mulch (Hussain *et al*., 1986; Terasaki *et al*., 2009; He *et al*., 2009; Tishehzan *et al*., 2011).

After completing the plant establishment period ,the juvenile date palms were irrigated based on the salinity of the irrigation water (May 2015). The Karun River water and other irrigation water were stored in 1000 liters tanks that were connected to the irrigation system separately.

The mean salinity of the Karun river water salinity was 2.5 dS m^{-1} during the experiment and saline irrigation water was obtained by mixing the drainage runoff and stored irrigation water (Table 2). Soil moisture was measured during the treatment of water salinity of 2.5 dS m^{-1} (Karun River) for determining irrigation interval. The net irrigation depth (d_n) was calculated for obtaining soil moisture deficiency:

$$d_n = (\theta_{fc} - \theta_i) Z \quad (1)$$

Where

θ_{fc} = Field capacity (m^3/m^3),

θ_i = Measured soil moisture (m^3/m^3),

Z = Root depth (mm).

The gross irrigation depth was determined based on leaching requirements (LR_t):

$$LR_t = EC_w / [2(EC_e)_{max}] \quad (2)$$

Where EC_w is the irrigation water electrical conductivity and $(EC_e)_{max}$ is the saturated extract electrical conductivity of the soil root zone for zero yield point which is 32 dS m^{-1} for the date palm (Ayers and Westcot, 1994).
The soil salinity was measured by sampling soil depths (0-25, 25-50, 50-75 cm) at the end of the experiment. The date plants growth characters such as number of leaves, leaf length, leaf width, leaf chlorophyll, number of leaflets, leaflet length, leaflet width, trunk perimeter were measured. Data was analyzed statistically using SPSS Statistics 19 software. the mean comparison was also performed using Duncan's Multiple Range test.

Results and discussion

ANOVA test of soil salinity in different layers (0-25, 25-50 and 50-75 cm) indicated that the effect of irrigation water salinity was significant at probability level 0.01. The highest soil salinity in 0-25 cm layer was obtained in water salinity of 12 dS/m (Table 3). There was a significant difference in soil salinity between water with 2.5 dS/m and 12 dS/m. Soil salinity for treatment of 12 dS/m (16.2 and 16.6 dS/m, respectively) was also more than other treatments in soil layers of 25-50 cm and 50-75 cm.

Table 2. Composition of irrigation water.

EC (dS m^{-1})	SAR	pH	Cation (meq/L)			Anion (meq/L)		
			Na^+	Mg^{2+}	Ca^{2+}	Cl^-	HCO_3^-	SO_4^{2-}
2.5	5.2	7.9	13.3	7.7	5.5	19.8	3.7	-
8.0	12.9	8.0	54.8	25.8	9.8	64.0	5.3	-
12.0	17.5	8.0	85.1	29.1	18.2	86.0	12.1	-

Table 3. Effect of water salinity on soil layers salinity*.

Treatment	0 - 25 cm	25 - 50 cm	50 - 75 cm	0 - 75 cm
WS_1	9.6 bc	8.5 c	8.1 c	8.7 bc
WS_2	11.2 ab	12.1 bc	12.2 b	11.8 b
WS_3	13.8 a	16.2 a	16.6 a	15.5 a

* Means followed by same letter in column are not significantly different at level 1%.

There was significant difference in soil salinity in this treatment with water of 2.5 dS/m and 8 dS/m.
The ANOVA test of soil salinity at different depths (0-75 cm) indicated that the effect of irrigation water salinity was significant at probability level 0.05. The mean of soil salinity (0-75 cm) is presented in Table 1. The highest soil salinity (15.5 dS/m) was obtained in water salinity of 12 dS/m. The results reported in Table 1 demonstrate clearly that soil salinity has a direct and significant connection with irrigation water salinity, as soil salinity in irrigation water of 12 dS/m was 1.8 and 1.3 times the irrigation water electrical conductivity levels of 2.5 and 8 dS/m, respectively. This condition is due to the increasing of total dissolved solids (TDS) of irrigation

water resulting into the enhancement of water electrical conductivity. The change process of soil salinity is according to other studies (Kamali *et al*. 2011; Salehi *et al*., 2011). This issue is important due to the salts effect on the physical and chemical characteristics of soil or growth location of the plant.

The survival rate of the juvenile date palms was 100 percent in all treatments. The date plants survival in the case of irrigation with saline water of 12 dS/m (soil salinity 15.5 dS/m) showed that the *Barhee* juvenile date palms tolerated irrigation water salinity. This result is similar to other research results. The survival of all *Barhee* juvenile date palms has been reported in the usage of saline water of 9 dS/m (Valizadeh *et al*., 2012) and in saline soil of 14.2 dS/m (Tishehzan *et al*., 2011).

The ANOVA test of juvenile date palms vegetative characters showed that the effect of irrigation water salinity was significant at probability levels of 0.05 on all vegetative characteristics except leaf chlorophyll and leaflet width. The highest and lowest plant vegetative characteristics except for leaflet width were formed in irrigation water of 2.5 dS/m and 12 dS/m, respectively (Tables 4 and 5). Duncan's test for comparison of the mean showed a significant difference in the number of leaves, leaf width, number of leaflets and trunk perimeter between water salinity treatments of 2.5 dS/m and 8dS/m. Saline water of 8 dS/m and 12 dS/m had a significant difference only in leaf width and trunk perimeter.

The evaluation of the effect of irrigation water salinity on the growth of 12 cultivars of United Arab Emirates date palm indicated that the number of leaves showed a significant reduction with the increasing of irrigation water salinity from 3000 to 6000 ppm (Alhammadi and Edward, 2009). Whatsmore, the growth response of date palm cultivars was significant in regards to irrigation water salinity. Irrigation with saline water of 11 dS/m reduced the leaf growth of two date cultivars *Sakkoti* and *Bartamoda* in Egypt significantly (Hussein *et al*., 1993). The salinity stress effect on the growth of three date varieties seedlings indicated that salinity of 4000 ppm NaCl created a significant increase in the growth of vegetative characteristics rate as compared to a salinity of 0.0 ppm, while salinities 8000 and 12000 ppm reduced the growth of vegetative characters significantly (El-Sharabasy *et al*., 2008).

Table 4. Effect of water salinity on date plants leaf characteristics*.

Treatment	Number of leaves	Leaf length (cm)	Leaf width (cm)	Leaf chlorophyll
WS_1	4.7^{a}	44.8^{a}	44.2^{a}	61.8^{a}
WS_2	2.0^{b}	39.8^{ab}	37.0^{b}	61.1^{a}
WS_3	2.0^{b}	34.8^{b}	33.2^{c}	59.9^{a}

* Means followed by same letter in column are not significantly different at level 5%.

Table 5. Effect of water salinity on leaflet and trunk characteristics*.

Treatment	Number of leaflets	Leaflet length (cm)	Leaflet width (cm)	Trunk perimeter (cm)
WS_1	375.0^{a}	25.4^{a}	1.83^{a}	13.8^{a}
WS_2	234.0^{b}	23.7^{ab}	1.94^{a}	9.8^{b}
WS_3	228.0^{b}	22.2^{b}	1.95^{a}	7.8^{c}

* Means followed by same letter in column are not significantly different at level 5%.

According to Ramoilya and Pandey (2003) the date palm is tolerant to salinity, because 50% *Rati* date seedlings grow in saline soil of 9 dS/m. The ability of date palm in osmotic pressure regulation rate in regards to Na^+ and Cl^- has been recognized as the reason for the tolerance of date palm to salinity (Al-Khayri, 2002). Kurup *et al*. (2009) reported that date palm response to salinity stress can be attributed to the availability, uptake and transport of elements within the plant. They state that irrigation water concentration of 7.8-12.5 dS/m is the salinity threshold for reducing date palm growth. Kafi *et al*. (2010) reported that plants are more sensitive to water and soil salinity in germination and the early stage of growth than other growth states.

Conclusion

The survival of all date plants even in saline water 12 dS/m indicates that juvenile date palm tolerate irrigation water salinity. This experiment shows that vegetative growth of *the Barhee* varety juvenile date palm in water salinity of 2.5 dS/m is more than saline water of 8 dS/m and 12 dS/m. The maximum and minimum of plant vegetative characteristics except leaf chlorophyll and leaflet width were obtained at water of 2.5 dS/m and 12 dS/m, respectively. There was a significant difference between water of 2.5 dS/m and 8 dS/m in terms of leaf number, leaf width, number of leaflets and truck perimeter. Therefore, saline waters (EC ≥8 dS/m) cannot be used for irrigation of the *Barhee* juvenile date palm variety.

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EFFECTS OF CLIMATE CHANGE ON SURFACE DRAINAGE (CASE STUDY: ILAM DAM WATERSHED)

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Abstract

Water is essential to human survival, and changes in its supply from overland flow can potentially have devastating implications, particularly in Iran, where much of the population relies on local rivers for water. Future climate change may pose one of the greatest threats to poverty eradication plans in this country, and related changes in surface water supply will exacerbate this threat. Climate change will alter the duration, intensity, type and timing of precipitation. This can cause unprecedented droughts and floods. Whatsmore, it changes the volume, timing, and duration of the runoff, leading to many changes and developments in the field of water resources management. Early spring runoff in snow-fed rivers will lead to increased flooding. In addition to the primary impact of floods on lives, crops, livestock, and property, they bring the threat of epidemics in their aftermath. Increased surface drainage capacity may be required to prevent crop damage or loss or even the threatening of haman and animal lives. Runoff and overland flow ultimately effect land erosion and sediment transport to surface drains. Sediment itself is a major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which in themselves affect the health of receiving open water bodies.

Ilam dam basin which is 471.6 km2 is located in western Iran. The basin consists of three rivers originating from three sub-basins joining at the dam site. Rain-fed cultivation is a prevailing type of agriculture in the aforementioned basin (about 80% of the total area of agricultural lands in the basin). Therefore Agriculture in this region depends critically on weather conditions so that every change in weather conditions can greatly affect the cropping pattern.

In this study, a commercial hydrological model (SWAT) with A2 and B1 emission scenarios predicted usingHadCM3 General Circulation Models (GCMs) in a future period (2046-2065) were applied to determine the total runoff volume and peak rate. By applying various climate change scenarios, the mean annual air temperature shows an increase from 1.47°C (B1) to 2.11°C (A2) in the future as compared to the baseline (1990-2010). The mean total annual precipitation also shows

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an increase from 35.4 mm (A2) to 63.8 mm (B1) in the same period. The results show that in the A2 scenario, the average annual discharge rate decreases by 24% in the future, while in the B1 scenario it increases up to 10% in the same period. According to the B1 scenario, an increase in total runoff is predicted. Although in the A2 scenario total runoff will decrease, the average number of days with heavy precipitation will increase. To cope with such changes, the drainage capacity must be increased. To reduce sediment transport and contaminants adhering to it, new approaches such as buffer strips should be considered. Finally, it is recommended that other scenarios that are more adaptable to the region's future conditions such as land use changes also be investigated.

KEY WORDS: Climate change, Surface drainage, SWAT Model, LARS-WG, Ilam dam watershed

Introduction

The growth of industries and factories since the industrial revolution and the consequential increased consumption of fossil fuels on the one hand and the destruction of forests and changes in agricultural land use, on the other hand, has resulted into increased emissions of greenhouse gasses, especially CO2 in recent decades. The concentration of CO2 has increased from 280 ppm in 1750 to 379 ppm in 2005 leading to global warming (IPCC 2007). The global air temperature has increased by 1.4-5.8°C as compared to the pre-industrial period (Houghton et al. 2001). Developing countries are more vulnerable to climate change since they have less social and financial resources and technologies for adaptation (UNFCCC 2007). Future climate change may pose one of the greatest threats to poverty eradication plans in such countries, and related changes in surface water supply will exacerbate this threat. Climate change alters the duration, intensity, form and timing of precipitation in different regions of the globe. This can cause unprecedented droughts and floods (Mendizabal et al. 2014). Whatsmore, it changes the volume, timing and duration of the runoff thus leading to many changes and developments in the field of agriculture and water resources management (Jothityangkoon et al. 2001; Leavesley 2002; Rudra et al. 2015). Surface drainage which requires the construction of small open ditches or waterways that take water away from fields to larger collection ditches or natural streams is directly affected by climate change. . Since surface drainage is highly dependent on the conditions of the hydrology of the basin such as changes in runoff, it can easily be affected by climate change (Skaggs et al., 1994).

In this study, the effects of climate change on the basin's total runoff has been investigated using a hydrological model (SWAT) with future climate change scenarios predicted by HadCM3 A2 and HadCM3 B1 model-scenarios (IPCC 2007). Runoff and overland flow ultimately effect land erosion and sediment transport to the surface drains. Sediment itself is the major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which affects the health of receiving open water bodies. Finally, the results obtained can be used to modify the capacity of the basin's surface drainage in the future.

Methods

In this study, a hydrological model (SWAT) for current and future climate change scenarios which were in themselves predicted by HadCM3 A2 and HadCM3 B1 model-scenarios was used. To predict the future temperature and precipitation, the fourth IPCC report (AR4) was used. The AOGCM model used in this study is HadCM3 and LARS-WG model has been used for downscaling the HadCM3 model outputs. After entering these values as SWAT model inputs, the future period's runoff is obtained Finally, a few strategies for surface drainage adaptation to climate change has been suggested. Figure 1 illustrates the procedure.

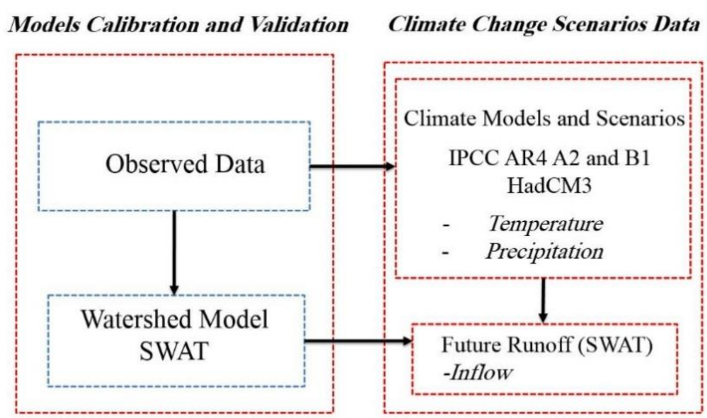

Figure 1. Schematic diagram of methodology used to simulate the future runoff of the basin

Study Area

The Ilam dam basin with a reservoir of 471.6 km2 is located in the West of Iran between 46° 20' 25" to 46° 36' 58" East longitude and 33° 23' 53" to 33° 38' 56" North latitude. The basin consists of three rivers originating from three sub-basins ithat is the Golgol, Chaviz and Ama rivers which convergeat the dam site (46° 40' E and 32° 48' N).

Rain-fed cultivation is a prevailing type of agriculture in the aforementioned catchment (about 80% of the total area of agricultural lands in the catchment). Therefore Agriculture in this region is critically dependent on weather conditions, so that every change in weather conditions can greatly affect the cropping pattern.

Data required to build the models used in this study has been collected from different organizations and companies. Figure 2 shows the geographic location of the basin and the location of the dam and the stations in the Ilam dam basin. Table 1 lists the stations used in each model.

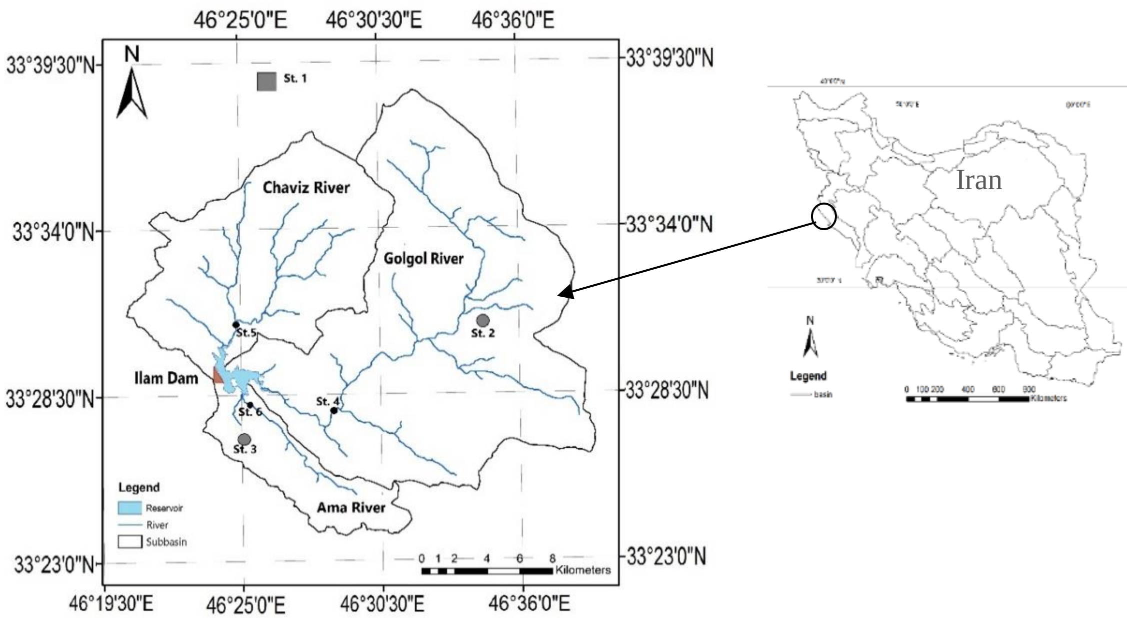

Figure 2. Location of Ilam basin and meteorological and hydrological stations

Table 1. Meteorological and hydrological stations data used in each model

Station No.	Station Type	Used in Model	Data Period	Latitude	Longitude	Elevation (m)
St. 1	Synoptic	LARS-WG SWAT	1987-2010	33° 38’	46° 26’	1337
St. 2	Rain Gauge	SWAT	1997-2007	33° 31’	46° 34’	1434
St. 3	Rain Gauge	SWAT	1999-2007	33° 26’	46° 25’	1360
St. 4	Hydrometric	SWAT	1998-2010	33° 27’	46° 28’	1100
St. 5	Hydrometric	SWAT	2003-2010	33° 30’	46° 24’	1067
St. 6	Hydrometric	SWAT	2003-2010	33° 28’	46° 25’	1032

General Circulation Models (GCMs) and their downscaling to suit the region

In the study, general circulation models (GCMs) were used to predict the thermal stratification in the reservoir. That is why two GCMs are reflected in the fourth report of IPCC (AR4) (Randall et al. 2007) Both were used to predict temperature and precipitation in the Ilam Dam basin in the middle of the current century (the horizon of 2055 or 2046-2065). In addition, GCMs were used to predict temperature and precipitation with greenhouse gas emissions scenarios (IPCC Special Report on Emission Scenarios or SRES 2000). In this study, B1 (lower) and A2 (higher) greenhouse gas emissions scenarios were used. GCMs are able to predict future situation on a global and continental scale but lack suitable accuracy in predicting climatic parameters on smaller scales because of the regional effects on the climate such as slope and aspect, elevation, proximity to the sea, etc. (Wigley et al. 1990). To use GCMs outputs, downscaling methods should be used. In this study, LARS-WG5.5 statistical model simulator was used for downscaling. In fact, LARS-WG is a model used for producing meteorological data. By Fitting a distribution function with 21 parameters on the measured data, it is able to reproduce the measured data. It can also generate future data in case a particular climate scenario for modeling is defined (Semenov and Barrow 2002).

Using measured data, LARS-WG model was calibrated in the Ilam Dam basin. Then, according to the median forecast of each GCM, future data was generated on a daily scale. To determine the quality of calibration results, the suitablity of fit (P-value) and correlation coefficients were used (Semenov and Barrow 2002). The results indicated an acceptable fitness at a confidence level of 95%. However, due to low precipitation levels in the summer, the calibration results in this season were weaker but still significant.

The Hydrological Simulator (SWAT)

The SWAT model is a comprehensive model on the basin scale provided by the U.S. Agricultural Research Service. It is a semi-distributed model utilized to predict the impact of different management methods on flow, sediment, nutrients and chemical balance in basins with different soils, land use and management conditions over long periods of time. The model includes hydrology, climate, erosion, plant growth, nutrients, pesticides, land management and flow routing. A more detailed description of the model has been given by Neitsch et al. (2002).

The following data for making hydrological model were obtained from a variety of sources:

Digital elevation model (DEM) from Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters (*http://www2.jpl.nasa.gov/srtm/*).

The land use map from Global Landuse /Landcover Characterization USGS with a spatial resolution of 1 km including 17 land use categories (*http://landcover.usgs.gov/glcc/*)

The soil map was obtained from the global soil map of the Food and Agriculture Organization of the United Nations (FAO) (FAO 1995), which provides data for 5000 soil types comprising two layers (0-30 cm and 30-100 cm depth) at a spatial resolution of 5 km (*http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/*).

Meteorological data (daily precipitation, maximum and minimum daily temperature and daily solar radiation) from St. 1, St. 2 and St. 3 were obtained from I.R. of IRAN Meteorological Organization.

The river flow in St. 4, St 5 and St 6 were obtained from Iran Water Resources Management Co.

At the end of the model making process, a model with 74 sub-basins and 274 HRUs was determined.

SWAT Calibration and Validation

In this study, SUFI-2 (Sequential Uncertainty Fitting) algorithm and SWAT-CUP program were used to calibrate and validate the model. SUFI-2 combines the calibration and uncertainty to find uncertainty parameters, so that the majority of measured data is in the estimation uncertainty range while creating the smallest band of estimation uncertainty. The uncertainty of the model output is calculated by uncertainty estimation at the level of 95% sampled from the domain at 2.5% and 97.5% of the cumulative distribution function of the output variable by the Latin hypercube method (Abbaspour et al. 1997, 2004).

Two indices are used to determine the performance of uncertainty; p-factor: the percentage of data that fall within the 95PPU (95 Percent Prediction Uncertainty) band (maximum 100%) and R-factor: the average thickness of the band divided by the standard deviation of the measured data. SUFI-2 assumes a large range of uncertainty for each parameter. Thus, the measurement data are initially at 95PPU level and this uncertainty is reduced in subsequent steps until two conditions are met: (1) the majority of the measured data is at 95PPU level (P-factor → 1), (2) the average distance between the upper and lower limits of 95% divided by the standard deviation of the measured data is as small as possible (R-factor → 0) (more details of SUFI-2 can be found in Abbaspour et al. 2007). NS factor was selected as the objective function. After sensitivity analysis of parameters in SUFI-2, 20 parameters were selected for the calibration and validation as shown in Table 2.

Table 2. Parameters used for calibration and validation of SWAT model

No	Variation	Parameter	Definition	Fitted value
1	Relative	CN2	Initial SCS runoff curve number for moisture (condition II)	0.07
2	Replace	USLE_P	Universal Soil Loss Equation coefficient	0.59
3	Replace	REVAPMN	Threshold depth of water in the shallow aquifer for "Revap" to occur (mm)	85.24
4	Replace	GW_REVAP	Groundwater "Revap" coefficient	0.13
5	Replace	ALPHA_BF	Baseflow alpha factor (days)	0.28
6	Relative	CH_K1	Effective hydraulic conductivity in tributary channel alluvium (mm/hr)	85.49
7	Replace	CH_COV1	Channel erodibility factor	0.42
8	Replace	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	114.19
9	Replace	CH_N2	Manning's "n" value for the main channel	0.026
10	Replace	ALPHA_BNK	Baseflow alpha factor for bank storage (days)	0.24
11	Replace	SURLAG	Surface runoff lag time (days)	11.52
12	Replace	SNOCOVMX	Minimum snow water content that corresponds to 100% snow cover (mm H_2O)	194.51
13	Replace	SMFMX	Melt factor for snow on June 21 (mm H_2O/°C-day)	4.02
14	Replace	HRU_SLP	HRU slope (m/m)	0.36
15	Replace	EPCO	Plant uptake compensation factor	0.39
16	Replace	SLSUBBSN	Average slope length (m)	41.10
17	Replace	CANMX	Maximum canopy storage (mm H_2O)	60.86
18	Relative	SOL_Z	Depth from soil surface to bottom of layer (mm)	1780.87
19	Relative	SOL_K	Saturated hydraulic conductivity (mm/hr)	0.31
20	Relative	SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)	0.18

Out of a 23-year statistical period, 5 years (from 2006 to 2010) were used for calibration of the discharge in St. 5 and St. 6 hydrometric stations. Eight years from 2003 to 2010 were used for the calibration of the discharge in St. 4 hydrometric station. Data over three years (from 2003 to 20060 was used for THE validation of St. 5 and St. 6. Six years from 1998 to 2003 was used for The validation of St. 4. The period from 1987 to the end of 1989 was used to warm-up the model. To assess the ability of the SWAT model in river discharge simulation, P-factor, R-factor, R2 and Nash-Sutcliffe (NS) were used. Table 3 shows the simulation results separately for the calibration and validation periods. Figures 3 to 5 show the calibration and validation of the hydrometric stations.

Table 3. SWAT model calibration and validation result in hydrometric stations

Criteria	St. 4		St. 5		St. 6	
	Calibration	Validation	Calibration	Validation	Calibration	Validation
R^2	0.71	0.77	0.79	0.56	0.79	0.79
E_{NS}	0.66	0.63	0.77	0.51	0.51	0.78
R-factor	1.07	0.77	1.16	0.58	1.47	0.74
P-factor	0.57	0.43	0.58	0.43	0.49	0.54

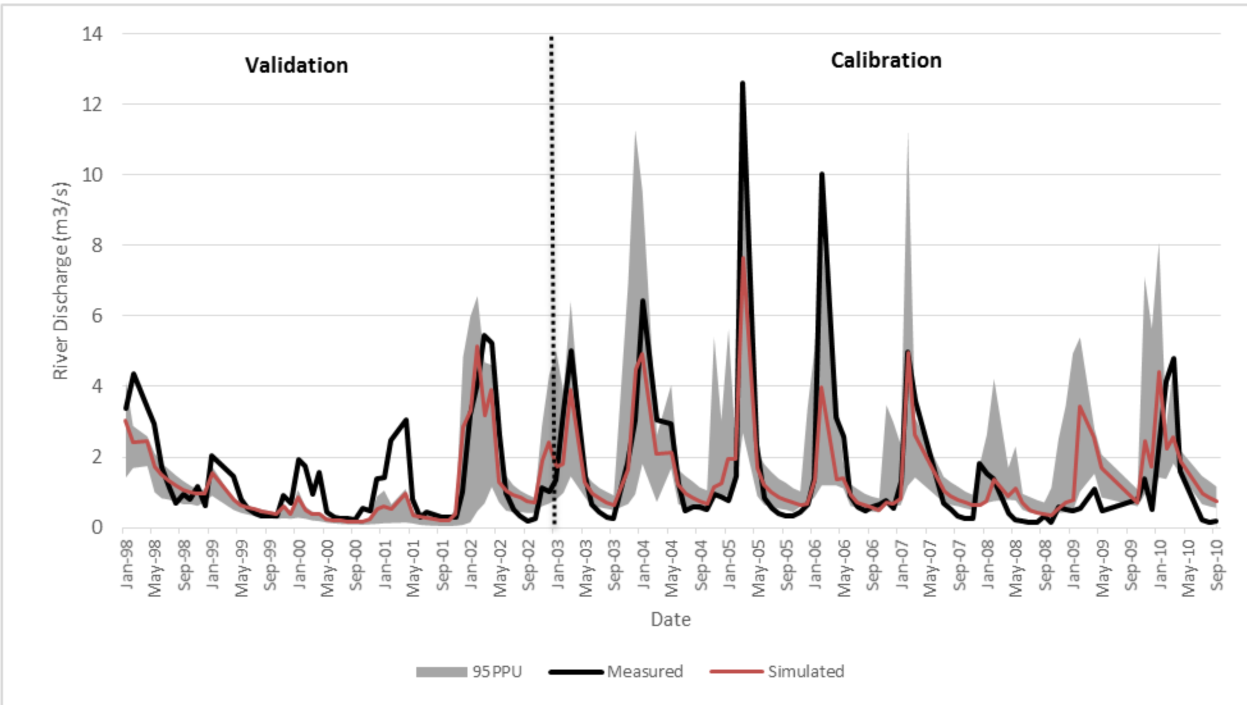

Figure 3. Result of SWAT calibration and validation for St. 4

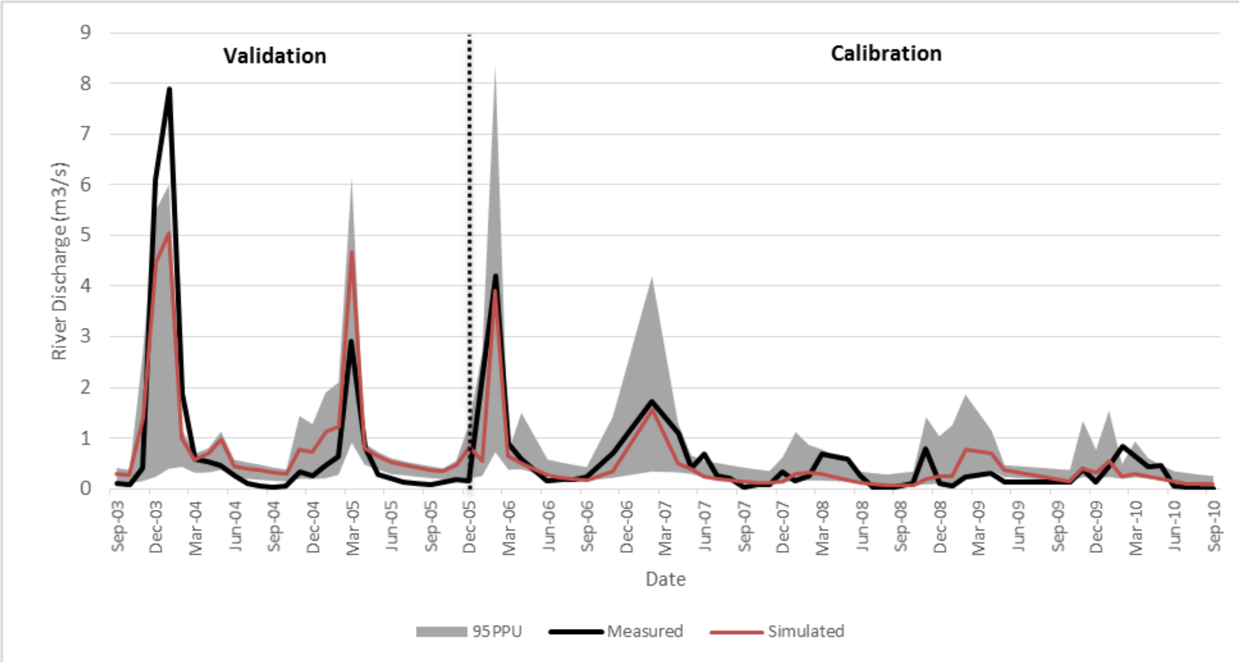

Figure 4. Result of SWAT calibration and validation for St. 5

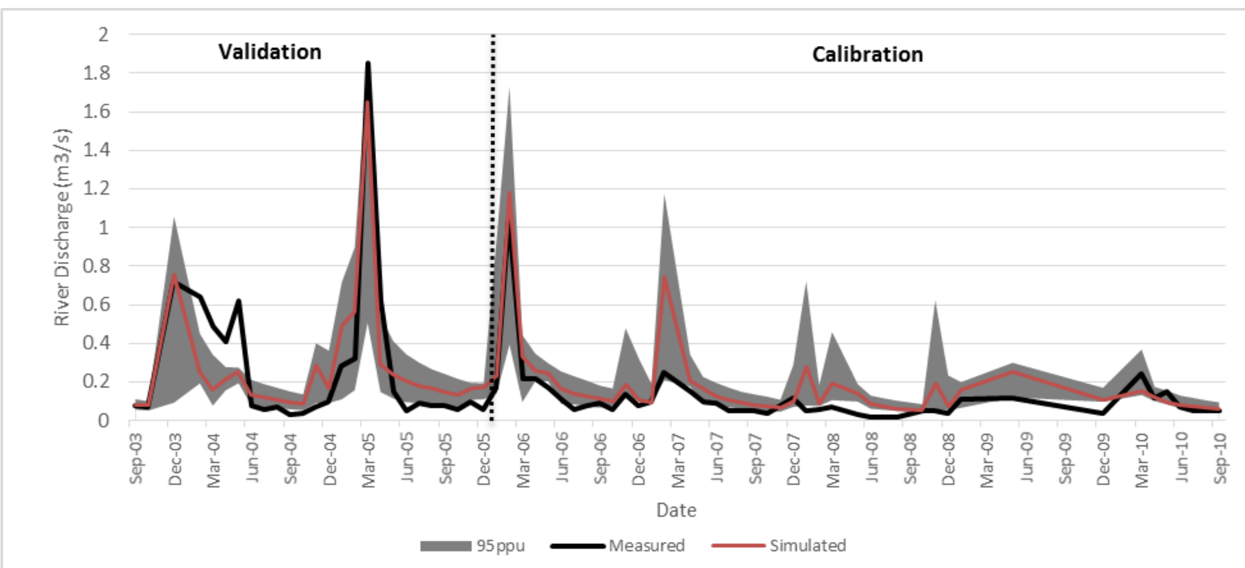

Figure 5. Result of SWAT calibration and validation for St. 6

Results and Discussion

Forecasting future temperature and precipitation by LARS-WG model

The downscaling results of the HadCM3model with a B1 and an A2 emission scenario for precipitation and temperature are shown in Figures 6 and 7. It should be noted that precipitation data is reported as the mean total monthly precipitation in mm and temperature is the mean monthly temperature in degrees Celsius.

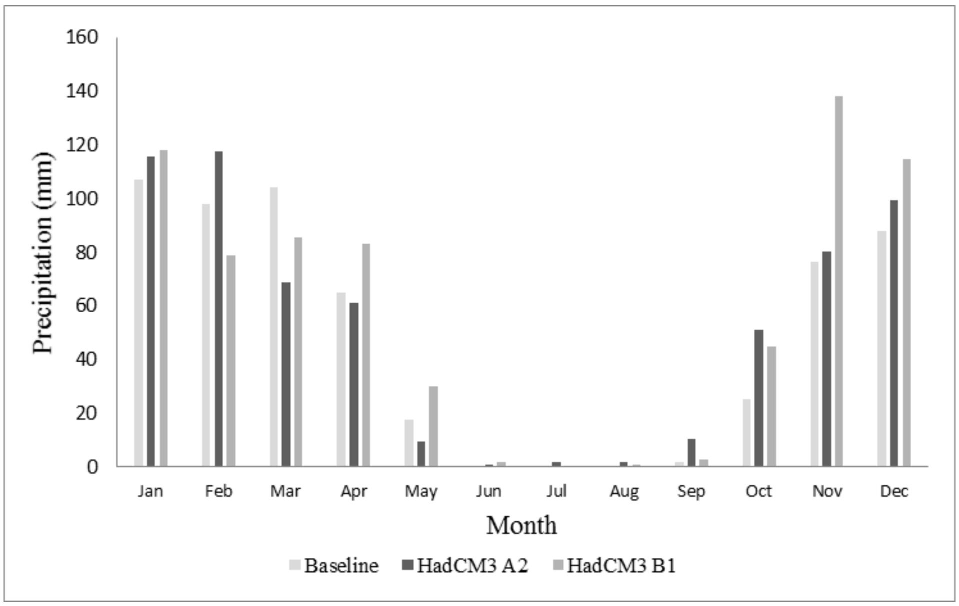

Figure 6. Mean total monthly Precipitation in baseline (1990-2010) and future (2046-2065) periods

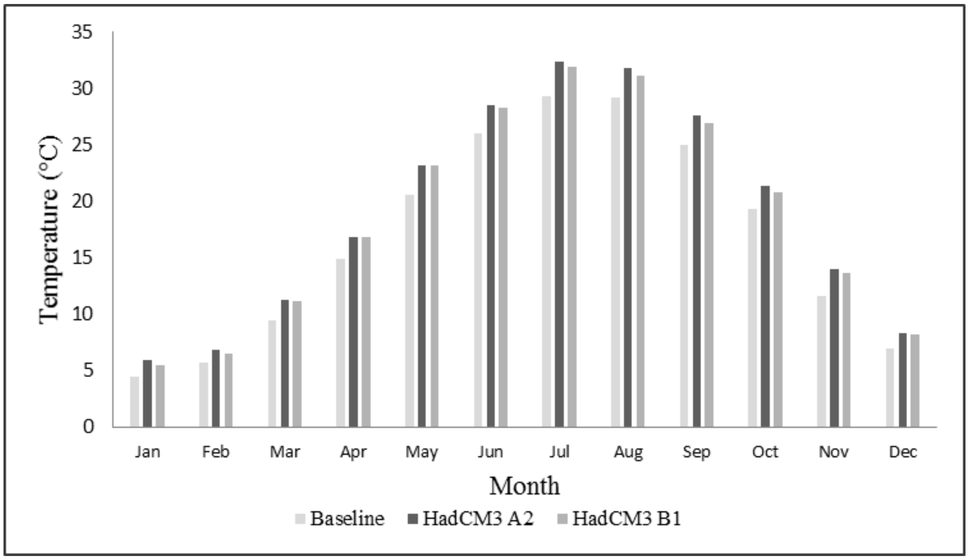

Figure 7. Mean monthly Temperature in baseline (1990-2010) and future (2046-2065) periods

Table 4. Mean annual temperature and annual precipitation values in the baseline (1990-2010) and future (2046-2065) periods

HadCM3		Observed	
B1	A2		Scenario
18.68	18.99	16.87	Mean Annual Temperature (°c)
647.5	619.1	583.7	Mean Annual Precipitation (mm)

Forecasting future runoff using the SWAT model

After downscaling the climatic data for future periods using the HadCM3 model with A2 and B1 scenarios, a 20-year time series data for the future period (2046-2065) was generated to be used in the SWAT model. Figure 8 shows the mean monthly discharge as it increases or decreases in the future period as the mean monthly discharge at hydrometric stations in the baseline and future periods.

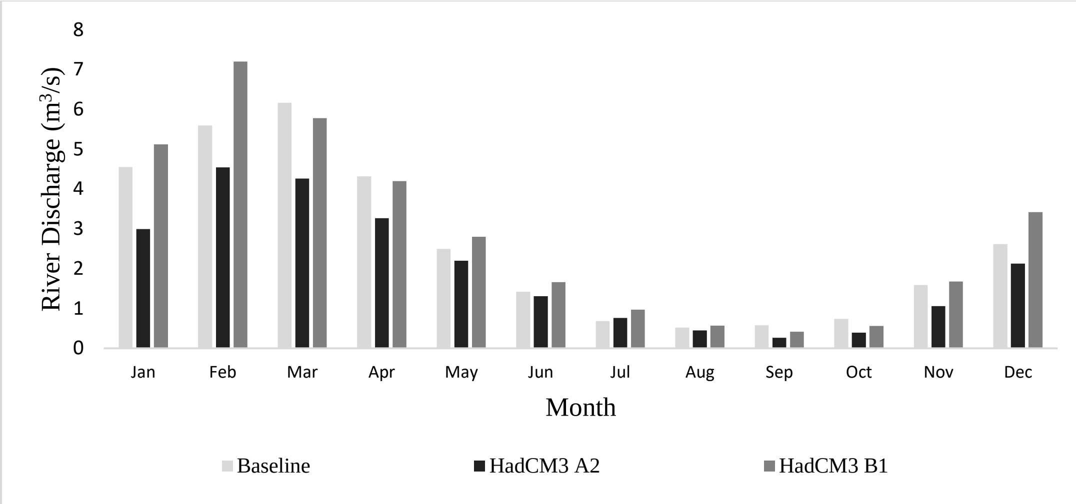

Figure 8. Sum of mean monthly discharge in Baseline (1990-2010) and future (2046-2065) periods in 3 hydrometric stations

As seen in Figure 8, the maximum average monthly discharge rate in the baseline period is seen in March, but in the future period Model-scenarios, it is observed to be in February. This change indicates that the time of occurrence of the maximum average monthly discharge rate has changed. In addition, future discharge rate change as compared to the baseline period. The results show that in the A2 scenario, the average annual discharge rate decreases by 24% in the future period, while in the B1 scenario it increases up to 10% in the same period.

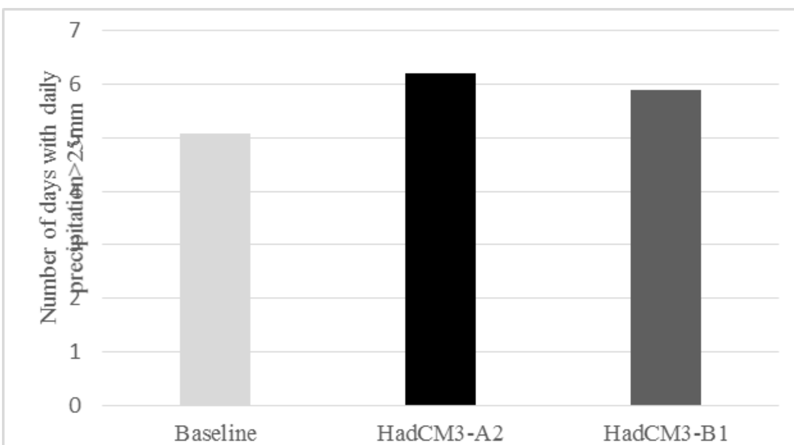

Figure 9. Comparison between number of days with extremely heavy precipitation between baseline and future periods

Figure 9 shows the average number of days with an amount of precipitation of more than 25mm in the baseline and future periods. According to the graph, in the future, approximately one day will be added to the number of days with heavy precipitation. Heavy precipitation refers to instances during which the amount of rain or snow experienced in a location substantially exceeds what is normal. What constitutes a period of heavy precipitation varies according to location and season. Climate change can affect the intensity and frequency of precipitation. Warmer oceans increase the amount of water that evaporates into the air. When more moisture-laden air moves over land or converges into a storm system, it can produce more intense precipitation. For example, heavier rain and snow storms (Melillo et al., 2014). The potential impacts of heavy precipitation include crop damage, soil erosion, and an increase in flood risk due to heavy rains which in turn can lead to injuries, drownings, and other flooding-related effects on health (Bell et al., 2016). In addition, runoff from precipitation can impair water quality as pollutants deposited on land wash into water bodies. Heavy precipitation does not necessarily mean the total amount of precipitation at a location has increased just that precipitation is occurring in more intense events. However, changes in the intensity of precipitation, when combined with changes in the interval between precipitation events, can also lead to changes in overall precipitation totals.

Conclusion

According to literature, a basin's hydrology is extremel sensitive to climatic conditions and basins respond to the changes quickly. Hydrology is the primary factor in various processes in the basin. Climate change will alter the hydrology of the basin ,leading to changes in temperature and precipitation patterns. In this study, a hydrological model was developed to consider the potential effects of changing basin variables on the basin's runoff.

To explain the mechanism affecting runoff volume in a basin and its impact on water needed for agriculture and surface drainage system, the hydrology, and hydrological relationships were investigated and simulated using a hydrological model. In the climate change scenarios, the A2 and B1 scenarios respectively assumed mean annual temperature increase of 2.11 °C and 1.47 °C in the 2046-2065 period based on 1987-2010 data. Furthermore, the mean total annual precipitation in the 2046-2065 period increased by 35.4 and 63.8 mm according to the A2 and B1 scenarios and 1987-2010 data, respectively. Finally, the effects of changes in precipitation and temperature on increase or decrease of the discharge of rivers was studied. The simulation results of the A2 and B1 scenarios have been compared with the results of the baseline period. The results showed that the total runoff for the period 2046-2065 will decrease 24% according to the HadCM3 A2 model scenario and will increase 10% according to the HadCM3 B1 model-scenario based on 1987-2010 data. Runoff and overland flow essentially effect land erosion and sediment transport to the surface drains. Sediment itself is the major carrier of contaminants such as phosphorus, heavy metals, and the residue of pesticides and herbicides, which affects the health of receiving open water bodies. In order to adapt to such changes, it is necessary to modify the surface drainage system and use methods to reduce water pollution as briefly described in the following paragraphs.

Increasing the capacity of surface drainage systems:

Because of the changes in the pattern and amount of precipitation and surface runoff volume and more heavy precipitation in the future period and in order to adapt to these changes, it is necessary to increase the capacity of the surface drainage system in the basin. Surface drainage improvements may consist of land smoothing, grading, precision, and land forming and the establishing of a slight grade on the land surface. A network of field ditches, laterals, and main canals also may be an integral part of a surface drainage system.

Using Buffer Strips:

Numerous studies have shown that cultivating green stripes as a buffer between the edge of streams and rivers has a significant effect in preventing or diminishing water pollution. Creating green stripes is considered as being one of the good practices in reducing water pollution. For example, a green margin of 15 meters on both sides of the river prevents the transport of sediment and nutrients from farm sewage to the water resource. To determine the proper width, information about the intensity of water pollution, soil type, slope of the land, and type of ground cover is essential (Anonymous, 1994). To create a green margin, bushy shrubs and grass can be used. Surface runoff and farm's sewage passes through the green strips and plants obstruct the sediments and suspended solids which are then deposited and as a result relatively clear water flows into rivers. For example nitrate in the surface runoff can be absorbed by plant roots and finally, during the Denitrification procedure, Nitrogen gas is released into the air. Phosphorus which has been deposited along with sediment in buffer strips is used to produce chlorophyll, which is gradually used by plant roots and prevents its transformation into the waters (Anonymous, 1995).

Finally, it is recommended that other scenarios that are more adaptable to the region's future conditions such as land use changes be investigated.

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CONTROLLED SUB-SURFACE DRAINAGE AS A STRATEGY FOR IMPROVED WATER MANAGEMENT IN IRRIGATED AGRICULTURE OF UZBEKISTAN

Victor Dukhovny[1], Shavkat Kenjabaev[2,*], Shavkat Yakubov[3], Gulomjon Umirzakov[4]

Abstract

An existing conventional subsurface drainage system (CVD) was modified to control the flow from the drainage lateral and to control the groundwater table depth in portion to the irrigated winter wheat field during the 2014-2015 crop growing season in the Fergana valley, Uzbekistan. Drainage outflow at the one out of two drainages was controlled (CTD) while the other was left free (CVD). Drainage water volumes and water quality were monitored from October 25, 2014 until June 15, 2015. The cumulative drainage water volume from the CVD treatment was 22% greater than the CTD treatment over this period. The flow weighted mean salt concentration of the drainage water was 7% lower at the CTD treatment (2.08 mS cm^{-1}) as compared the CVD treatment (2.24 mS cm^{-1}). In addition, the effect of CTD experiment on crop growth parameters as well as on grain yield was evaluated by comparing a ratio of the field level hydraulic parameters between transects #A and #B (1) vs. #B and an open collector (2) along the drainage course. The ratio of soil water content in the 1 m soil profile between (1) and (2) was 1.20 which indicated that the upper part of the field contained 20% greather soil moisture for the crop to utilize during the growing period as compared with the lower portion of the field. Conversely, the ratio of the water table depth between (1) and (2) was 0.78 indicating that the water table of the upper portion of the field was 47 cm (22%) shallower than the lower part. Thus, CTD increased the moisture storage of the soil layer at the upper part of the field as compared with the lower part. Managing the water table resulted in less water stress between irrigation events and increased grain yields in the area with shallowest groundwater. Introduction of the CTD at the farm level has the potential to improve the livelihoods of farmers by reducing costs associated with water application and maintaining agricultural production in water short years as well as reducing collector-drainage water outflow.

KEY WORDS: Controlled drainage, Groundwater table, Drainage outflow, Wheat yield.

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Introduction

Rapid expansion of irrigated lands during 1960-1980 in Uzbekistan is followed by installation of drainage systems in response to water logging and salinity problems. Currently, artificially drained area in Uzbekistan covers about 2.9 Mha, of which 19% (about 13% of country's irrigated land) constitutes subsurface drainage systems (Dukhovny et al, 2007). Depending on hydrological and economic conditions, the depth of subsurface drainage installation is usually 0.3-1.0 m deeper from the depth of active groundwater level (GWL) while space between two laterals is not less than 50 m (Dukhovny et al., 2005a;b; 2007). Peculiarity of drainage system in arid areas is that installation depth and the lateral spacing are nearly twice deeper and 4-5 times greater than those in humid areas, respectively (Ayars et al., 1996). However, the principal differences of subsurface drainage system design in arid areas compared to those in humid areas are grounded on peculiarity of natural-climatic condition (high evaporation intensity, moisture deficit, soil salinity etc.) that stipulated for deeper installation (2.5-3.5 m against 0.8-1.2 m), lesser intensity, considerably higher designed discharge and therefore deeper GWL and higher surface water application for agricultural crops. However, there is no need to drain soil much deeper than the root zone.

Another peculiarity of these drainage systems is their design that discharges water continuously, without regard to environmental consequences. Conventional agricultural land drainage systems are usually over designed to cope with worst-case situations in terms of crop rooting depths and drainage requirements, as well as the expected loss of performance as systems age. For many crops and for much of the time this results in more water being removed from the soil profile and passed to drains than is necessary to control water-logging or the buildup of salinity in the soil profile. Analysis of approximate water-salt balance at district level across provinces of Uzbekistan, demonstrated that the majority of drainage systems were over-draining, as they were removing 2.3 times more salt than was applied by irrigation water (Fig.1). In general, farmers frequently over-irrigate to compensate for rapid removal of water by drainage systems.

Negative environmental impacts caused by mismanagement, deterioration and aging of collector-drainage network is accompanied with lack of management of return water effluent into the main rivers, lakes and wetlands releasing salts and pollutants from different water economy sectors. Coupling with that the increase of water mineralization in Syrdarya and Amudarya rivers was observed in time and along the course since 1950-1970 (Kenjabaev, 2014). Moreover, existing irrigation system efficiency is low being 0.48-0.73 thus only 30–35% of water drawn from the source is used for irrigation of agricultural crops (Ikramov, 2007). Partially water losses return to the main stream as a return flow from collector-drainage systems. Hence, mean multiyear stocks of collector-drainage water (CDW) in Uzbekistan makes 21±2 км^3. About 95% out of total return CDW comes from irrigated lands and is almost 43±6% of total agricultural water withdrawal (CAWATERinfo, 2016).

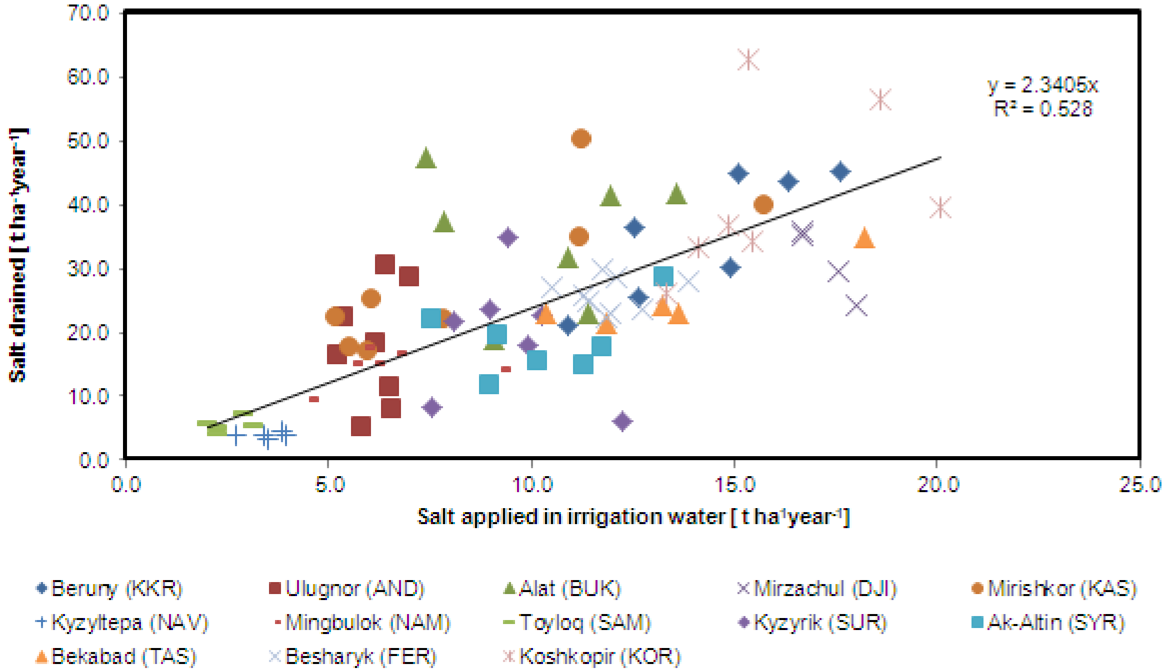

Figure 1. Salt loads in irrigation water and drainage water from various irrigation districts in Uzbekistan (based on data for 1995-2003 periods from the Ministry of Agriculture and Water Resources, the Republic of Uzbekistan)

Note: KKR: Karakalpakistan Republic, AND: Andijan, BUK: Bukhara, DJI: Djizakh, KAS: Kashkadarya, NAV: Navoi, NAM: Namangan, SAM: Samarkand, SUR: Surkhandarya, SYR: Syrdarya, TAS: TAshkent, FER: Fergana, KOR: Khorezm provinces.

One of the ways to solve the problem of further development of water management in agrarian sector is elaboration of large-scale measures to reduce collector-drainage runoff through reuse in place of its formation (Berdjansky & Zaks, 1996). Nowadays about 13% of total return water is re-used for irrigation purposes (Dukhovny et al., 2007), mainly in upper and middle course provinces of Uzbekistan. Although conventional drainage decreases soil salinity under leaching/irrigation mode, improves soil aeration, thereby machine trafficability and increases crop yields (Dukhovny et al., 1979; Madramootoo et al., 2007), it can also lead to soil water stress during the dry periods. As Ayars (1996) stated "in arid areas, subsurface drainage design is based on the concept of "dynamic equilibrium" which assumes that the range of the cyclic annual water table fluctuation is constant". Therefore, the mid-point water table height reaches the maximum height above the drains at the same time each year, generally by the end of the growing season. Moreover, the laterals in a subsurface drainage system design in arid areas have typically been laid to parallel the surface grade of the field being drained. Hence retrofitting an older system to include control structures may not be practical because the slope of the field and drain laterals may require many control structures in the field (Ayars & Shoneman, 2006). The challenge for the most effective water table management system is to find the drainage system, where the laterals having been installed perpendicular to the surface grade or to develop a new system design and installation which enables water table control over a large part of the field with a minimum number of control structures.

Coupling to that it needs a new approach to subsurface drainage that applies management to these drainage systems to reduce their downstream environmental impacts whilst maintaining agricultural production. Controlled drainage may be an option with an existing drainage system that contributes a reduced drainage flow and lower irrigation requirements. Hence it can help farmers to better manage the soil moisture by removing excess water in wet periods as well as to retain moisture in the field during dry periods through regulation of the drain outlets (Singh et al., 2014). In addition, in a controlled drainage system the water table is maintained at a shallower depth by a control structure which reduces deep percolation below the root zone by reducing hydraulic gradients and increases potential capillary upflow as evapotranspiration depletes soil water in the root zone. In addition, the flow lines, in controlled drainage implemented land area, are shallower than in the uncontrolled system and are more concentrated closer to the soil surface. In soil profiles with zones of lower soil salinity at the soil surface this will result in decreased drain water salinity compared to the uncontrolled system. The reduced drain flows and lower salinity result in much reduced salt loads; hence their downstream environmental impacts are minimized. However, it seems more local research will be required to reach to new standards and design criteria leading to optimize technical, economic and environmental issues. After carrying out researches, we would expect a reduction in drainage environmental problems by practicing alternative methods. Therefore, the aim of this study is to know how the management of the GWL by controlled subsurface drainage will provide the opportunity to increase in situ crop water use, which should result in improved irrigation efficiency, and reduced drainage outflow.

Materials and methods

Site description

The experimental site, so called "Azizbek" site (40°28’N; 71°32’E) is situated in the water users association “Oktepa Kyrgizobod ziloli” under the command area of “Naryn-Fergana” administrative irrigation system of Fergana province, Uzbekistan. Two fields at the experimental farm of SANIIRI’s branch in Fergana were selected as research objects. The fields lie within the irrigation zone of Big Fergana Canal (BFC) at flat smooth proluvial plain that constitutes the peripheral part of the alluvial cone of the Margilansay, Shahimardansay, and Isfaramsay transboundary small rivers (Stulina et al., 2005). Slopes are northward and relatively plain, being 0.002 to 0.003 (Stulina et al., 2005; Dukhovny et al., 2005a). Water for irrigation is distributed to the fields through 4 km long concrete-flume canal “Pakhtakor-4” delivering water from the BFC. Hence the fields are suffering with frequent water shortages due to improper water management within the system as well as their location at the tile course of the canal. The field agronomical monitoring as well as research was conducted at two fields (contours: 13/14, 20.2 ha and 15/16, 16.3 ha), with total area of 36.5 ha (Fig.2).

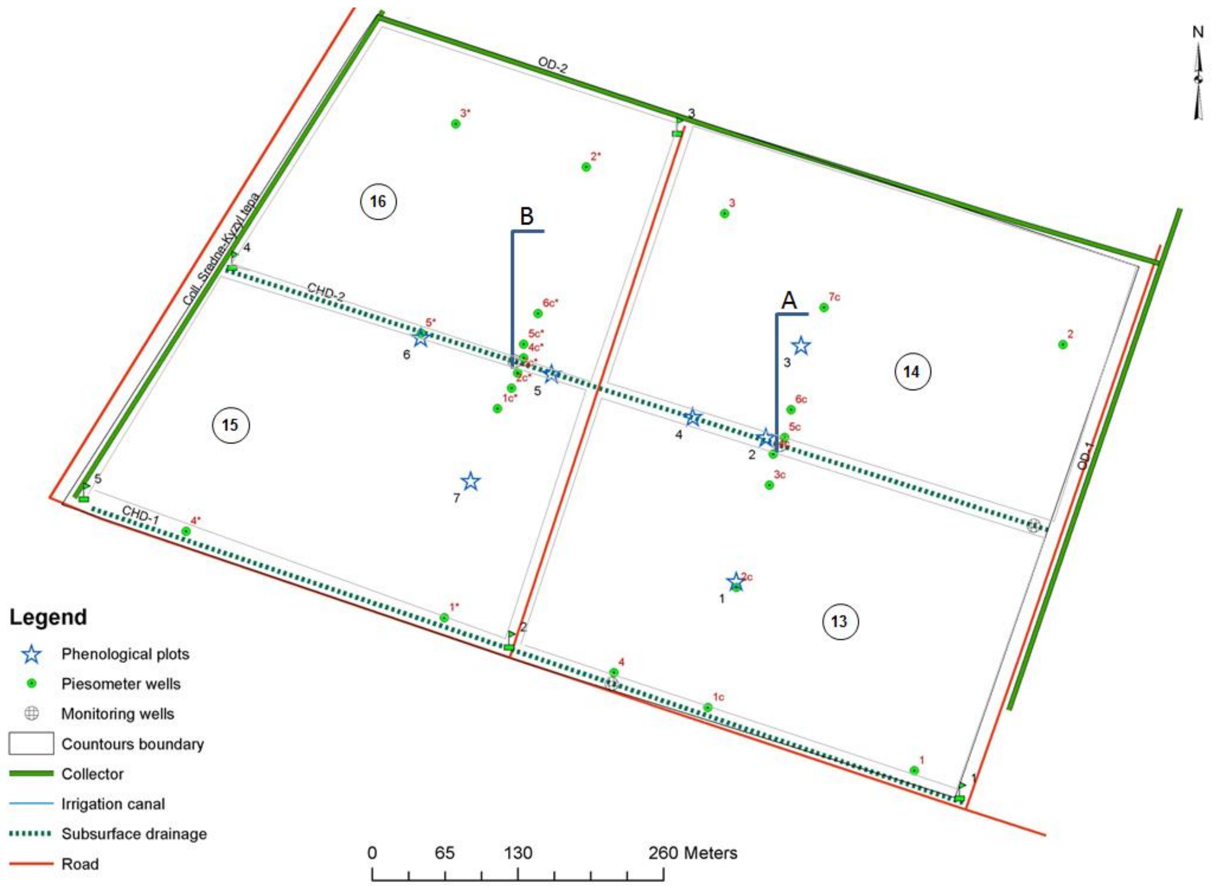

Figure 2. General overview of the experimental site

The study site belongs to the Central Climatic zone (Ц II) (FAO, 2003). The general climatic characteristic of the region according to Köppen-Geiger climate classification varies with typical continental, cold, arid, desert and steppe climate (BWk and BSk) (Kottek et al., 2006). The climatic condition of the study region is characterized by data from meteorological station “Fergana”. There is a positive regime of temperature with mean annual air temperature during the period being +15.3 °C. Mean air temperature during vegetation (from April 1, 2015 to September 30, 2015) and non-vegetation period (from October 1, 2014 to March 31, 2015) was +23.7 and +5.9, respectively. Mean wind velocity during 2001-2015 was 1.2 with daily value fluctuating from 0 to 8.0 m s^{-1}. Mean relative humidity (RH) during 2001-2013 was 64%. The average daily RH during non-vegetation period (October, 2014-March, 2015) and vegetation period (April-September, 2015) was 78 and 55%, respectively. Mean daily sunshine duration hours during 2001-2015 was ranged from 3.3 to 8.0 hours with maximum being 13.8 hour per day. Precipitation data shows that there was relatively similar rainfall during the growing season in 2014 (68 mm) and 2015 (59 mm) compared the 13-yr average annual precipitation (67 mm). However, this amount is not evenly distributed throughout the year and about 64% of rainfall falls during non-growing period (October-March). Reference evapotranspiration (ETo) during 2001-2015 was fluctuated from 0.3 to 10.3 mm day^{-1} with mean value for the period – 3.2 mm day^{-1}. Total calculated ETo for vegetation period in 2014 and 2015 as well as non-vegetation period in 2014-2015 was 1100 and 850 mm and 215 mm, respectively.

Lithological structure is presented by melkozems and sandy stratum with lesser depth. According the Russian classification, soils are calcic sierozem and loams are less permeable (percolation rate 0.2 to 2.0 m day^{-1}). They are formed on alluvial-proluvial deposits of talus train. According to the FAO classification, soils are calcaric gleysols (Gc) (FAO, 2003) in which there is substantial secondary accumulation of lime and has a gleyic colour pattern. According to the World reference base for soil resources (WRB, 2006), common name for many Gleysols is gley and meadow soils. In terms of hydrology, the study site is located within the area of a shallow water table and groundwater discharge zone influenced by both groundwater and artesian water. Artesian water is exposed at a depth of 120-200 m and is related to sandy-gravel sediments of Golodnostepsky and Tashkent system. Groundwater fluctuation is 1.0-2.6 m (even shallower during irrigation events) and located within sandy loam and loam layers with salinity ranging from 2.9 to 4.6 g l^{-1}. Groundwater salinity is higher at deeper levels. Chemical composition of groundwater is sulphate-chloride and sulphate. Water table gradient is northwestward with a gradient of 0.002-0.0025 that indicates weak drainability.

Agronomical practices and phenological observation

Winter wheat (*Triticum aestivum* L.) variety "Tanya" was sown by broadcasting with a seeding rate of 240-260 kg ha^{-1}, under not yet harvested cotton on October 7-8, 2014 in C-13/14 and October 15, 2014 in C-15/16. One or two times cultivation was conducted in cotton fields before and after wheat has been sown in order to incorporate seeds into the soil. Plant density was ranged from 228 (plot #5) to 507 (plot #1) plants m^{-2}. Fertilization was carried out by tractor-broadcast (with aggregate NRU-0.5). The total amount of nitrogen (N) comprised 250-275 kg N ha^{-1} (in nutrient form) during the growing season of wheat. N was applied in three splits during the growing period. Six irrigations with gross amount of 530 and 550 mm have been carried out during wheat growth period at C-13/14 and C-15/16, respectively (Tab.1). The length of the total growing period (life cycle) of wheat ranged from 246 (C-15/16) to 250 (C-13/14) days. Phonological observations of wheat (plant height and root depth at bi-weekly interval and plant density at maturity and yield at harvest) were performed at 7 plots with plot size of 1 m^2 following the approach proposed by Dospekhov (1985). In addition, soil moisture, soil salinity and groundwater table (GWT) were measured routinely using state-of-the-art devices nearby phonological plots (see Fig.2). Installed state-of-the-art devices are described in following sections.

Table 1. Gross irrigation amount for winter wheat in fields C-13/14 and C-15/16

Irrigation No.	Date of Irrigation		Gross irrigation (mm)	
	C-13/14	C-15/16	C-13/14	C-15/16
1	13-14.10.2014	16-24.10.2014	125	75
2	20-26.01.2015	12-20.01.2015	119	129
3	18-23.03.2015	12-20.03.2015	109	83
4	23-28.04.2015	25-30.04.2015	61	87
5	10-19.05.2015	13-20.05.2015	92	133
6	29.05-06.06.2015	29.05-06.06.2015	27	40
Total			**533**	**547**

Design characteristics of the tile drainage system

The site is bordered with open drainages (OD-1 and OD-2) at the south and south-east, road at the west and collector "Srednekyzyltepa" at the north-west (see Fig.2). Two closed horizontal drainages (CHD) made out of asbestos-cement tubes perforated from bottom with 11 openings (Ø= 0.8 cm) at 1 m length and surrounded by sand-gravel as a filter (Shamsutdinov, 1966). The specific length of subsurface drainage is 25 m length per hectare. The drainages are operating since the last 55 years. Both drainages discharge their water into the collector "Srednekyzyltepa", which has a depth of 3.5-3.7 m, bottom width – 1-1.5 m and bank slope - 1:1.25-1-1.5. The designed parameters of the CHD are given in Tab.2. Two and three observation wells (inspection sump) made from reinforced concrete with depth and diameter -100x100 cm are installed with four sections at the CHD-1 and CHD-2, respectively (Fig.3A). However, one out of two observation wells was operating in CHD-1 before start of the design. Hence, the second well was cleaned as well in order to create a free water flow into the collector.

Table 2. Designed parameters of the subsurface horizontal drainages in experimental site

Sub-surface drains #	Service area (ha)	Depth (m)	Slope	Distance (m)	Length (m)	Inner diameter of pipe (mm)	Pipe type	Designed modulus ($ls^{-1}ha^{-1}$)
CHD-1	40	3.2	0.0025	250	1670	147	asbestos-cement	0.17
CHD-2	20		0.002		750			

Experimental design

Installation of control structure

Based on existing groundwater control construction techniques (Nyvall, 1998; Singh, 2013; Wesström et al., 2014), the polyvinyl chloride (PVC) risers on the drainage laterals to control drainage outlet used by Hornbuckle et al. (2005) seemed to be more practical and cost effective. Hence, a similar PVC riser was developed manually and entered into a drainage pipe outlet in the monitoring well (inspection sump) in order to grab free water flow. Sump sections are hermitically sealed with cement and further covered by bitumen in order to prevent raised water outflow from the sump. The 3rd and 4th sections of the inspection sump was marked with the red and blue color with 10 cm scale increments in order to easy eye monitor water level rise between the drainage pipe bottom and riser opening (Fig.3B).

In this experiment, the CHD-1 was leaved as free outlet drain due to difficulties in cleaning the drainage pipe. Therefore it operated on submerged mode during the observations and considered as a similar with controlled drainage. For controlled drainage, the CHD-2 was considered. Outlet was closed at two sections of the CHD-2 pipe line (e.g., at the inspection sump #A and B, see Fig.2). Water exited through outlet A, when the water table rose above the desired 90 cm level, was then captured at outlet B. Raised water table above the desired level at outlet B thereafter flowed freely into the open collector "Srednekyzyltepa".

Monitoring of drainage water flow volumes and salinity was undertaken at both drainage outlets (mouth). Drainage volume was measured in a 5-10 days interval (daily during irrigation events) with already installed weir "Chippoletti" with bottom width – 50 cm. Drainage salinity was measured in-situ using ES-2 sensor (Decagon Devices, Inc.) and ProCheck handheld reader (ICT International).

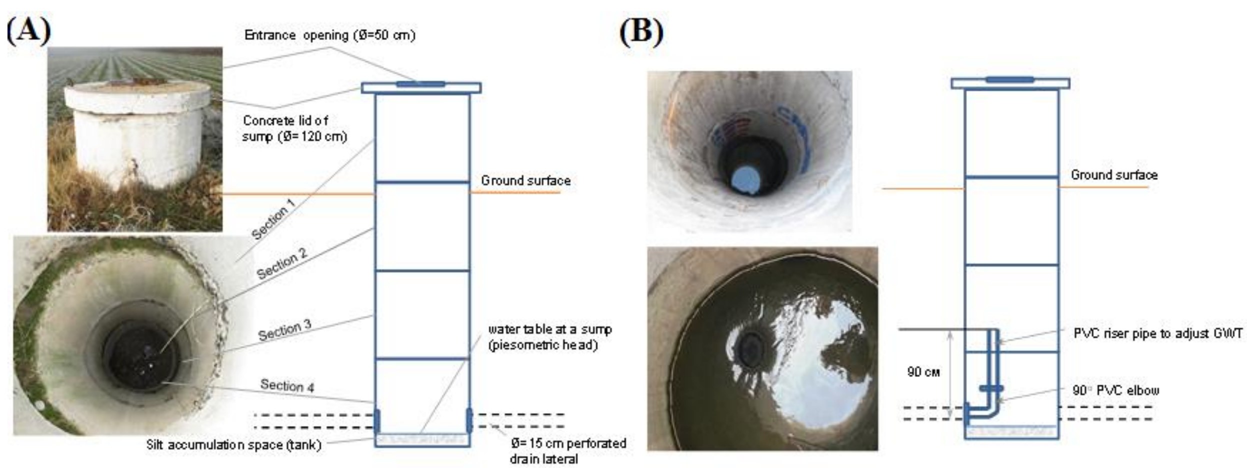

Figure 3. Cross-section of inspection sump (A) and raised water table after installation of pipe riser on lateral drain (B)

Installation of groundwater table monitoring piezometers

In total 22 piezometer wells were installed (see Fig.2 for location) using hand operated auger drill in the experimental site to study groundwater regime between subsurface drainages. Wells are made out of polyvinyl chloride (PVC) pipe (Ø 40 mm), with a length of ~ 3.33 m, perforated (Ø 3-4 mm) from the bottom depth of 1.2 m and covered by thin synthetic material (Ø 0.3 mm, approximately) as a filter to prevent silting. Man-made flap (*xlopushka*) and 3.5 m ruler type were used to measure GWT. Measurements are performed with frequency of 5-6 days during October 26, 2014 to June 15, 2015.

Installation of state-of-the-art devices

The following devices were installed near to the phenological plots:

Four 5TE sensors (Decagon devices, Inc.) with increments of depth 0-30, 30-60, 60-90 and 90-120 cm and one CTD-10 sensor (Decagon devices, Inc.) were installed nearby piezometer at the phenological plots #1, 2, 3 and 6. In addition five 5TE sensors with increments of depth 0-30, 30-60, 60-90, 90-120 and 120-150 cm were installed into phenological plot #5. All these sensors were wired into EM50G data loggers on March 3-4, 2015 and removed on June 14-15, 2015 before harvest of winter wheat. Measurements are done in an hourly basis.

Results and discussion

Crop growth

At sowing date till emergence (9-10 days), mean daily air temperature ranged from 12.5 to 15.6 ^{o}C. Prolonged periods below 5 ^{o}C (Nov. 26, 2014 - Feb. 22, 2015) caused dormancy in wheat. Optimum growth was started when mean daily temperature was between 15 and 23 ^{o}C. Grain filling was started on May 20-25, 2015 when mean daily temperature was ranged between 21-25 ^{o}C.

Fig.4 shows development of height and rooting depth at 7 phenological plots during main growing period of wheat. Based on this figure, it can be noted that plant height on May 30, 2015 (maturity stage) is relatively taller at plots ## 2, 4 and 5 (along the CHD-2), ranging from 79.5 to 104 cm, whereas plant root depth is shallower, e.g., 59-64 cm at these plots compared those at plot ## 1, 3 and 6 (74-77 cm and 59-71 cm). From these values, it is evident that root depth at the plots aside from the CHD-2 line is penetrated deeper due to increase in water table depth. In contrary, lower root depth of ## 2, 4 and 5 plots mainly resulted from the restriction of water table on the downward penetration of root system. Brisson et al. (2002) reported that root growth slowed down and stopped when oxygen concentration of the soil was below a critical value due to saturated soil moisture content. This indicates that shallower groundwater level increase plant root water uptake and thus reduces root development. These parameters at plot # 7 (in-between CHD-1 and CHD-2) are almost the same as observed at plot # 6.

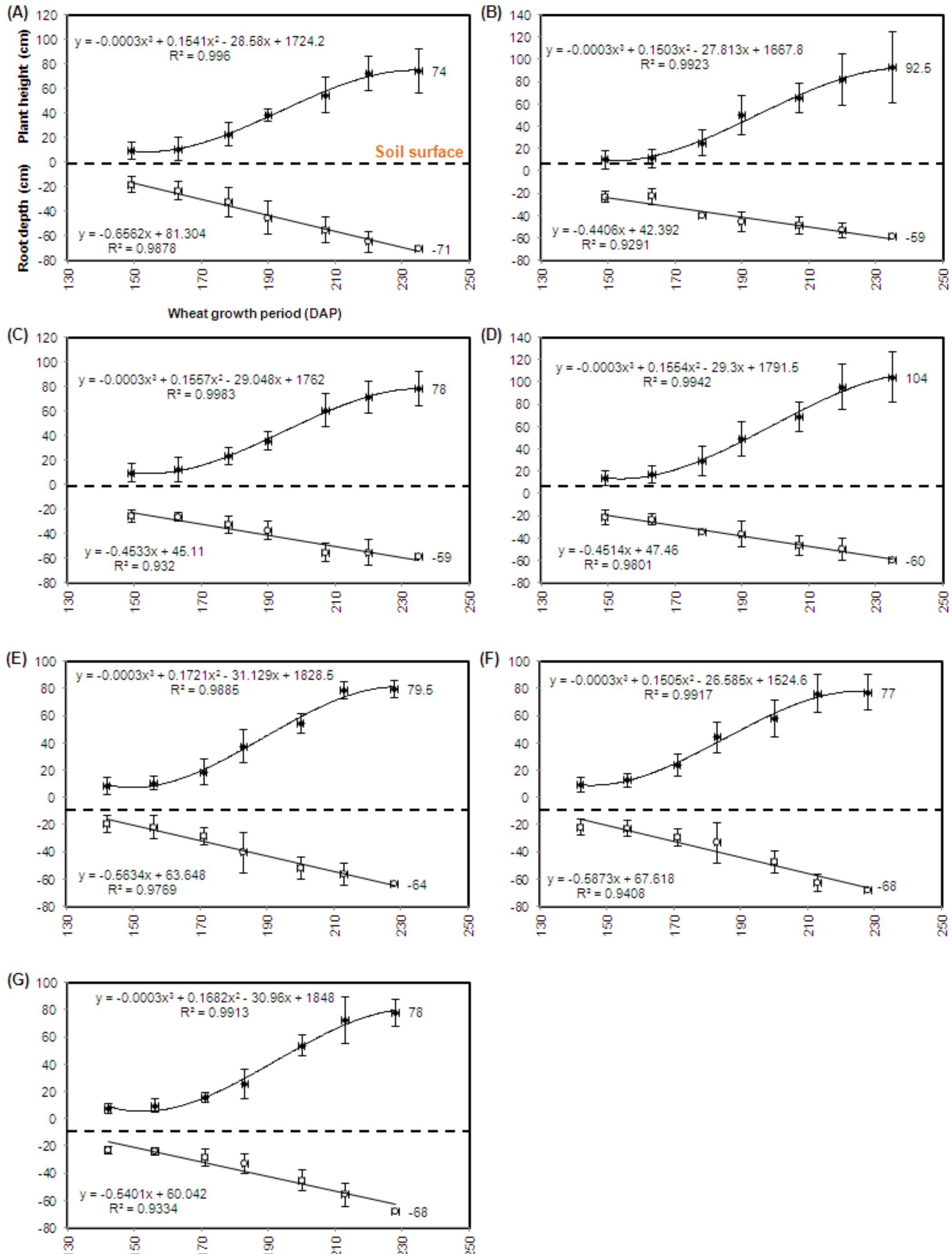

Figure 4. Dynamics of height and rooting depth of winter wheat during the growth period (day after planting, DAP) at Plot #1 (A), Plot #2 (B), Plot #3 (C), Plot #4 (D), Plot #5 (E), Plot #6 (F) and Plot #7 (G) (for plot location refer Fig.2)

Drainage control structure

The overflow level of the drainage monitoring well at the sections # A and B is presented in Fig.5. The overflow levels of the drain outlets were elevated for the first time in March 20, 2015 when

3rd vegetative irrigation was started in C-13/14 (during that time it was completed in field C-14/15). Although irrigation was started on March 18 at C-13/14, the initial overflow level was raised up to 45 and 70 cm above the drain outlet levels at monitoring wells # A and B, respectively. Due to finishing the 3rd irrigation at field contour C-15/16 on March 20, the maximum overflow level at well # B was smaller (111 cm) compared well # A (200 cm). Starting in third decade of April, when 4th vegetative irrigation was initiated, the overflow levels raised from 58 and 68 cm up to 158 and 148 cm in well # A and B, respectively. It should be noted that the control structure was not removed during the vegetation period of wheat. This is due to fact that existing open drainage (OD-2) and collector (Srednekyzyltepa) as well as existence of sand and sand-gravel layers at the depth of 1.5-1.75 m, apart 30-75 m from the tile drain CHD-2 line in the C-13/14 had a greatest impact on maintaining groundwater table. This enabled to maintain water table between 90-251 cm above drainage pipe level throughout 5th to 6th irrigations.

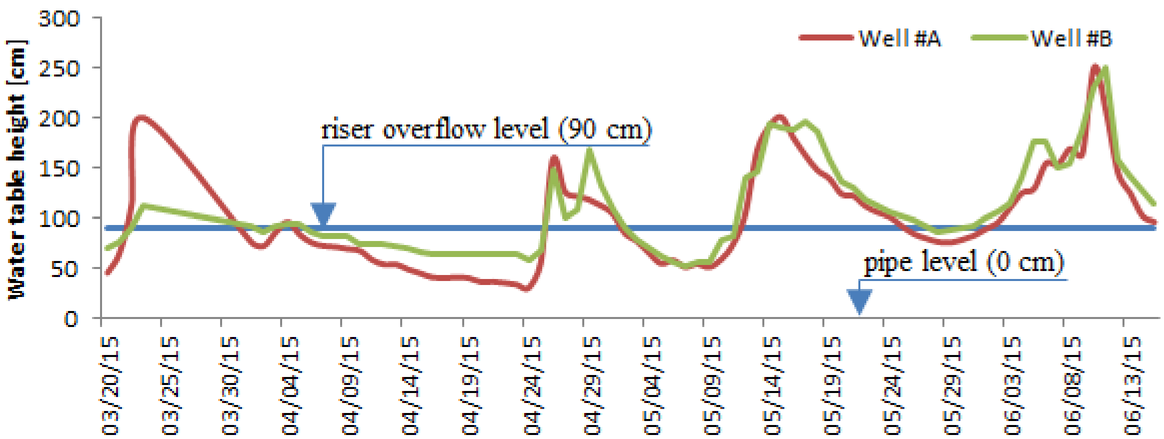

Figure 5. Relative water level (below fixed riser at 90 cm) and overflow level (above the fixed riser at 90 cm) from drainage installation depth at the drainage wells # A (C-13/14) and B (C-15/16)

Soil moisture

Soil moisture measured by 5TE sensor from March 4 to April 16 at Phenological plots ##1 (A), 2 (B) and 3 (C) (C-13/14) is given at Fig.6. Hence, the irrigation in each application is rotated within a field (e.g., 60-100 furrows simultaneously irrigated within a day then water is applied for the next 60-100 furrows following day and so on), the rise of soil moisture content (SMC) is concomitant to that point where irrigation water reaches (both vertical profile as well as spatial scale). This can be seen at Fig.6A, e.g., 3rd vegetative irrigation was started on March 18 while water reached the phenological plot #1 on March 20 at 3:30 PM (e.g., after two days) increasing SMC from 18.8 to 20.0 %vol at 30 cm depth soil profile with maximum - 34.5 %vol at 12:00 AM on March 21. Thereby SMC rise at the vertical profiles delays from upper soil (3:30 PM for 30 cm) to lower soil (6:30 PM for 120 cm). Consequently applied irrigation water reach phenological plot #2 and plot #3 on March 22 (4:30 PM, Fig.6B) and on March 24 (1:30 AM, Fig.6C), respectively.

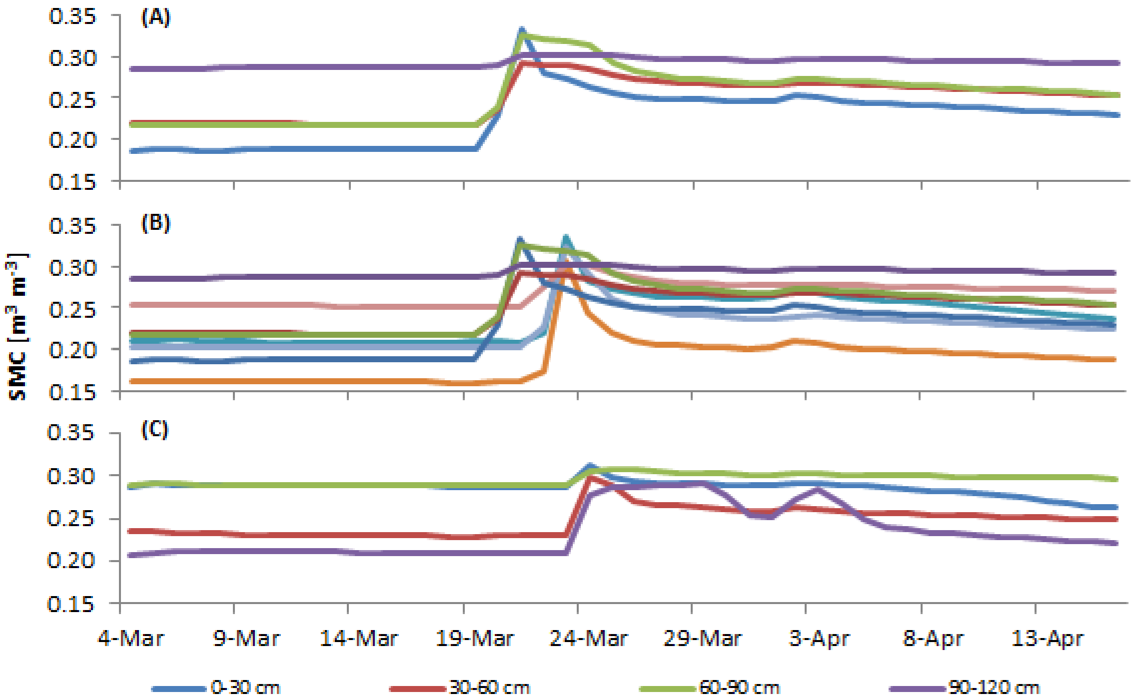

Figure 6. Dynamics of soil moisture content (m^3 m^{-3}) during 2nd irrigation of winter wheat at phenological plots # 1 (A), 2 (B) and 3 (C) in field C-13/14

Groundwater table

Groundwater table (GWT) measured by CTD-10 sensor during 3rd irrigation of wheat is given at Fig.7. The graph shows that water levels tend to increase gradually, indicating delayed response to the input of irrigation water from phonological plots #1 to 3. In fact, the maximum rise of the GWL (even though irrigation was started 1-3 days before) was concomitant with irrigation of the part of the field where the piezometers are located. During the third irrigation of wheat, in phenological plot # 1 located mid-point of drainages CHD-1 and CHD-2, the duration to rise GWL from 180 cm up to 20 cm was 1.5 days (excluding irrigation start of 3 days), while it took 11 days to drop down to the initial level (180 cm) (Fig.7). Similarly the third irrigation of wheat in phenological plot # 3 located mid-point of drainage such as CHD-2 as well as open drainage OD-2, the duration to rise GWL from 180 cm up to 25 cm was 1 day (excluding irrigation start of 3 days), while it took 6.5 days to drop down to the initial level (180 cm). In general, in the part of the plots (## 1&3) located at the drain mid-spacing, the lagging of GWL lowering is higher, i.e. this process is slower. Whereas, it took 1.4 days (excluding irrigation duration - 3 days) to raise the GWL from 180 cm up to 3 cm and 6.2 days to drop down till 180 cm, i.e. the rate of drop is 4-fold longer of that of rise.

It can be concluded that close up of the regulation structure during irrigation in observation well # A at CHD-2 prolonged GWT drop down on 11 days at the mid-space of CHD-1&2 thus maintain soil moisture for the longer periods. This duration should be longer at phenological plot #5 in C-15/16 due to its location from closed drain outflow at observation well #B.

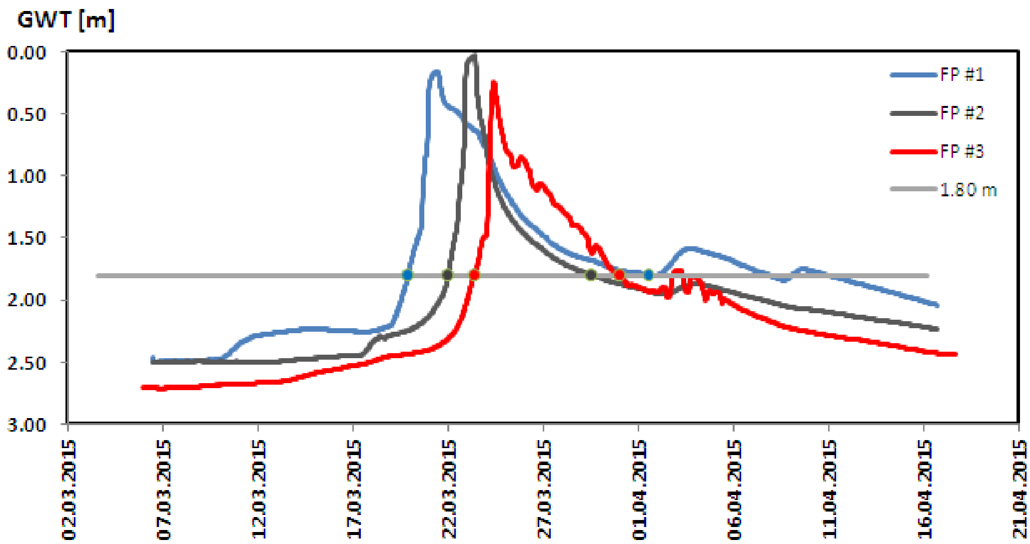

Figure 7. Accession and recession of the GWT during the second irrigation of winter wheat in C-13/14 measured using CTD-10 (30-min interval) at phonological plots ## 1-3 in 2015 (straight horizontal line is given for comparison purpose)

Mean water tables manually measured from 22 wells in total at C-13/14 and C-15/16 for the wheat growing period is presented in Fig.8. The rise of GWT in the hydrograph indicate that all irrigations (including charging irrigation during October 25-November 11, 2014, not shown) at the both fields were concomitant with application dates (refer to Tab.1). In addition, it can be seen from the hydrographs that two fields showed some delay of water table peak during periods of high recharge (during irrigation events).

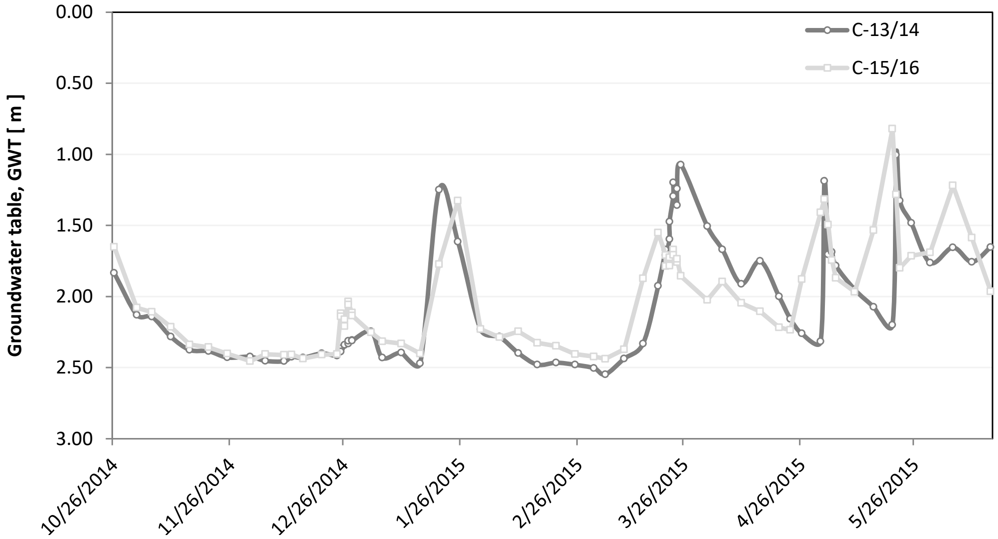

Figure 8. Dynamics of GWT (averaged from 11 wells in each field)

Water fluxes

The effect of controlled drainage experiment was evaluated by comparing a ratio of the field parameters between transects #A and #B (1) vs. #B and collector "Srednekyzyltepa" (2) along the CHD-2 (Tab.3). The ratio of soil water content in the 1.2 m soil profile between (1) and (2) was 1.20 which suggested that the upper part of the field contained more soil moisture for the crop to utilize during the growing period compared with the lower portion of the field. Conversely, the ratio of the water table depth between (1) and (2) was 0.78 indicating that the water table of the upper portion of the field was 47 cm (22%) shallower than the lower part (Tab.3). Thus, subsurface irrigation increased the moisture storage of the soil layer at the upper part of the field compared with the lower part.

The most important quantitative hydrological monitoring results are summarized in Fig. 9. This graph presents the irrigation and precipitation amount, soil moisture content, groundwater levels and drainage amount at 5 phenological plots during March 3, 2015 to June 15, 2015. Although the 3rd vegetation period irrigation was started on March 18, 2015, applied water is reached to phenological point #1 after 3 days, hence average weighted soil moisture at 1 m soil profile and GWT are raised from 22 %vol to 32 %vol and from 220 cm up to 27 cm, respectively (Fig. 9A). Based on this graph it can be noted that soil moisture at the phenological plot #5 (Fig. 9D, between transects A and B) is fluctuated lesser compared other plots due to closed drainage outflow during the period. The average soil moisture content during the study period (i.e. ≈0.31 m^3m^{-3}) at maximum root zone distributions (90 cm) in phenological plot # 5 (Fig. 9D) were not much different from the average field capacity values (i.e. ≈0.30 m^3m^{-3}). As expected, the average root zone soil moisture content under plot ## 3 and 5 (0.27-0.30 m^3m^{-3}) was greater than those observed at plot ## 1 and 6 (0.24-0.25 m^3m^{-3}), because closed outflow of the tile drainage CHD-2.

Table 3. Average values of field parameters and its ratio between upper part of the drainage field (transects A and B) and lower part (transect B and collector) measured during March 3-June 15, 2015

Parameters	Statistics	Transects A and B (1)	Transect B and collector (2)	Ratio (1)/(2)
Soil water content at 0-120 cm soil profile	Minimum (mm)	220.3	117.4	1.88
	Maximum (mm)	354.7	355.8	1.00
	Mean (mm)	298.6	248.1	1.20
	Standard deviation (mm)	29.9	45.5	
	Coefficient of variation (%)	10.0	18.3	
GWT	Minimum (cm)	64.0	86.3	0.74
	Maximum (cm)	242.0	249.6	0.97
	Mean (cm)	163.5	210.4	0.78
	Standard deviation (cm)	38.0	35.7	
	Coefficient of variation (%)	23.3	17.0	

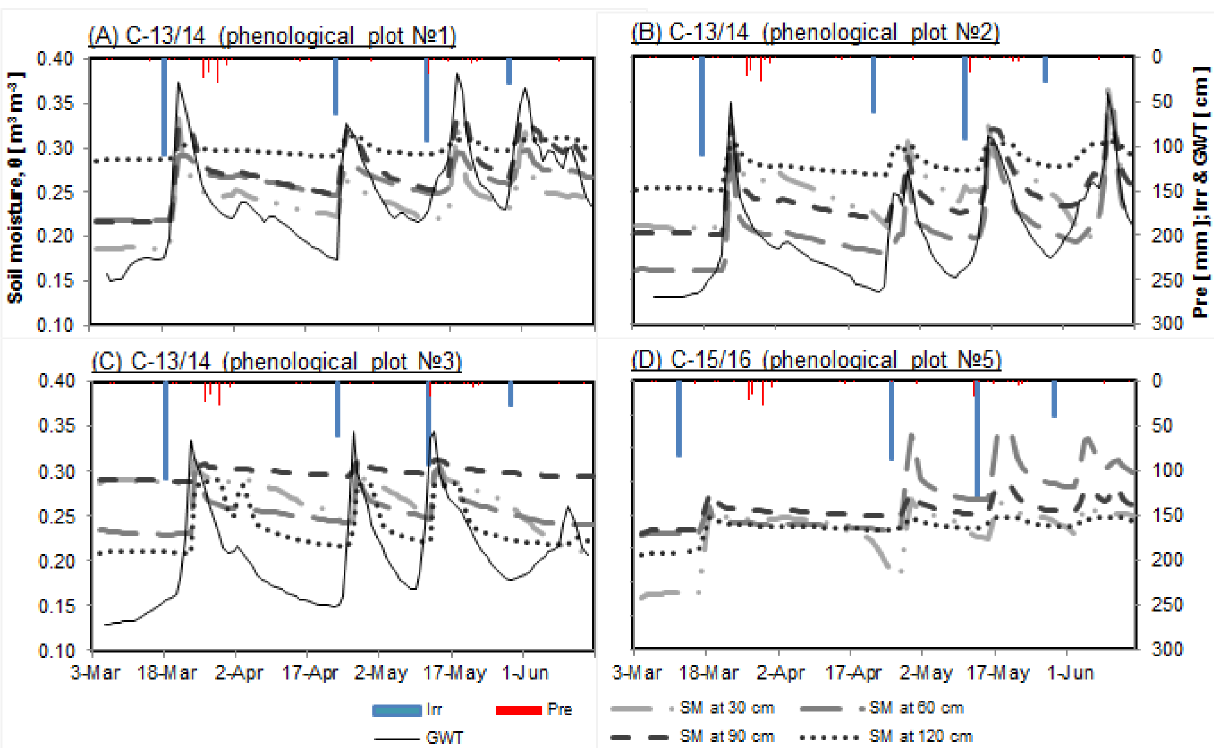

Figure 9. Combined results of hydrological measurements (Irr: irrigation, cm; Pre: precipitation, mm; GWT: groundwater table, cm; soil moisture, m^3 m^{-3}) at phenological plots #1 (A); #2 (B); #3 (C); #4 (D)

Crop yield

The yields and its components under different soil moisture conditions and groundwater table were presented in Tab.4. The results suggested that, soil moisture content had notable effect on the yield of winter wheat (Fig.10A). However, shallow GWT was negatively affected to grain yield (Fig.10B). It was consistent with the finding in other studies which were under the irrigation condition (Karimov et al., 2014). The maximum yields were 429 and 506 g m^{-2} in phenological plots # 2 (average soil moisture content ≈0.24 m^3m^{-3}) and # 4 (0.34 m^3m^{-3}), respectively. The root zone moisture content in phenological plots # 1 (≈0.26 m^3m^{-3}) and # 3 (≈0.27 m^3m^{-3}) produced lower yield (Tab.4).

Table 4. Wheat yields under mean soil moisture content and groundwater table from March 3 to June 15, 2015

Parameters	Phenological plots ##						
	1	2	3	4	5	6	7
Grain yield (g m^{-2})	276	429	298	506	434	465	356
Soil moisture content (m^3 m^{-3})	0.26	0.29	0.27	0.34	0.30	0.28	0.31
GWT (cm)	154	201	197		163	210	157

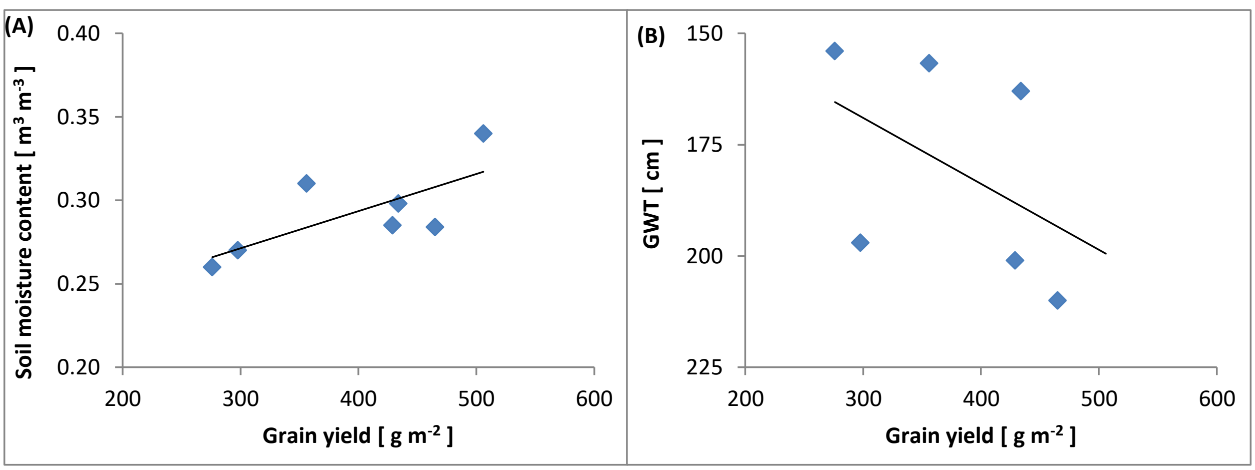

Figure 10. Wheat yield trend at the 7 phenological plots under average soil moisture content (A) and GWT (B) levels

Conclusion

Our experimental setup produced valuable insights in the hydrological effects of controlled drainage. The introduction of controlled structure on tile drainage at the monitoring well increased the soil moisture storage in the studied field-site.

Studies suggests, that it is possible to control the water table depth at monitoring wells. However, it is difficult to manage irrigation and drainage system at the larger fields to control groundwater table and assess its impact on maximizing crop yield. Nevertheless, this study is helpful to manage irrigation and control shallow water tables and the results of the study can support the first view of controlled drainage studies that provide good short-term returns in the form of higher crop yields due to reduced water deficiency stress.

Based on the findings from this experiment, the following recommendations can be highlighted:

- a new approach, e.g., integrated irrigation and drainage water management system is needed in order to apply controlled drainage management. This implies interactivity between the operation of the irrigation system and the management of the drainage system. In this instance, the drainage system will be managed to control the flow and water table depth in the course of time in response to the irrigation management and deep percolation;
- control of the water table at the inspection sump is possible using manually developed PVC riser, but is only feasible in flat lands because of the alignment of the subsurface drains relative to the grade of the field surface. However, careful selection of proper drainage site is needed. For controlled drainage to be effective, soil texture under the site selected, has to be more or less homogeneous with less or no sand and sand-gravel layer near the control structure. In addition, one has to be sure that tile drainage pipe has no perforations near to control structure in the monitoring sump. These implies consideration of structures in future for the control of the water table position in new tile drainage system design;
- careful monitoring of all water balance components and irrigation water management will be required when implementing controlled drainage.

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DRAINAGE WATER MANAGEMENT BY FUZZY ANALYTICAL HIERARCHY PROCESS MODEL FOR THE DECLINE OF DRAINAGE WATER VOLUME

Mahboobe Ghasemi[1,*], Abdolrahim Hooshmand[2], Abd Ali Naseri[3], Gholamhosein Heidarpour[4], Masoud Sayedipour[5]

Abstract

In the past decade, major changes in water management in arid and semi-arid areas have emerged. Previously, the focus was on the design and management of irrigation systems and subsurface drainage to compensate for shortcomings. A result of the previous design was high deep percolation losses which led to greater than necessary drainage. The selecting of the depth of drains in the past resulted into large spacing between the drainage pipe and saved costs. These systems reduced cumulative salt in the root zone, causing the low quality water to flow into groundwater sources. To minimize the short-term and long-term detrimental effects of drainage water on the environment, plant products, soil fertility and water quality, in addition to paying attention to the decline of drainage water volume issues is important. Hence, the aim of the present study is to prioritize and assess influencing factors in prioritizing the preference of drainage water management specialist using fuzzy AHP.

Analytical hierarchy process (AHP), multi-attribute utility theory, outranking theory and goal programming are among the most common used multi-criteria methods. Although AHP has had a great potential in the evaluation of multi criteria options, it is not compatible with existing uncertainties in paired comparisons and their effect in the selection process. Therefore, in recent years, the application of of Multi-criteria decision-making methods has been expanded. Fuzzy multi-criteria decision making methods are combined with fuzzy logic and multi-criteria decision processes. The numbers used in this procedure are fuzzy triangular numbers.

In this study, water conservation, Drainage water reuse, drainage water disposal and drainage water purification were reviewed. The model includes the steps of problem definition, calculation, and ranking of drainage water management options and fuzzy hierarchical structures that

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encompass three targets, in addition to the main criteria and sub criteria. In order to select the criteria, sub criteria and factors and determine the relative importance of each of them, researchers and experts' opinions, as well as a summarizing of the results of the questionnaire were used. In the next step, using Chang's extent analysis, various water management options based on the criteria and sub criteria and selected factors were evaluated. The results show that water conservation is the most important option in drainage water management. Among the sub criteria water conservation, and source reduction are the highest priority. Among the main criteria of drainage water management the second priority is placed on the reuse of water. Among its sub criteria wildlife and wetland criteria, with a weight factor of 0.260 is the most important. Sequential use of drainage water criterion of with a weight factor of 0.248 is the second priority .

The treatment and disposal of drainage water are the third and fourth priorities respectively. Among the disposal of drainage water sub criteria, draining into oceans and salt lakes are the best options. The physical – chemical index among drainage water treatment options with a weight factor of 0.605 has a higher priority than the biological index.

KEY WORDS**:** Drainage water management, Fuzzy hierarchical analysis, Resource conservation, Reuse of drainage water, Sequential use of drainage water.

Introduction

In the past decade, major changes in water management in arid and semi-arid areas have emerged. Previously, focus was on Design and management of irrigation systems and subsurface drainage to fix shortcomings. A result of the previous design was High deep percolation losses which led to high draining. Selecting depth of drains in the past caused the large distances between the drainage pipe and save the costs. These systems are to reduce Cumulative salt in the root zone, causing the low quality water flow into groundwater (Chang et al., 2014).

After the World Summit in 1992, the International Committee on Irrigation and Drainage focused his full attention on the management of drainage water. So not only need for drainage as Critical Supplements for irrigation development in arid and semiarid areas was emphasized , but also simultaneously emphasis was placed on the conservation and reuse of fresh water resources in concept of Integrated Resource Management .

For the present drainage system, a number of available options of drainage water management for achieve the goals of development is available. These options can be divided into four major groups "water conservation, reuse of drainage water, the disposal of drainage water and drainage water treatment". Each of these options has certain potential effects on Hydrology and Water Quality of region. Thus, planners, decision makers and engineers for choosing among different options and to assess the impact and contribution of each for achieving the development goals, need certain framework. Furthermore, in order to achieve a superior selection from value of effect of distinctive options, technical expertise's opinion and guidelines for each of the options are needed.

Analytical hierarchy process (AHP), multi-attribute utility theory, outranking theory and goal programming are among the most common used multi-criteria methods. AHP is broadly applied in preference analysis of complex and multi-attribute issues (Varis 1989). By its flexibility in setting the objectives ,AHP can proportionate the qualitative and quantitative decision attributes (Kangas, 1993). According to Alphonce (1997), AHP can eliminate certain decision problems in agriculture.

Although AHP has great potential in the evaluation of multi criteria options, but is not able to impose on existing Uncertainties in paired comparisons and their effect in the selection process (Hajeeh, 2010). Therefore, in recent years, using of Multi-criteria decision-making methods has been expanded. Fuzzy multi-criteria decision making methods are combined of fuzzy logic and multi-criteria decision processes (Chang, 1996). Chang in 1992 provided a very simple way to expansion of AHP to fuzzy space. The numbers used in this procedure are fuzzy triangular numbers. This method is based on the *arithmetic mean,* expert's opinion and Saaty's *normalization* method (Chang, 1996).

From conducted researches with fuzzy AHP in irrigation systems and water resources can be mentioned the fuzzy hierarchical model for the assessment of global water partnership (GWP) Irrigation and Drainage Networks .Montazar and Zadbagher (2010) developed an analytical hierarchy model for assessing the Global Water Productivity (GWP) status of irrigation networks. For this purpose 14 criteria, affecting water productivity, and 14 major modern irrigation networks of Iran are analyzed. Dez and Saveh irrigation networks, with the relative weights of 0.112 and 0.045, show the highest and lowest GWP, respectively. The results obtained by AHP model are in good agreement with the results determined from the field survey.

Srdjevic and Medeiros (2008) introduced a fuzzy AHP methodology for solving fully structured decision problems with criteria, sub-criteria and alternatives. The introduced methodology was applied for the evaluation of water management plans in part of the Paraguacu River Basin in Brazil.

In other research, irrigation networks by Montazar et al (2013) are investigated. four irrigation projects is applied in this research and the results is showed that the managerial criterion has the greatest impact on the assessment process .The technical, social, economical, and environmental criteria rank next in effectiveness, respectively .Hence, in order to improve irrigation system performance, all rehabilitation tasks should focus more on the managerial issues.

Fuzzy hierarchy process is applied to improve irrigation project. The results is showed that irrigation professionals give the first priority to water delivery services project-wide and they consider that irrigation hardware of primary canals is more important than that of secondary canals(Okada, 2008).

Since achieving a superior choice among the effect of distinctive options, needs technical expertise and Instructions for each of the options. The aim of this study is to propose an appropriate priority for various metrics of agricultural drainage water Management Using hierarchical fuzzy model.

Materials and Methods

The purpose of this study is to identify and set priorities infrastructures of agricultural drainage water Management with fuzzy AHP approach. Based on algorithm research, first, Determining criteria Priority, and infrastructures of agricultural drainage water management will be discussed. For setting priorities in agricultural drainage water management AHP technique with fuzzy approach is used. *Analysis of* data was performed in Excel software environment and Coding was done in Visual Basic.

To determine the priority of the performance factors technique of fuzzy analytic hierarchy process (FAHP) is applied. The analysis is as follows :

1- Paired comparisons on the main criteria based on the purpose and determine weight of main criteria

2- Paired comparison on sub criteria of each criterion, and determining the weight of each sub criteria cluster

3- Weight of sub criteria multiplied by the weight of relevant criteria to determine the final weight of sub criteria

The first step of this study was to Set Priorities of criteria and sub criteria of agricultural drainage water Management. Basic infrastructures for the management of agricultural drainage waters in this study include water conservation, reuse of drainage, effluent disposal and effluent treatment. For each of these criteria, indices have been considered. So in total 24 the sub criteria have been chosen. Also criteria and sub criteria in table 1 are named with a numeric index in order to track and study easily. Pattern of network of the relationship between variables is presented in Figure 1. Paired comparison of elements has been done by Saaty's 1-9 Scale .Saaty's 1-9 Scale was presented by Thomas L. saaty theoretician of the Analytic Hierarchy Process (AHP). Also in this study, fuzzy approach was used to quantify the values. Therefore, the fuzzy domain has been used (table 2).

For mentioned analysis in first step the main criteria were compared in pairs based on goal. Paired comparison is very simple and all the elements of each cluster must be mutually compared. So if there is n elements in a cluster $\frac{n(n-1)}{2}$ comparisons will be made. Because there are four criteria so numbers of made comparisons is :

$$\frac{n(n-1)}{2} = \frac{4(4-1)}{2} = 6 \qquad (1)$$

After forming matrix the paired comparisons, Eigenvector is calculated. First of all fuzzy summation of each row is calculated .

$$\sum_{j=1}^{n} M_{g_1}^{j} \quad (2)$$

Then fuzzy summation of the preferences column set is calculated as :

$$\sum_{i=1}^{n} \sum_{j=1}^{n} M_g^j \quad (3)$$

For normalize preferences for each criterion, the total value must be divided by the sum of all preferences (elements of columns). Since values are fuzzy therefore, the fuzzy summation of each row multiplies by inverse of the sum. Inverse of the summation is calculated as:

$F_1^{-1} = (1/u_1, 1/m_1, 1/l_1)$ (4)

$$P_k = * \left(\sum_{i=1}^{n} \sum_{j=1}^{n} M_g^j \right)^{-1} \quad (5)$$

Each of the obtained values of fuzzy weights and normalized are related to the main criteria. For defuzzification of obtained Values there are a variety of methods. One of the methods used for the defuzzification is calculation of degree of preference, and also Crisp number. In this study, Preference degrees are calculated.

Calculation of Degree of Preference

Calculation of degree of preference (Possibility Degree) P is a fuzzy number fuzzy number that is larger than k .

P_i; i=1,2,…,k

$V(P_i \geq P_k)$

$V(P_i \geq P_k)$

$$V(S_i \geq S_k \begin{cases} 1 & \text{if}(m_i \geq m_k) \\ \frac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)} & \text{else} \end{cases}$$

V(C1>Pk)=1.000; V(C2>Pk)=0.682; V(C3>Pk)=0.462; V(C4>Pk)=0.056; V(P5>Pk)=0.043

If it is assumed that d'(Ci)=minV(Pi≥Pk then the weight vector follows as:

W' = (d'(C1)… d'(Cn))

It calculated weights are defuzzification but should be normal .

To determine the final priority of water management by FAHP techniques weights of the main criteria (W1) and the weight of indices based on each criterion (W2) must be available. The results of sub criteria comparison their corresponding weights forms make up matrix W2. To determine the final priority of indexes with AHP technique, Indices weight based on each criterion (W2) must multiply by the weight of the main criteria (W1). Each of these matrices is calculated in the previous steps. With inserting CRISP values in superdecision software, by using this software the final priority of indices are calculated.

Results and Discussion

Paired comparison has been done by team approach of ten experts. Expert's opinion was quantified by fuzzy scale. Gathering the views of experts was done Saaty's 1-9 Scale. By fuzzy mean the views of experts, paired comparison matrix is shown in Table 3.

The final weight for each option which in fact calculated from *linear* combination of options, criteria and sub criteria is shown in Figure2.

Accordingly, Eigen vector of preference of criteria is W1.

$$W_1 = \begin{pmatrix} 0.444 \\ 0.350 \\ 0.106 \\ 0.099 \end{pmatrix}$$

According to obtained eigenvector water conservation with normal weight of 0.444 has the highest priority. Reuse of effluent with normal weight of 0.35 is the second priority; effluent disposal with normal weight of 0.106 is the third and eventually last priority is effluent treatment. Inconsistency rate over comparisons is 0.059 which is smaller than 0.1 and therefore regarding to comparisons the disposal of drainage water can considered as the first option among the criteria. Among the research which done in the field of water conservation conducted experiments by Hanson and may (2004) can be pointed out. Experiments were conducted in three tomato farms under subsurface drip irrigation and sprinkler irrigation with saline water and shallow groundwater conditions has been performed. Results have shown that subsurface drip irrigation compared to sprinkler irrigation under conditions of salinity and shallow groundwater is largely beneficial for reduce of produce of drain water.

In the second step of the FAHP technique related sub criteria of each class are compared.

Sub criteria of water conservation priority

Sub criteria of water conservation are Source Reduction, shallow water table management and fallow land. Fuzzy values of mean of expert's opinion to priority of water conservation sub criteria are presented in Table 4. Due to the use of four indices of water conservation, six paired comparisons have been made.

Each of obtained value fuzzy weight and normalized in Table 4, are related to the main criteria. For defuzzification of values calculations of preference degree were used.

According to table 6 Eigen vector of water conservation criteria priority is WC1.

$$W_{C1}=\begin{pmatrix}0.383\\0.244\\0.244\\0.129\end{pmatrix}$$

According to obtained eigenvector source reduction with0.383 weight has the highest priority. Water table management and the management of the shallow groundwater with the same weight of 0.244 are central priorities. Finally, fallow land is the last priority. Inconsistency rate is obtained 0.02, which is smaller than 0.1. Thus, comparisons are trusted. The conventional approach to subsurface drain design was to install the drain laterals as deep as was practical which would result in the biggest spacing and minimize the installation cost. These depths of installation were also thought to be needed to reduce salinity accumulation in the root zone by upward flow from saline groundwater (Ayars, 1993). This study shows that resource reduction is an important factor in Drainage Flow reduction.

Priority of sub criteria of reuse of drainage waters

Reuse of drainage water for irrigation is known as a viable means of reducing the amount of saline-sodic spent water that will finally need treatment or disposal in the western San Joaquin Valley (SJVDP, 1990).

Sub criteria of reuse of drainage include using in saline land, wildlife and wetlands, agriculture, sequential use of drainage and soil amendment. Figure 4 shows related priorities of each sub criteria of drainage reuse. According to eigenvector of setting priority wildlife and wetland with Weight of 0.260 is the most important. A criterion of sequential use of drainage with weight of 0.248 is the second priority. Saline soil amendment with weight of 0.213 is the central priority. Agricultural index with weight of 0.124 is the last priority. Inconsistency rate is obtained 08/0 which is smaller than 0.1. Therefore, using of conducted comparisons of drainage reuse in the process of decision making is permitted. In a research presented by Ayars and Sope (2014) Drainage water from irrigated areas with fresh water and sensitive plants field, were used for halophytes .The results shows that the sequential use of drainage water is a temporary solution for replacing with Disposal of drainage water until a stable system can be developed. Díaz et al (2013) With the use of six halophyte species use drainage water in growing they concluded that drainage water can be used to produce these species for producing livestock forage, but their use is not recommended for long-term because level of sodium, chlorine, Boron, selenium and nitrate in leaf tissue of halophytes is dangerously and critically collected.

Priority of sub criteria drainage water

In this study criterion of drainage water disposal consist of four sub criteria of river, evaporation ponds, oceans, salt lakes and grouting into soil. According eigenvector prioritization and Figure 5, it is clear that the index of oceans and salt lakes with weight of 0.341 is the most important. Evaporation ponds with weight of 0.327 are the central priority and the rivers with weight of 0.134 is the last priority. Inconsistency rate is obtained about 0.018 so obtained judgments are consistent and using of them in selection process, is permitted.

Priority of sub criterion of drainage water treatment

In this study, criterion of drainage water treatment consists of two sub criteria Physical - chemical and biological. The fuzzified values of expert opinion mean for determining the priority of sub criteria of drainage water treatment is presented in Figure 6. It is clear that, the physical – chemical index with weight of 0.605 has higher priority than the biological index. Also, because there are only two sub criteria and a comparison inconsistency rate is zero.

Sub criterion of Physical - chemical is composed of five sub indices. These indices include sedimentation, adsorption, ion exchange, reverse osmosis, precipitation. Also the sub criterion of biological is composed of five sub indices Rehabilitation / oxidation, uptake plant, evaporation, artificial wetlands. According to calculations the final weight of these indices are shown in Figures7 and 8. As it seen in Figure 7, among the options for physical – chemical treatment uptake with weight of 0.282 has the highest priority. After that reverse osmosis with weight of 0.221 is selected as the next appropriate option. Sequestration, with weight about 0.136 is the next priority which is chosen the last option in sub criterion of water drainage treatment. Prioritizing of sub criteria related to Physical - chemical treatment presented in Figure 8. As it can be seen the use of plants and special algae for water drainage treatment should be the first priority of biological treatment. The weight of this criterion is obtained 0.282. Other sub criteria Rehabilitation, evaporation and artificial wetlands are next priorities respectively.

(C4)

The results of calculation and the weights of indices are given in Figure 9. As the graph in Figure 9 shows source reduction with final weight of 0.17 options is the best option. However, the other options such as drainage management which is consist of shallow water table management, underground water management, wildlife and wetlands, sequential useof drainage water, saline soil amendment, physical - chemical treatment, fallow land, use in saline soil lands, agricultural, biological treatment, evaporation ponds, rivers, oceans and lakes, salts and grouting deep into the soil are 2 to 16 priorities.

Conclusions

The present study reviews and prioritizes influencing factors on water drainage management expert's preference using fuzzy AHP. Examined options in this study include water conservation, reuse of drainage water, drainage water disposal and drainage water treatment.
The results show that water conservation is the most important option in the drainage water management. Among sub criteria water conservation, source reduction are the highest priority. Among main criteria of drainage water management the second priority place on reuse of water. Among its sub criteria wildlife and wetland criteria, with weight of 0.260 is the most important. Sequential use of drainage water criterion of with weight of 0.248 is the second priority .
Treatment and disposal of drainage water management are the third and fourth priorities respectively. Among disposal of drainage water sub criteria, draining into oceans and salt lakes are the best options. Physical – chemical index among drainage water treatment options with weight of 0.605 has higher priority than the biological index.

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THE TENDENCY OF DRAINAGE RUNOFF IN CLIMATE CHANGE CONTEXT

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Abstract

The present article analyzes the change of climatic conditions in the Central Lithuania. Meteorological conditions in 1969–2009 were studied while analysing changes in seasonal distribution of the average air temperature and precipitation amount in Central Lithuania during the period of four decades, meanwhile complete studied period was divided each ten years. The activity of drainage during various seasons and the impact of meteorological conditions on drainage runoff in different seasons (winter, spring, summer and autumn) are reviewed.

KEY WORDS: Drainage, Runoff, Precipitation, Temperature, Climate.

Introduction

Global increase of precipitation is forecasted under changing climatic conditions; however, its extremes will also increase (Climate…, 2007). Simulating the impact of climate change on runoff has been realized in recent years. By applying projected climate scenarios into a validated hydrological model, hydrologists could assess potential variation tendencies of flow components in the future (Bastola *et al*., 2011; Bergstrom *et al*., 2001; Harding *et al*., 2012; Raghavan *et al*., 2014). Hydrology plays a key role for productivity of different biomes, including agriculturally used land. Therefore understanding relevant influences on hydrological processes is fundamental for ecosystem management (Yu *et al*., 2016). Land use and climate are two main factors that affect watershed hydrologic processes (Brath *et al*., 2006; Chien *et al*., 2013; Wu *et al*., 2012). Drainage of agricultural fields is not only a modern tool for removal of excess water, but also a great component of water balance of open water ponds. Runoff is a key water loss component with strong impact on crop production, vegetation restoration and ecosystem services such as water resource conservation (Gyssels *et al*., 2005; Valentin *et al*., 2005). When analysing the elution of biogenesis from soil through drainage, much research have been carried out (Sileika, Guzys, 2003; McDowell *et al*., 2001; David *et al*., 2008; Tan *et al*., 2008). (Malisauskas, Kutra, 2008) determined that the highest trend of increase of nitrates in drainage water is in May, and the

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concentration of nitrates in drainage water was characterized by the lowest increase in October. Climate changes (temperature increase, precipitation decrease) may be related with the environmental pollution. In case of low temperature and low moisture, assimilation of nutrients goes on much worse; therefore, they are leached from the soil with the drainage runoff more intensely (Soussana, Luscher, 2006). The major factor, which leads to the pollution, diffused by biogenesis N and P through drainage runoff and how the pollution occurs under various natural and agricultural conditions. The most important is the size of drainage runoff (Saulys, Bastiene, 2008).

Materials and methods

Experimental site layout

The field study was carried out in the southern part of Kaunas district, in the territory of training farm of Aleksandras Stulginskis University, Lithuanian (54.879485, 23.861525). Drain depth of 0.8, 1.10, 1.40 m, the drainage distance - 12, 18 m. Average surface test object slope - 0.008. The test site soil according to FAO: calcar - HypogleyicLuvisol, texture - light loam, dripping down on medium loam. Topsoil layer thickness is 0.2 to 0.25 Arable layer of filtration rate - 1.0 to 2.0 m / day, the lower layers of soil - from 0.01 to 0.004 m / day. The meteorological parameters (precipitation and average air temperature) of 1969–2009 were analysed in this article meanwhile data was obtained from Kaunas Meteorological Station, which is the nearest to the analyzed object (at the distance of 0.5 km Summarize the five long-term drainage systems (area 0.44 ha, 0.45 ha, 0.44 ha, 0.44 ha, 0.45 ha) of drainage studies, the data.

Results and discussion

One of the key factors in determining the size of runoff is precipitation. In the researched object the doughtiest year was 2010, the moistest – 1992. The integral curves of average precipitation height deviation from the average show the trends of precipitation height change: the linear trend, defining the trend of chronological sequence change, is positive (Figure 1).

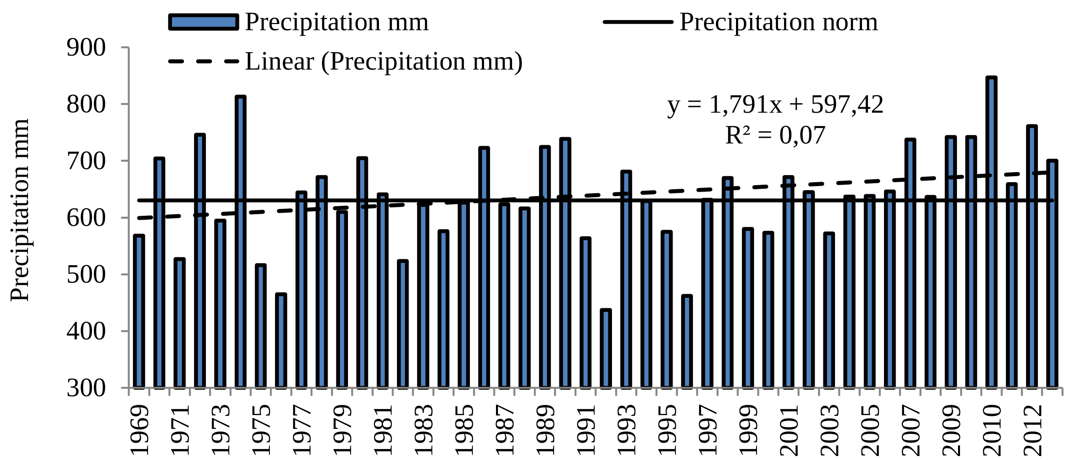

Figure 1. Dynamics of annual precipitation amount and their linear fluctuation trend

While analyzing the annual air temperature for the period of 1969–2013, it is seen that the highest average temperature was in 2008, and the lowest - in 1993. The linear trend, defining the trend of chronological sequence change, is positive (Figure 2).

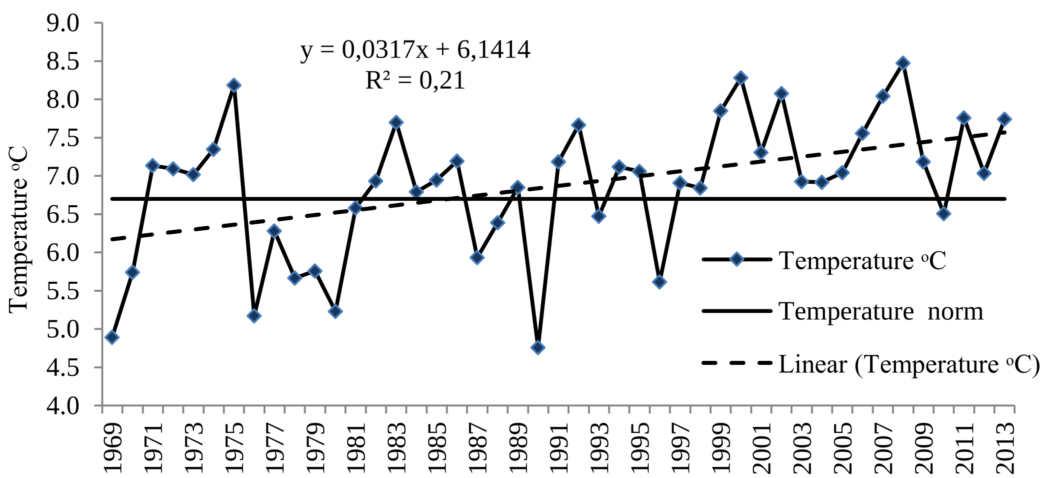

Figure 2. Annual temperature and they linear fluctuation trend

Meteorological conditions in 1970–2009 were studied while analysing changes in seasonal distribution of the average air temperature and precipitation amount in Central Lithuania during the period of four decades (1970–2009), meanwhile complete studied period was divided each ten years. In the recent decade (2000-2009) the average winder air temperature in Kaunas was 0.71°C warmer in compare with average temperature of the four decades (1970–2009), and amount of precipitation increased only in 0.7 mm in compare with average of 40 years period (Figure 3).

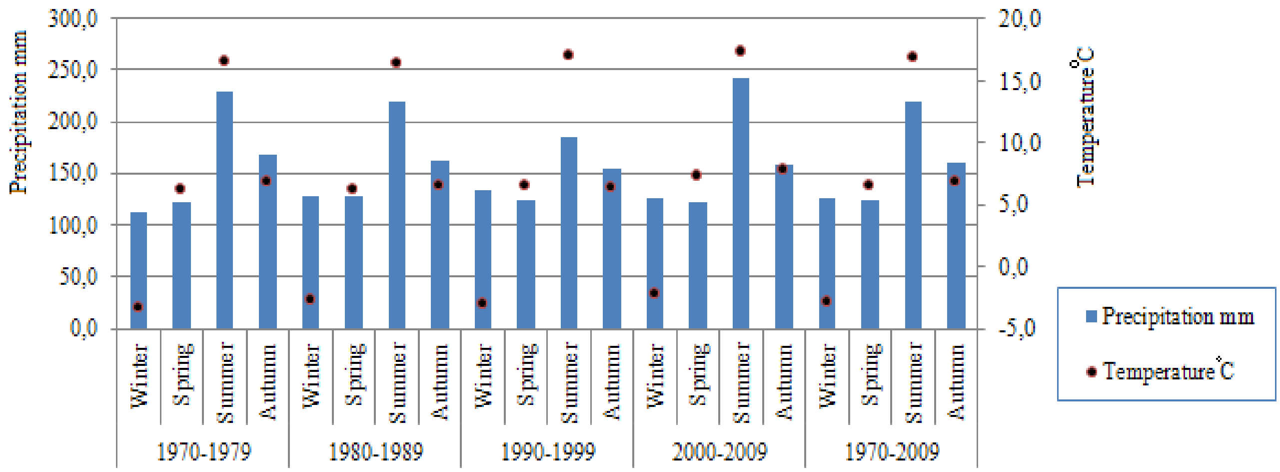

Figure 3. Perennial (of 1970–2009 period) and four decades (1970–1979, 1980–1989, 1990-1999, 2000–2009) average air temperature and precipitation amount of different seasons

During analysis of the temperature in decades it was revealed that in the spring it was always increasing and during the past decade (2000–2009) was 1.13°C warmer in compare with average temperature of year 1970–2009. Average sum of precipitation amount in spring (124.0 mm) and winter (125.1 mm) is very similar, and during the past decade average precipitation amount had decreased only in 1 mm in compare with the average precipitation amount of the complete period. Temperature in the summer was also increasing, and in 1970-1979 it was insignificantly (0.1°C) higher than in 1980-1989, and in the last decade (2000–2009) the summer temperature was in 0.5°C higher than the average temperature in 1970-2009 (Figure 3). The biggest amount of precipitation is in summer months. In the June-August of the last decade amount of precipitation increased in 33.3 mm in compare with the average of complete period, and when comparing with decade of 1990-1999 – amount increased even 56.6 mm. In the last decade (2000-2009) autumn in the region of Central Lithuania was warmer in 0.9°C, although during analysis of the last four decades data in decades, decrease of average temperature was observed (in 1980-1989 and 1990-1999). Autumn season is also characterized by plenty of precipitation, although in the last two decades insignificant decrease in precipitation amount was observed (in 1990-1999 – 6.2 mm, in 2000-2009 – 0.7mm.) in compare with average precipitation amount of the studied period. Analysis of air temperature and precipitation amount change during four decades of 1969–2009 had shown that the average air temperature of 2000–2009 was the highest, and the lowest average temperature was observed in 1970–1979 (Figure 4). The smallest amount of precipitation was in 1990-1999, and the largest amount – in 2000-2009, although it was only in 5.2 mm more than before three decades (in 1970-1979). During analysis of the drainage runoff dynamics it can be seen that the largest runoff was in 1980-1989, and the smallest, the same as in the case of precipitation amount – in 1990-1999.

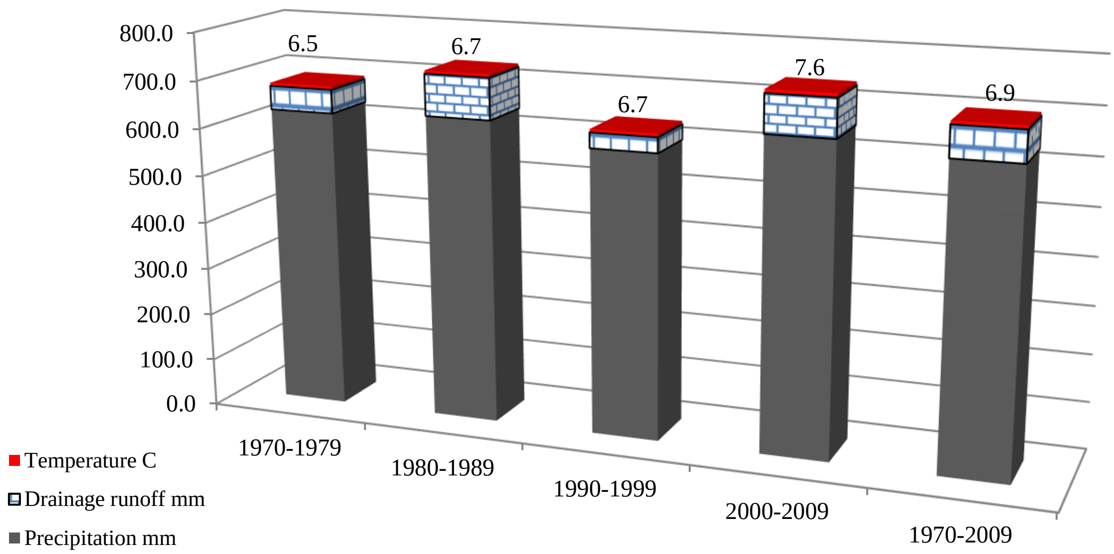

Figure 4. Perennial (of 1970–2009 period) and four decades (in 1970–1979, 1980–1989, 1990-1999, 2000–2009) average air temperature, amount of precipitation, drainage runoff and precipitation amount of different seasons

When studying seasonal distribution of the drainage runoff in decades, the summer season should be distinguished as constantly decreasing, meanwhile the average drainage runoff of the other seasons during decades is fluctuating. Although in the last decade the winter season had distinguished itself – the average runoff height was 32.4 mm (average of the four decades is 17.2 mm). When analysing data of 1970-2009 in the studied territory it was determined, that the smallest precipitation amount is in spring (19.7 %), in winter – very similarly (19.9 %), and the largest precipitation amount is in summer (even 34.8 %) and in autumn. Analysing distribution of the percent amounts of the average precipitation and drainage runoff in 1970–2009 according to the seasons, the highest drainage runoff is namely in spring (48.7 %), and the lowest – in summer (4.9 %), meanwhile the highest precipitation - in summer (34.8 %), and the lowest – in spring and summer (about 20 %, Figure 5).

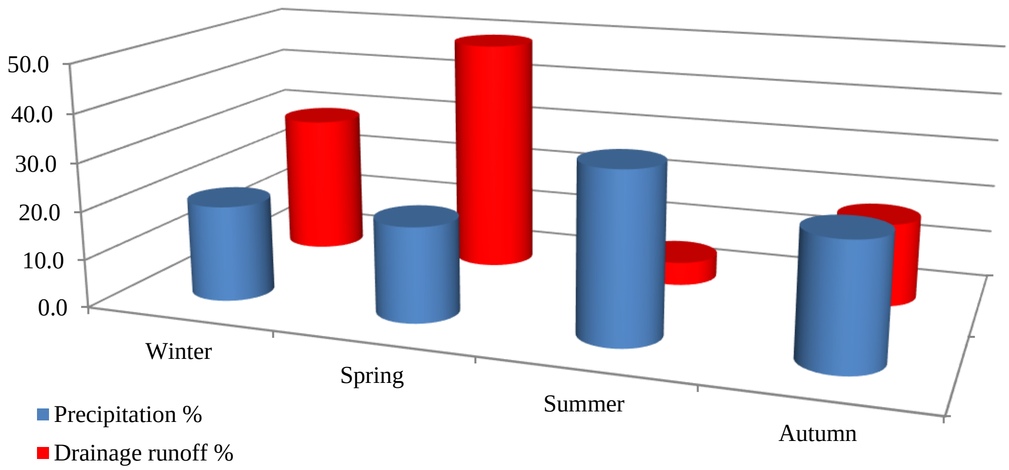

Figure 5. Distribution of the percent amounts of the average precipitation and drainage runoff

After performance of correlation-regression analysis of the study data it was revealed that relation between drainage runoff and precipitation amount during different seasons was weak (in spring (r=0.3) and in summer (r=0.33) or average (in winter (r=0.41) and autumn (r=0.40, Figure 6).

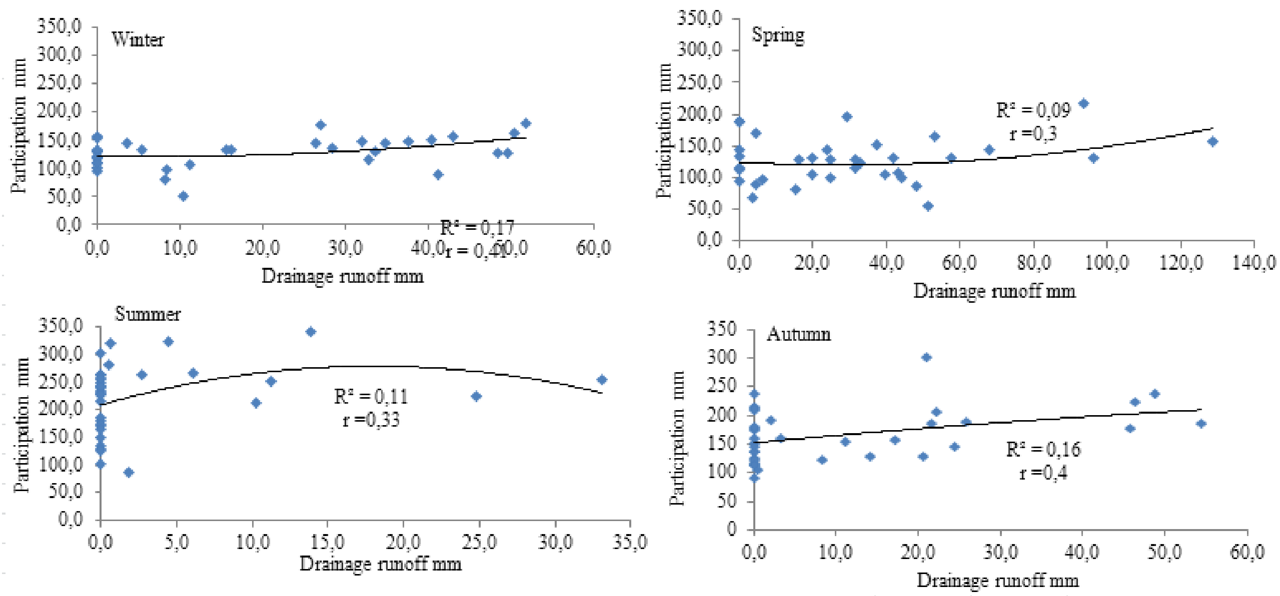

Figure 6. Dependence of the monthly drainage runoff from the average precipitation amount in different seasons (r_w – winter, r_{sp} – spring, r_{su}- summer, r_a – autumn).

When studying relations between drainage runoff and average air temperature in different seasons it was determined that in winter there was an average link (r=0.55), and in other seasons – the inter-relation was very weak (in spring (r=0.17), in summer (r=0.17) and in autumn (r=0.14, Figure 7).

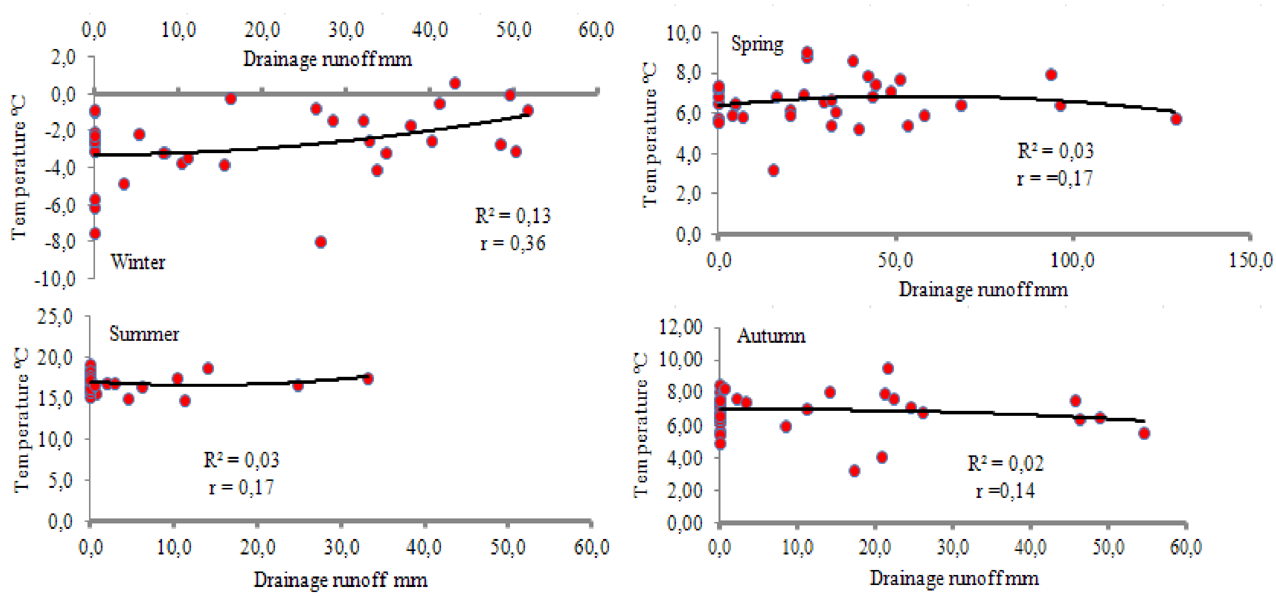

Figure7. Dependence of the monthly drainage runoff from the average air temperature in different seasons (r_w – winter, r_{sp} – spring, r_{su}- summer, r_a – autumn).

Table 1 presents the aggregate statistics of significant trends (5% significance level) of researched runoff characteristics, determined by Mann-Kendall test. It is obvious that in spring, summer and autumn (1969-2009) negative trends, i.e., the reduction of runoff, are determined, and runoff increases in winter (29%), and the change of total annual runoff has a plus. The sequences of multi-year air temperatures have already shown the increase of temperature of year and all seasons, except autumn (Rimkus *et al*. 2007). The depth, duration and temperature of frozen ground of soil depends on winter duration and air temperature, thickness of snow layer, vegetation layer, thermal characteristics and humidity, texture of soil, depth of ground water. Since the middle of twentieth century the duration of frozen ground has shortened by approximately two weeks, moreover, the probability of its total thaw and repeated freezing has increased. An increased incidence of thaw of frozen ground demonstrates that water infiltration conditions of cold season must have changed. Water, present in thinner capillaries of clay and loam soil, freezes at lower temperature. On the other hand, wet soil freezes less, since during water freezing heat of water crystallization is released, which slows down the further drop of soil temperature. Snow layer and vegetation also protect soil from deep freeze.

Table 1. Mann-Kendall test results

Month	Sum of year	MK-Stat	p-value
1	29	2.89	0.01
2	29	3.59	0.01
3	29	2.66	0.01
4	29	-0.36	0.72
5	29	0.21	0.84
6	29	-1.53	0.13
7	29	-1.13	0.26
8	29	-0.06	0.95
9	29	1.39	0.17
10	29	1.10	0.27
11	29	1.18	0.24
12	29	2.17	0.03

Conclusion

After performing the analysis of annual drainage runoff change during the period of 1969-2009, the significant one-trend change was not determined; however, the insignificant statistical linear trend is noticed. An important factor for runoff formation is precipitation intensity and duration, since intensive short rain forms a larger surface runoff, while the rain of lower intensity and longer duration better infiltrates into soil and evaporates from ground surface. After correlation-regression analysis of the study data it was revealed that relation between drainage runoff and precipitation amount during different seasons was weak (in spring and in summer), and average in winter and autumn. The analysis of runoff observation data revealed that seasonality, typical for run-off change, remains, however, the drainage runoff during winter season has increased significantly over the past four decades. Mann-Kendall test showed the significant increase of winter runoff during the analysed period. It was also influenced by growth of multi-year temperatures of all seasons, except autumn: the frozen soil is characterized by low water permeability, irrespective of its content. Significant decrease of drainage runoff is observed in

July and August. It is related with redistribution of precipitation amount, which increased in winter and decreased in summer.

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THE EFFECT OF CLIMATE CHANGE ON THE QUANTITY AND QUALITY OF AGRICULTURAL RUNOFF (CASE STUDY: GOLGOL RIVER BASIN)

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Abstract

Nowadays, the effects of climate change due to global warming and changes in precipitation patterns is quite evident. The increase of greenhouse gases has had an extensive negative effect on almost all regions of the Earth and on different systems, such as water resources, the environment, agriculture, industry, and health. Climate change and global warming have caused an intense deficiency of available potable water. This deficiency can decrease the quality of water as well. One of the prominant effects of climate change is on agriculture and water. Changes in demand for agricultural products can affect water resource management seriously. The reuse of agricultural runoff in areas facing water deficiency is important. A study was carried out in the Golgol River Basin. This river is one the main sources of the Ilam reservoir dam. Nearly 27 percent of the total basin area is under irrigated and rain-fed cultivation. In the case of rain-fed cultivation, wheat and barley are dominant crops. In this basin, wheat and corn are often grown under irrigated cultivation. Using fertilizers, which may have a significant impact on the quality of runoff. In order to predict temperature and precipitation under the effect of climate change, using the output of a HadCM3 model under the A2 emission scenario for two future periods (2046-2065 and 2080-2099) were used. The scenario of high population growth and a lesser dependency on economic development has been used on a regional scale in order to determine the amount of greenhouse gases. The LARS-WG model was used for downscaling. The results show that the temperature increases during the two periods and also changes in precipitation is observed. In order to simulate the runoff, an organic nitrogen and nitrate hydrological model (SWAT) and for calibration, SWAT-Cup and Sufi2 method were applied. Introducing downscaled results of AOGCM models to the hydrological model and assuming similar regional conditions including fertilizer and land use, changes in runoff and pollutants in the future were also simulated. It was observed that during 2046-2065, the average monthly Runoff, Nitrate and Organic nitrogen loads would decrease by

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27, 18, 13.5 percent. 2080-2099 period when compared to the present, show that the average monthly Runoff, Nitrate and Organic nitrogen loads would decrease by 45, 33, 35 percent. To prevent economic and agricultural losses and concerns about the decrease in the quality of water resources, runoff management might be required in the future.
KEY WORDS: Climate change, River water quality, Agricultural runoff, SWAT, LARS-WG.

Introduction

Climate change, particularly changes in temperature and precipitation are the most important issue in the field of environmental sciences (IPCC, 2007), but it does not only involve an increase in average temperature, it also results in changes to natural phenomena such as extreme temperatures, wind, snowfall, rainfall, and an increase in sea level that directly and indirectly affect human life (Kang et al., 2016). Although various economic sectors including agriculture, forestry, water, industry, tourism and energy affected by climate change but agriculture is the most dependent part to climate (Kemfert, 2008). Several studies have been conducted on the potential impacts of climate change on water resources, including the impact on water quantity, hydrology and water demand (Jung and Chang, 2011). Access to water, plays a key role in development. It sustains human life, both through direct consumption and use in agriculture and industrial activities (Melese, 2016). The effects of climate change on water resources and hydrological cycle is a global concern and has long been considered by the international community (Arnell, 1999; Barnett et al., 2005; Piao et al., 2010). Water resources management and planning around the world have become a challenging task due to climate change uncertainties (Ficklin et al., 2013). Agriculture has always been the dominant end-use of diverted water; this will only intensify with increasing needs for irrigation brought on by higher temperatures and reduced precipitation, coupled with increasing populations (Melese, 2016). climate change is expected to affect the agricultural water cycle, the agricultural water demand, potential for drought and surface runoff, and agricultural production (Tao et al., 2003). Global climate change include changes in patterns of rainfall and temperature may have significant effects on the watershed water quality and quantity and fresh water sources used for drinking, health, agriculture and industry (Tu, 2009; USEPA, 2014). Weather temperature increased has caused an increase in the biological interactions and consequently has altered the nutrients cycle, increased eutrophication and decreased water quality (Bouraoui et al., 2004; Chiew and McMahon, 2002; Fan and Shibata, 2015; Jha et al., 2004; Wilby and Harris, 2006). In addition, the decrease in water resources may increase the concentration of pollutants and nutrients and thus it is possible that water quality faces by further reducing. Weather temperature rise due to increased primary production, decomposition of organic matter and nutrients flow rates in rivers and lakes leads to lower dissolved oxygen levels affecting water quality. Climate change decreases quality and quantity of irrigation water and agricultural runoff. As runoff moves, it picks up and carries pollution, which it can deposit into ponds, lakes, coastal waters, and underground sources of drinking water. So, agricultural runoff management means controlling the quantity and quality of produced runoff which will be used in agriculture.

The confrontation with climate change is also inevitable in Iran and given that Iran is located in arid and semiarid region and faced by the water shortage problem, thus, the effects of climate change and global warming could aggravate the shortage of potable available water. In this study, Golgol River basin in Ilam province is considered as study area. Given the importance of climate change and its impact on runoff quantity and quality from Agricultural lands, in this study we emphasize applying a model that is able to simulate the runoff and nutrients. One of the appropriate tools for the relation between meteorological data (for example, temperature and precipitation) and basin-scale water cycle and nutrients is Soil and Water Assessment Tool (SWAT) (Gassman et al., 2007). Therefore, SWAT (Arnold et al., 1998) model is used to simulate river basin in this study. This model is one of the best options available for the comprehensive and specialized review of the watershed. According to past studies, this model has a proper performance and efficiency in the simulation of runoff and nutrient load in the different basins (Abbaspour et al., 2007b; Alansi et al., 2009; Singh et al., 2005; Tripathi et al., 2003; Wu and Chen, 2015; Xu et al., 2009). In order to predict temperature and precipitation influenced by climate change, the outputs of atmosphere-ocean general circulation model HadCM3 have been used under the emission scenario A2 in two periods 2046-2065 and 2080-2099. To apply the large-scale outputs of atmospheric general circulation models we need a model to downscale these data and use the downscaled data to study the effects of climate change. In this study, statistical models have been used to downscale general circulation models among which LARS-WG model was chosen as selected model.

Material and methods

Study area and Data

The study area in this research is Golgol River watershed (Figure 1). The length of the main branch of this river to the Ilam dam is 35.2 km and its catchment area is 279.52 km2 (46° 24’ 30” to 46° 38’ 00” east longitude and 33° 25’ 30” to 33° 38’ 30” north latitude)

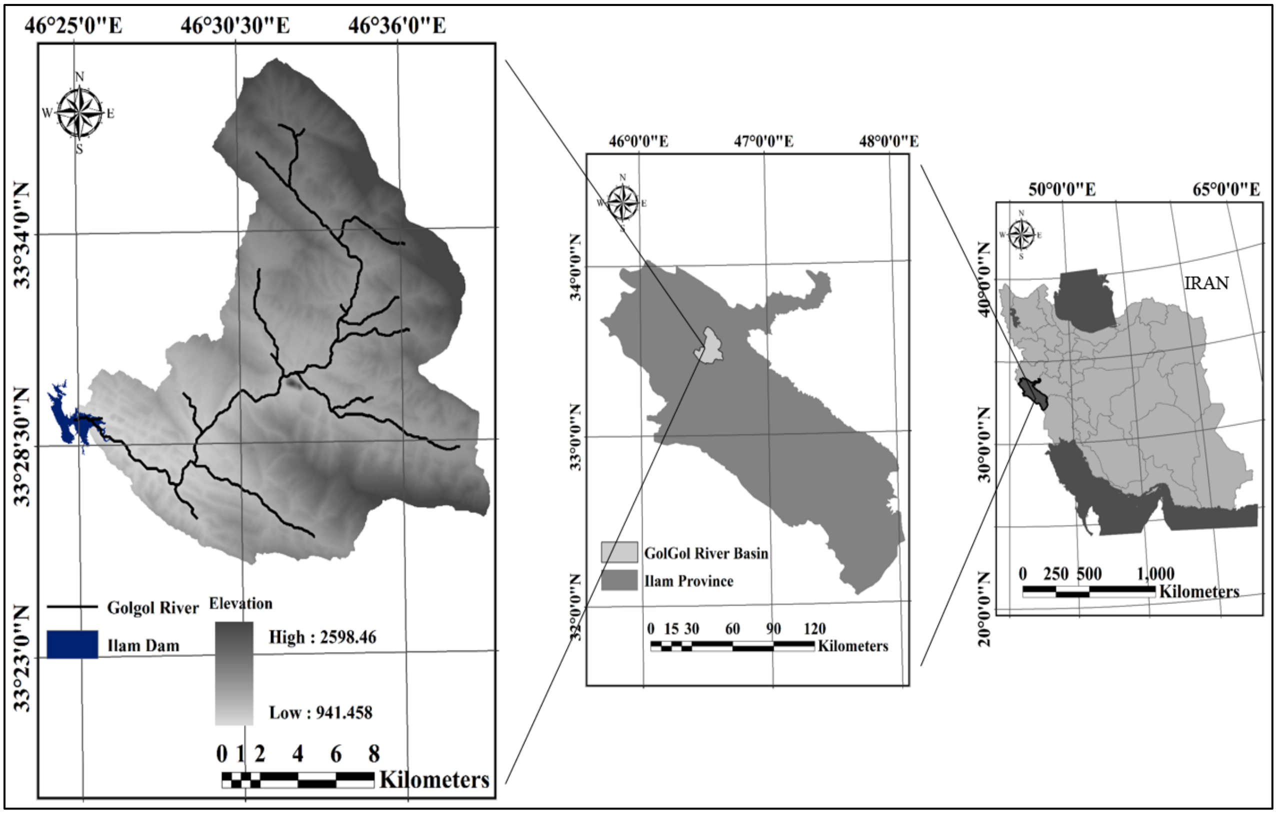

Figure 1: Gogol river basin in Iran

Ilam synoptic station data are used to examine the meteorological status of the Golgol river watershed. The most important sources of pollutants in this watershed are agriculture and grazing as non-point sources of pollutants. The dominant crop rotation in this area is both irrigated and rain-fed agriculture. The following data (Table 1) has been used to progress the research.

Table 1: Data description and sources used in project

Data type	Source
Digital elevation model (DEM)	Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters (http://www2.jpl.nasa.gov/srtm/).
soil	the Food and Agriculture Organization of the United Nations (FAO) spatial resolution of 5 km (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/).
Landuse	Global Landuse /Land cover Characterization USGS with a spatial resolution of 1 km (http://landcover.usgs.gov/glcc/)
Climate	I.R. of IRAN Meteorological Organization.
River discharge	Iran Water Resources Management Co.
Nitrate and organic nitrogen loads	Consulting Engineers Co. Mahab
Agricultural management and water resources (Planting,harvesting, fertilization)	Agriculture Organization of Ilam (http://www.jkoi.ir/)

As shown in Figure 2, 23% of landuse in the Golgol river basin is rain-fed cultivation and 4% of it is irrigated cultivation. it means that 85% of cultivated lands is rain-fed and other 15% is irrigated.

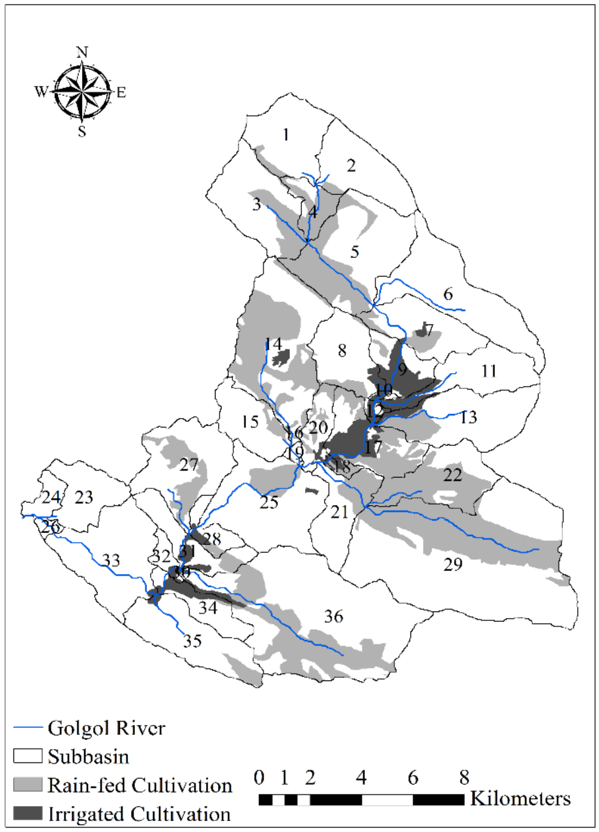

Figure 2 : rain-fed and irrigated cultivation in golgol river basin

Climate change model

IPCC[1] determines the values of climatic parameters change on the basis of scenarios in which predicts the general policy of the world of population growth, economy, environmental sustainability and type of consumption energy points of view. These policies are presented numerically using integrated assessment models which their outputs will be the final result of scenarios families for each policy. Currently the most reliable tool to develop climatic scenarios is AOGCM[2](Mitchell, 2003; Wilby and Harris, 2006). It should be noted that the information derived from the general circulation models are not possible to use unprocessed for local predictions they should be downscaled in the study area (Diaz-Nieto and Wilby, 2005). There are generally two ways for downscaling: statistical downscaling and dynamical downscaling methods (Arabi et al., 2008; Fakhri et al., 2013; Wilby and Harris, 2006). LARS-WG is synthetic generator of weather data which could be applied to simulate the meteorological data in an individual location under present and future climatic conditions. Data are created in daily time series for a series of appropriate climatic variables such as precipitation, minimum and maximum temperatures and radiation. Currently, the outputs of global climate models have limited spatial

[1] Intergovernmental Panel on Climate Change

[2] Atmospheric-Ocean General Circulation Models

and temporal accuracy. A synthetic generator model for weather data can be used as an inexpensive calculating tool in the production of multi-year scenarios of climate change in the daily time scale (Racsko et al., 1991; Semenov and Barrow., 1997). In this study, outputs of atmosphere-ocean general circulation model is used to predict temperature and precipitation under the effects of climate change. HadCM3 model used under emission scenario A2 in two periods 2046-2065 and 2080-2099. According to researches were done in this basin HadCM3-A2 is the most critical scenario model (Dalilsafaee et al., 2015 ; Moshtaghi et al., 2015).

SWAT model

SWAT model is a comprehensive model to simulate different processes within the watershed and has been developed for the US Department of Agriculture (Arnold et al., 1993).This model is composed of eight important parts: agricultural management, crop growth, hydrology, nutrients, pesticides, sediment, soil temperature and weather (El-Khoury et al., 2015). This semi-distributive model is continuous in time and watershed scale (Arnold et al., 2012; Gassman et al., 2007; Neitsch et al., 2005) and is developed to predict the effect of land use management on water, sediment and agricultural chemical products in large and complex watersheds with different soil, land use and management conditions in long-term periods (Abbaspour et al., 2015).

SWAT model setup

The first step in configuring the watershed is entering the DEM of the area into the model. In order to draw sub-basins and waterways using DEM, considered sub-basin definition threshold as equal to 500 hectares. Considering location of hydrometric and qualitative stations, 36 sub-basins were considered for this watershed. The next step of modeling is introducing the information layers required for the formation of hydrological response units into the model. In this study, hydrological response units were evaluated in different conditions in order to determine the number of HRUs. The multiple HRU and taking into account the 15% sub-basin area threshold for land use, soil and slope is used in this study. Thus, 174 hydrological response units in 36 sub-basins of the watershed were formed.

SWAT has allowed the user to enter the crop pattern and also the type of fertilizer used in the area to the model so that the pollution from these sources of contaminants to be considered in the model (Neitsch et al., 2005). In this regard, crop pattern and amount of fertilizer consumption per dominant crop of the area were obtained according to data from Agriculture Jihad Department of Ilam Province. In the case of rain-fed cultivation, wheat and barley are dominant crops. In this basin, often wheat and corn are grown under irrigated cultivation. The level and type of fertilizer consumed for any of these crops were determined using the data from the Agriculture Jihad Department of Ilam province. In addition, cultivation date and other agricultural practices such as tillage, fertilizing and harvesting were considered according to local climate and experts. Also the pattern and type of cultivation were considered fixed during the simulation as the assumptions of this investigation.

SWAT calibration and validation

In this study, the calibration has been done using SUFI-2 algorithm (Abbaspour et al., 2007b). This algorithm has been used in SWAT-CUP software format(Abbaspour et al., 2009, 2007a). The error criterion function used in this study is Nash–Sutcliffe Equation (NSE) (Nash and Sutcliffe, 1970). The uncertainty is calculated by two evaluation criteria P-FACTOR and R-FACTOR. In order to evaluate the model efficiency, Correlation coefficients (Equation 1) and Nash-Sutcliffe (Equation 2) coefficient of efficiency were used.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i^{sim} - X_i^{simav})(X_i^{obs} - X_i^{obsav})^2\right]}{\sum_{i=1}^{n}(X_i^{sim} - X_i^{simav})^2(X_i^{obs} - X_i^{obsav})^2} \quad (1)$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(X_i^{sim} - X_i^{obs})^2}{\sum_{i=1}^{n}(X_i^{obs} - X_i^{obsav})^2} \quad (2)$$

The simulation in SWAT model has performed from 1988 to 2010 that is during the entire statistical period of which first three years have been used for Warm up period of the model. From 2001 to 2010 and from 1998 to 2000 periods were selected as river discharge calibration and validation period, respectively. In the case of sediment calibration, two periods, from 2001 to 2009 and from 1998 to 2000 were chosen for calibration and validation, respectively. In this regard, in order to simulate the nutrient load, the data relating to the first half of 2010 was used for calibration and the data from second half of 2009 was used to validate; this model time step is on a daily basis.

Results and discussion

Downscaling results

According to the average prediction GCM model, the data of daily minimum and maximum temperature and precipitation for the period 2046 to 2065 and 2080 to 2099 were produced under HADCM3-A2 for Ilam station. The results are presented the following. In the case of precipitation values on average, total precipitation in mm per month and on average in °C per month are presented during the statistical period.

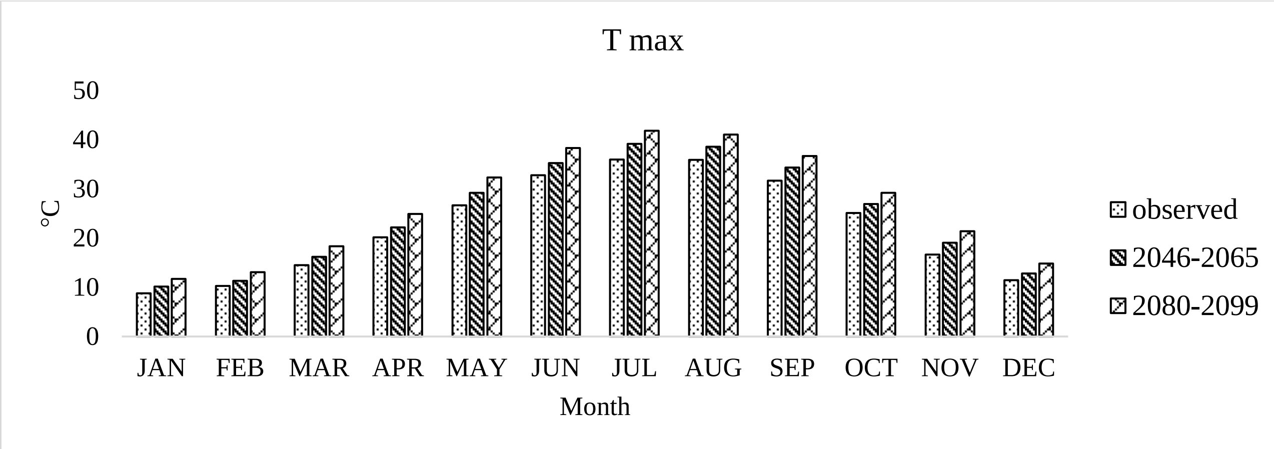

Figure 3: Compare average observed maximum temperature in each month with model- scenario in two periods

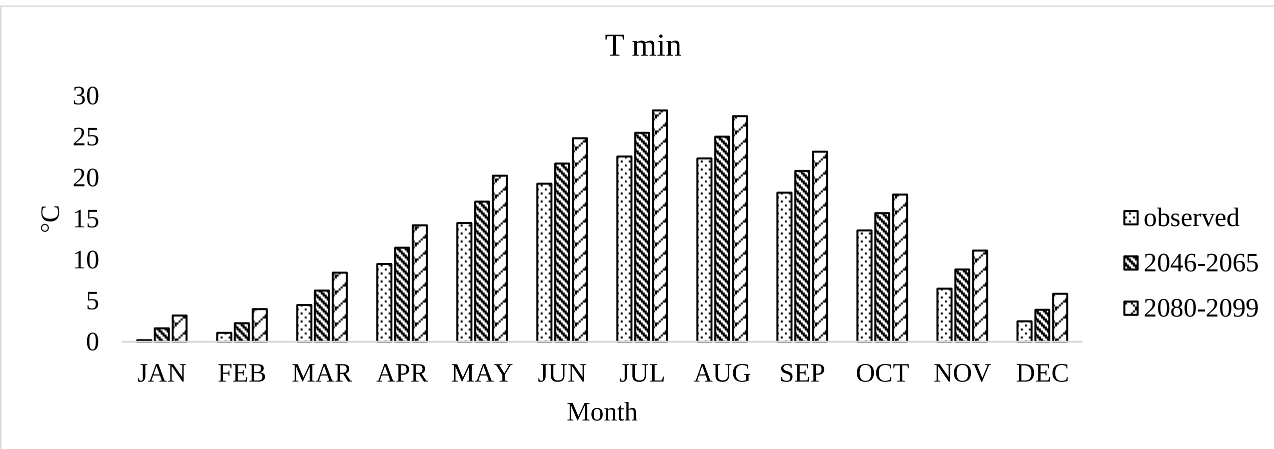

Figure 4: Compare average observed Minimum temperature in each month with model- scenario in two periods

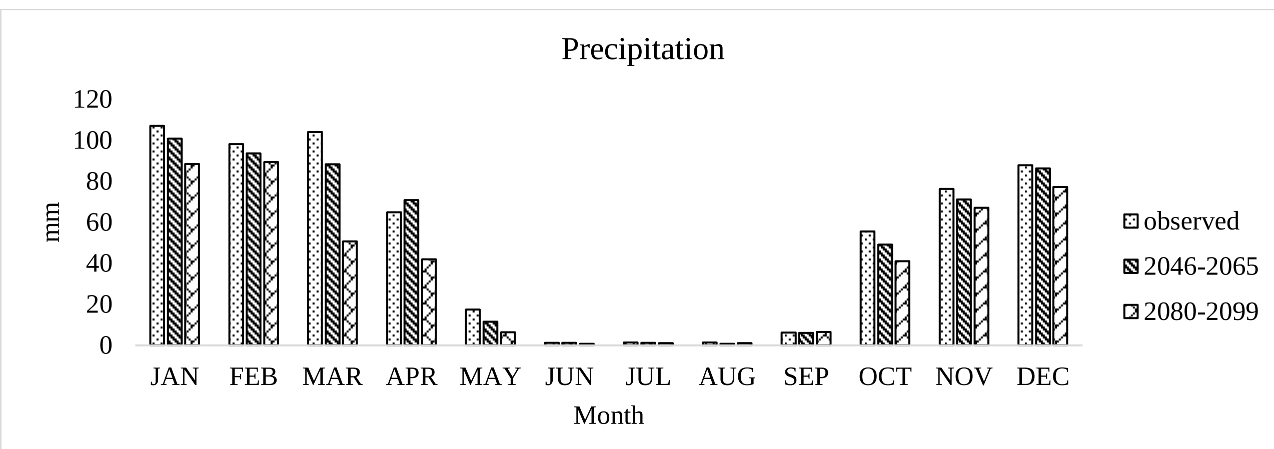

Figure 5: Compare average observed precipitation in each month with model- scenario in two periods

Table 2: summary of results from the impact of climate change

Period	Observed	HadCM3-A2	
		2046-2065	2080-2099
Mean Monthly Max Temperature (°c)	22.52	24.61	27
Mean Monthly Min Temperature (°c)	11.24	13.37	15.75
Mean Monthly Precipitation (mm)	51.7	48.39	39.26

SWAT Calibration and verification results

Selected final parameters and their variation range are shown in the Table 3. These values have been determined according to the results suggested by SWAT-CUP model as well as engineering judgment and taking into consideration the allowed range for each parameter.

Table 3: List of some SWAT's parameters that were fitted and their final calibrated values

Parameter	Parameter description	Final parameter value
v_SFTMP.bsn	Snowfall temperature (°C)	-3.13
v_SURLAG.bsn	Surface runoff lag coefficient	4.712
v_SNO_SUB.sub	Initial snow water content (mm H2O)	119.09
v_EPCO.hru	Plant evaporation compensation factor	0.841
v_REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur (mm H2O)	93.443
v_SLSUBBSN.hru	Average slope length (m)	22.81
v_SMTMP.bsn	Snowmelt base temperature (°C)	2.535
r_SOL_BD.sol	Moist bulk density(Mg/m3 or g/m3)	0.145
r_SOL_K.sol	Saturated hydraulic conductivity (mm H2O/ h1)	-0.064
r_SOL_AWC.sol	Available water capacity of the soil layer (mm H2O/mm soil)	-0.02
v_CH_K2.rte	Effective channel hydraulic conductivity (mm/hr)	59.046
v_CH_N2.rte	Manning's n value for the main channel	0.119
v_USLE_P.mgt	support practice factor	0.653
v_ESCO.hru	Soil evaporation compensation factor	0.95
v_GW_REVAP.gw	Groundwater 'revap' coefficient	0.068
v_ALPHA_BNK.rte	Baseflow alpha factor (days)	0.199
v_CANMX.hru	Maximum canopy storage(mm H2O)	38.265
r_CN2.mgt	SCS runoff curve number for moisture condition II	0.004
v_ALPHA_BF.gw	Baseflow alpha factor (days)	0.629
v_GW_DELAY.gw	Groundwater delay (days)	57.27
v_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm H2O)	0.409
v_PRF.bsn	Peak rate adjustment factor for Sediment routing in main channels	1.145
v_SPCON.bsn	Channel re-entrained linear parameter	0.0011
v_SPEXP.bsn	Channel re-entrained exponent parameter	1.16
v_CH_ERODMO.rte	Channel erodability factor	0.909

v_RCN.bsn	Concentration of nitrogen in rain (mg N/L)	8.399
v_NPERCO.bsn	Nitrate percolation coefficient	0.015
v_CDN.bsn	Denitrification exponential rate coefficient	0.023
v_SDNCO.bsn	Denitrification threshold water content	0.096
v_AI1.wwq	Fraction of algal biomass that is nitrogen (mg N/mg alg)	0.385
v_SOL_NO3.chm	Initial NO3 concentration in the soil layer (mg N/ kg soil or ppm)	0.075
v_SOL_ORGN.chm	Initial organic N oncentration in the soil layer (mg N/ kg soil or ppm)	10.15
v_ERORGN.hru	Organic N enrichment for loading with sediment	0.981

To evaluate the performance of SWAT model to simulate variables in the calibration and validation period, the accuracy evaluation indicators of the simulation are shown in figures below.

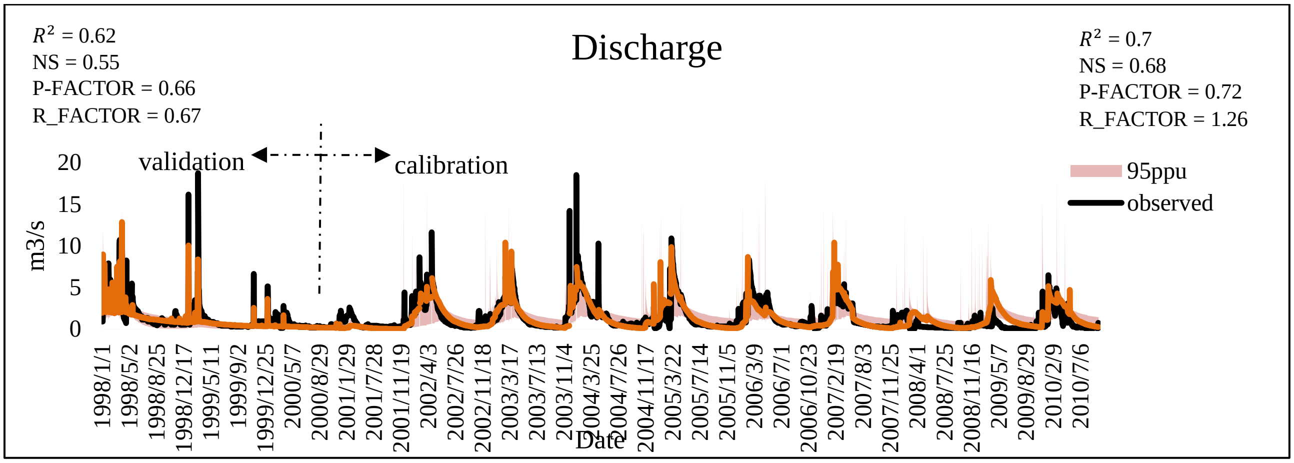

Figure 6: Results of Swat calibration and validation for daily river discharge

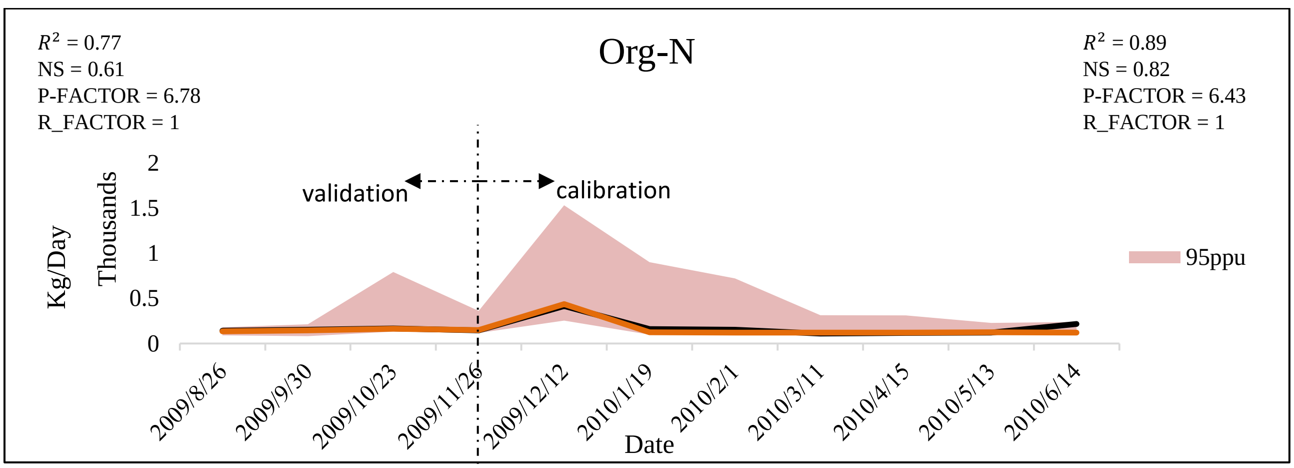

Figure 7: Results of Swat calibration and validation for daily Org-N loads

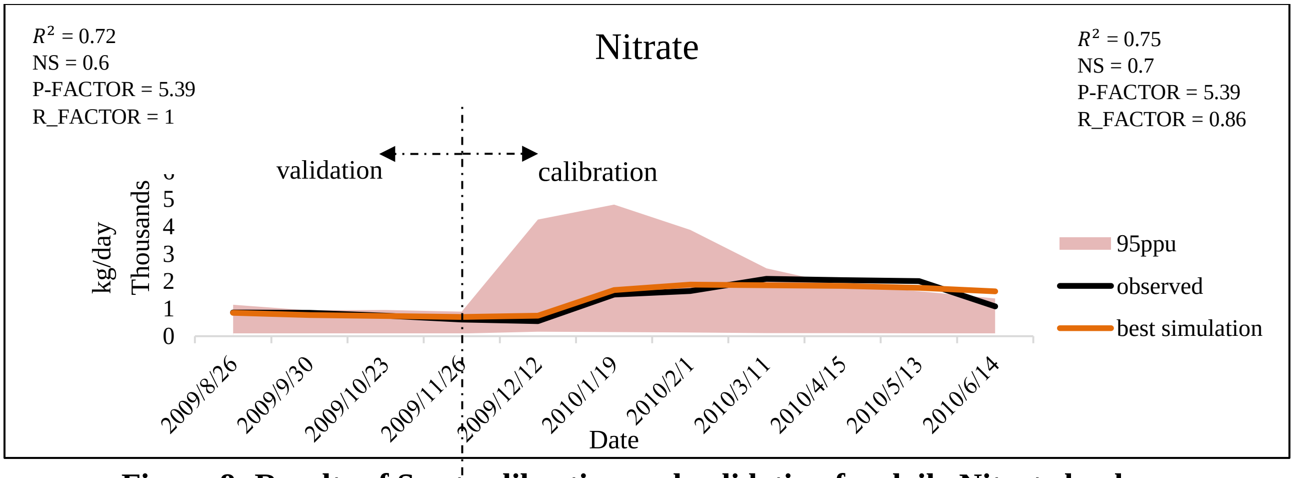

Figure 8: Results of Swat calibration and validation for daily Nitrate loads

46 initial parameters have been entered to model previously which were declined to 33 final parameters after calibration and removing parameters with less sensitivity to the model variables. CN2 had the most sensitivity compared to other parameters. Correlation coefficients, Nash-Sutcliffe coefficient, P-FACTOR and R-FACTOR for the variables of interest during the calibration and verification indicate the success of the model using the optimized parameters given daily step to simulate river discharge (Figure 6) and nutrients (Figure 7 and Figure 8) in Golgol Watershed.

Impact of climate change on Runoff, Nitrate Load and Org-N Load

The results from climate change was calculated as long-term average of each month in future period and baseline period assuming no change in land use and stability of the cropping pattern in the area; the results are displayed in the following graphs.

Irrigated cultivation

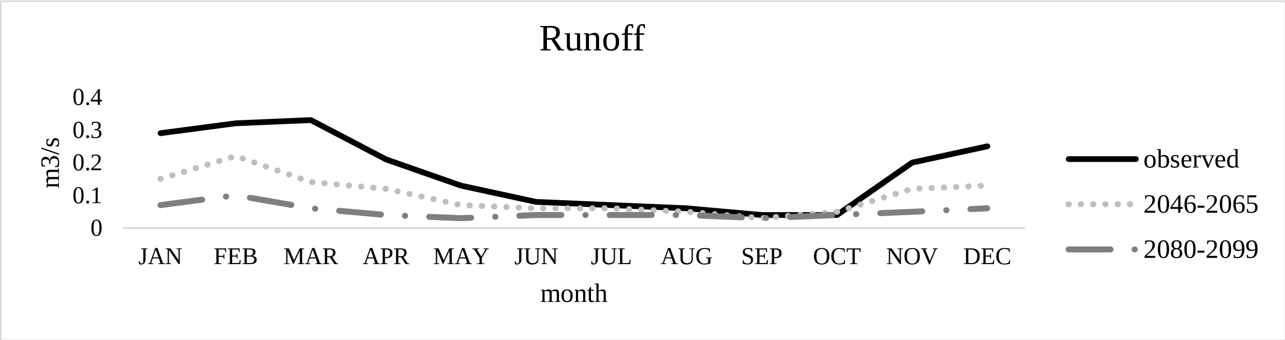

Figure 9: Comparison of average monthly Runoff from Irrigated cultivation in two periods relative to baseline period

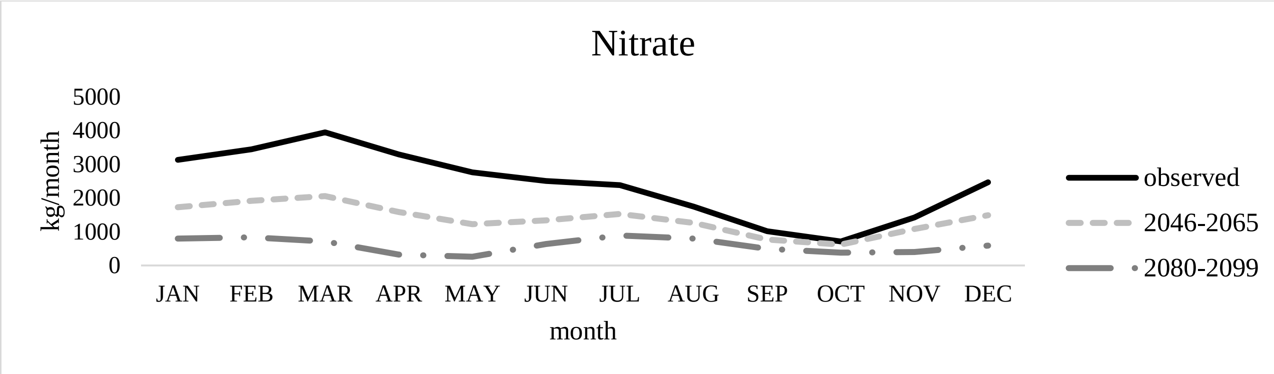

Figure 10: Comparison of average monthly Nitrate loads from Irrigated cultivation in two periods relative to baseline period

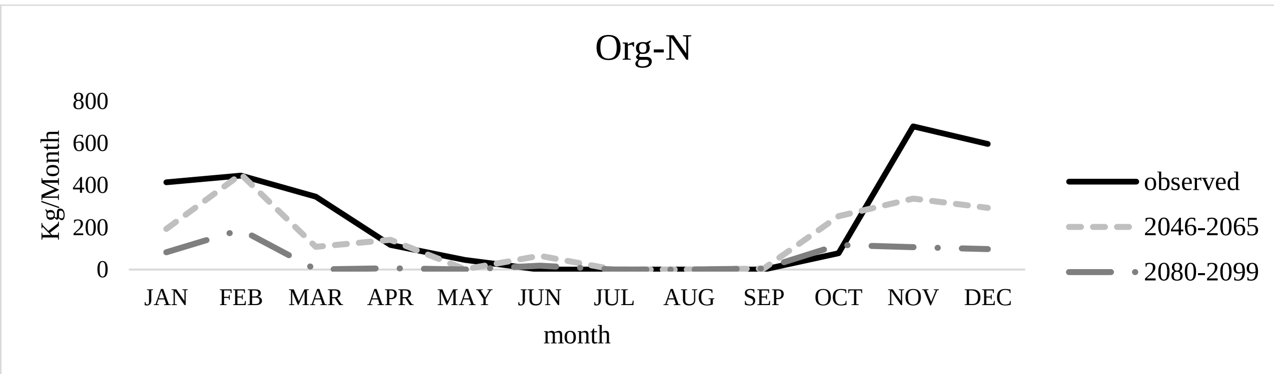

Figure 11: Comparison of average monthly Org-n loads from Irrigated cultivation in two periods relative to baseline period

Rain-fed cultivation

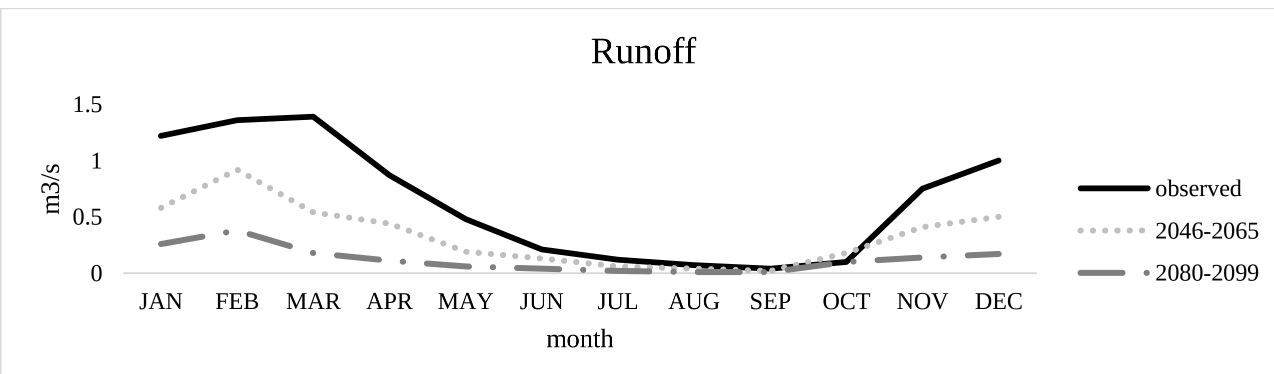

Figure 12: Comparison of average monthly Runoff from Rain-fed cultivation in two periods relative to baseline period

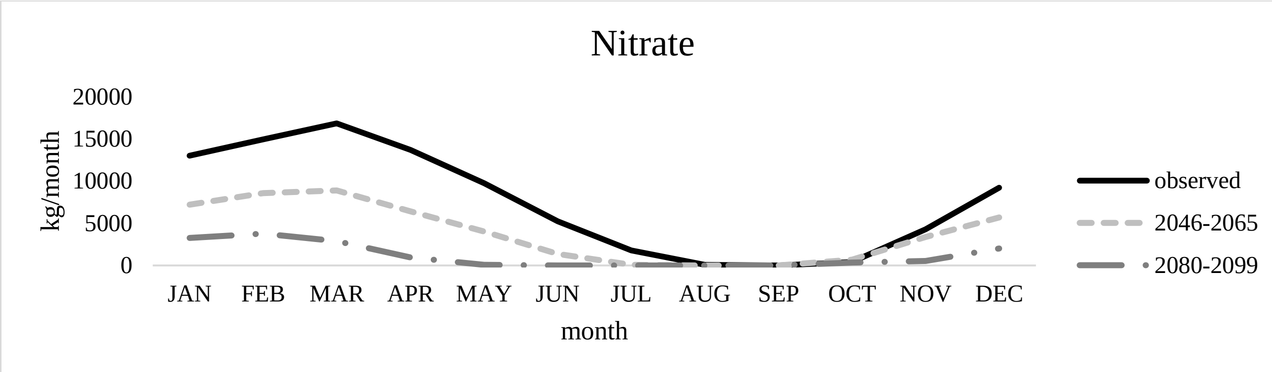

Figure 13: Comparison of average monthly Nitrate loads from Rain-fed cultivation in two periods relative to baseline period

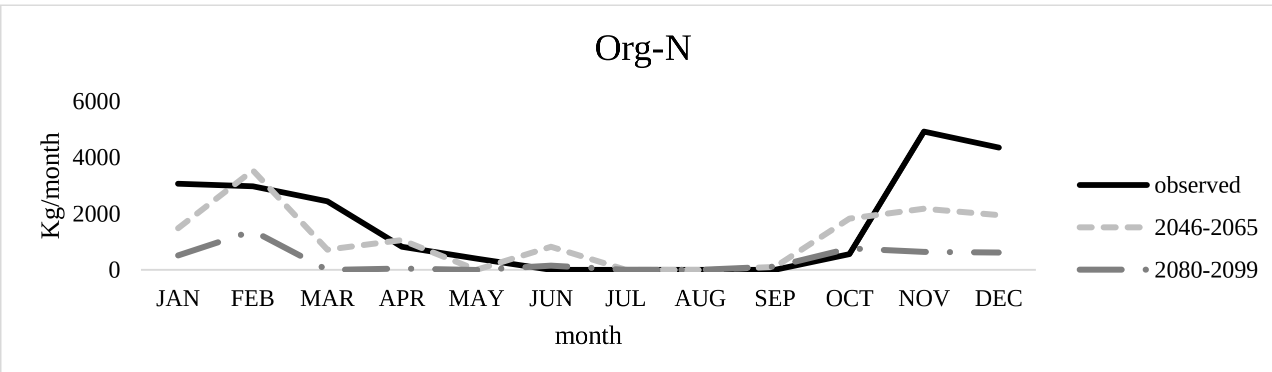

Figure 14: Comparison of average monthly Org-N loads from Rain-fed cultivation in two periods relative to baseline period

According to Figure 9 the amount of runoff from Irrigated cultivation of two periods are lower than the observed discharge in most months of the year indicating the impact of climate change on the area. The average monthly runoff is decreased from 0.17 M3/s to 0.13 in 2046 and to 0.1 in 2080 so decreasing from 23 to 41 % has been observed. according to Figure 12 Rain-fed cultivation runoff decreased from 0.46 in observation period to 0.31 in 2046 and to 0.23 in 2080. and this means 33 to 50% decrease. by comparing this two periods it is obvious that the runoff decrease about 20% in Irrigated cultivation and about 25% in Rain-fed cultivation.

According to Figure 10 the amount of Nitrate load in Irrigated cultivation from 2402.6 to 1984 kg/month in 2046 and to 1593.2 kg/month in 2090. according to Figure 13 in Rain-fed cultivation this amount decreased from 7443.9 to 6063 kg/month in 2046 and to 4916.2 in 2080 kg/month. Also by comparing two periods is found that annual nitrate load decreased 20% in Irrigated cultivation and 18% in Rain-fed cultivation.

The average of monthly Org-N load decreased from 227 kg/month in observation period to 193.6 kg/month in 2046 and to 151.2 kg/month in 2080 in Irrigated cultivation (Figure 11). according to Figure 14 the amount of nitrogen load in Rain-fed cultivation decrease from 1629.1 in observation period to 1403.7 in 2046 and to 1055.3 in 2080. In Irrigated cultivation the annual Org-N load decrease from 22% in 2080 compared to 2046 and in Rain-fed cultivation, 25%.

Conclusion

The aim of this study was to investigate the impact of climate change on the quantity and quality of agricultural runoff of Golgol River basin in which the SWAT model was used to simulate three water quality and quantity parameters and the LARS-WG model was applied for downscaling the atmosphere-ocean general circulation model. The temperatures increase in all model-scenarios. Precipitation also faced with both decrease and increase which the latter has no effect on the river discharge, therefore, it can be concluded that these increases are due to higher intensity of rainfall which may lead to floods and also Raising the temperature give rise to surface evaporation which paves the way for decresing river discharge. In two periods runoff and nutrient loads from agriculture lands have been reduced. But reducing the nutrients load associated with a sharp reduction in runoff so we face increasing in Concentrations of pollutants. Since iran is located in Arid and semi-arid regions, reusing the runoff is a good way to decrease water shortage. Another point is that some villages are located in Golgol glen. When runoff enter the river, this villages face water quality degradation. So according to runoff quality degradation, actions must be taken to reduce pollutants. There are many ways that agricultural operations can reduce nutrient pollution, including:

- Watershed efforts: The collaboration of a wide range of people and organizations often across an entire watershed is vital to reducing nutrient pollution. State governments, farm organizations, conservation groups, educational institutions, non-profit organizations, and community groups all play a part in successful efforts to improve water quality.
- Nutrient management: Applying fertilizers in the proper amount, at the right time of year and with the right method can significantly reduce the potential for pollution.
- Cover crops: Planting certain grasses, grains or clovers can help keep nutrients out of the water by recycling excess nitrogen and reducing soil erosion.
- Buffers: Planting trees, shrubs and grass around fields, especially those that border water bodies, can help by absorbing or filtering out nutrients before they reach a water body.
- Conservation tillage: Reducing how often fields are tilled reduces erosion and soil compaction, builds soil organic matter, and reduces runoff.
- Managing livestock waste: Keeping animals and their waste out of streams, rivers and lakes keeps nitrogen and phosphorus out of the water and restores stream banks.
- Drainage water management: Reducing nutrient loadings that drain from agricultural fields helps prevent degradation of the water in local streams and lakes.(USEPA, 2016)

  Adapting to climate change should include reducing the multiple pressures on freshwater resources (such as water quality degrading and excessive exploitation) as well as improving drinking water and sanitation and providing management solutions.

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2

Topic 2:
Measures to Improve Drainage Water Quality

MODELING NITRATE-N LEACHING IN NO-TILL FIELDS WITH DRAINMOD-N II

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Abstract

Conservation agriculture, especially no-tillage, has proven to result into sustainable farming in many agricultural environments globally. In spite of some advantages of no-till systems, this practice may increase infiltration into the soil and leaching to groundwater. This method can also enhance the movement of mobile nutrients and some pesticides to subsurface drains and to deeper groundwater along preferential pathways in the soil profile. In this study, DRAINMOD-N II was utilized for the simulation of nitrate-nitrogen (NO3-N) concentration in till drainage water outflows in no-till filed of Truro, Nova Scotia, Canada from2003-2006. The model performance was evaluated first by comparing the observed and simulated drain outflow data that is an essential prerequisite for the model to obtain a proper prediction of NO3-N movement, and then by comparing the observed and simulated NO3-N concentration in no-till fields using three statistical indices, relative root mean square error (RRMSE), average absolute deviation (AAD) and the correlation coefficient (R^2). The RMSE, AAD and R^2 for validation period were determined to be 1.09 mm, 1.85 mm and 0.83 for drain outflow, and 1.43 mg/l, 0.51 mg/l and 0.79 for NO3-N concentration respectively. The results showed that DRAINMOD-N II predicted reasonably well NO3-N leaching in drainage outflow of no-till fields over the whole years.

KEY WORDS: No-till, DRAINMOD-N II, Nitrate, Leaching.

Introduction

No-till farming has been recognized as an efficient practice to conserve soil and water, and to improve soil quality and to ensure food security (Lal 2004). No-till, also known as direct drilling or zero tillage (conservation tillage in the USA and Australia), means sowing directly into the residue of the previous crop without any prior topsoil loosening. Under such practices, a 30% or greater cover of residue from the previous crop is left on the soil surface. For example, a 60%

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reduction in surface runoff was reported for no-till corn in Quebec when compared with conventional tillage (McRae et al. 2000). The adoption of conservation tillage practices has resulted into lesser periods when soils are left bare and exposed to erosion. It reduced the number of bare soil days per hectare per year in Canada around 20% in 1981 to 1996 (McRae et al. 2000).

No-till generally increases the macro porosity of the soil since reduced tillage allows increased aggregation. Changes in pore size generally allow for enhanced infiltration but can cause an increase in bulk density in high-traffic areas (although no-till often can increase bulk density). The results of different studies showed that tillage and cropping have more effects on preferential flow through macro pores and solute transport (Kamau et al. 1996, Rasse and Smucker 1999).

Although minimum-tillage may reduce losses of water and the intrusion of some pollutants into surface drainage, this practice may increase infiltration into the soil and leaching to groundwater. This can enhance the movement of mobile nutrients and some pesticides to subsurface drains and to deeper groundwater along preferential pathways (e.g., cracks and worm holes) in the soil profile (Drury et al. 1996, Gaynor et al. 2002).

Rasse and Smucker (1999) and Ogden et al. (1999) found that no-till increased the flow volume as compared to conventional-till. In both studies, the amount of solute loss, whether nitrate-nitrogen or bromide, was essentially the same, even though flow was greater under no-till.

In Nova Scotia, Canada, the use of no-till increased from 4% of the total area prepared for seeding in 1991 to 14% in 2006 (Hofmann 2008). Many soils in Nova Scotia have poor drainage capabilities and receive an annual precipitation that exceeds potential evapotranspiration (Carter et al. 1996). Hence, the use of subsurface drainage systems is necessary to improve internal soil drainage for ensuring better crop growth.

The performance of the DRAINMOD model in colder regions has been evaluated in previous researches. Luo et al. (2001) used DRAINMOD ,version 5.1, to simulate water table and subsurface drainage for three fileds in Carsamba, Turkey; Truro, Canada; and Lamberton, Minnesota .This model gave reasonable predictions of field hydrology. Dayyani et al., (2009) assessed the hydrological performance of DRAINMOD 5.1 for Southern Quebec region with due consideration tofreezing/thawing conditions. The result showed that the DRAINMOD 5.1 performed well in simulating the hydrology of a cold region.

DRAINMOD−N II is a field−scale, process−based model that was developed to simulate nitrogen dynamics and turnover in the soil−water−plant system under different management practices and soil and environmental conditions. Youssef et al (2005) show that the model is capable of simulating N dynamics under different management practices and environmental and soil conditions. It operates in three modes with different levels of complexity, so it can be adapted to the system being simulated.

It is necessary to look for a model that can accurately predict Nitrate-N leaching in no-till fields. Therefore, the goal of this study was to evaluate the capacity of DRAINMOD-N II to simulate subsurface Nitrate-N leaching in no-till fields throughout the year in a cold climate, such as Truro, Nova Scotia.

Materials and methods

Site Description

A subsurface drainage system was installed in a six ha field in Truro, Nova Scotia, Canada in 1995 (45o 22' N, 63o 16o' W). The system had previously been used to compare the effects of composted poultry manure and fresh manure on water quality (Thiagarajan et al. 2007). The plot was divided into 10 plots (36 m × 72 m) with each plot isolated hydrologically by buffer drains. These plots consist of five conventional tillage (CT) and five zero tillage (ZT) systems. The plot layout, drainage and treatment details are illustrated in Figure 1. Since plot 6 (no-till plot) had a complete dataset, the data for this plot was used to evaluate the model. Perforated drainage conduits (100 mm in diameter) are located at an average depth of 80 cm with 12 m spacing. The drainage system information is given in Table 1. Soil in plot 6 wass imperfectly drained and was classified as Pagwash 52. Soils of the Pagwash group develop in coarse loamy till which is derived from sandstone of the carboniferous period. Pagwash 52 soils have 50 to 80 cm of friable, coarse loamy solum over firm, coarse loam, lower soil material (Webb 1991). Soil water characteristic of this soil were obtained using the standard pressure plate method. Saturated conductivities were determined by adjusting the values from the core method with the field effective soil hydraulic conductivities (Madani and Brenton 1995, Madani et al. 1997).

The cropping system was a wheat-soybean rotation from 2003 to 2006, respectively. Spring Wheat (var. Belvedere) and Soybeans (var. DKB 00/99) were planted using a no-till planter for all plots during the spring.

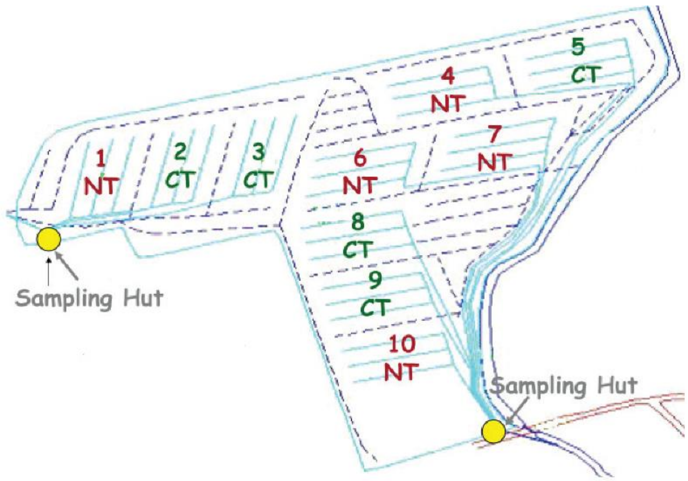

Figure1. Experimental field plot layout (CT: Conventional tillage, ZT: zero tillage)

Table 1. DRAINMOD input parameters

Parameters	Values
Drainage System	
Drain depth (cm)	80
Drain spacing (cm)	1200
Effective radius of drain (cm)	5
Actual distance to impermeable layer (cm)	100
Drainage coefficient (cm d^{-1})	2
Maximum surface storage (cm)	0.5
Kirkham's depth for flow to drains (cm)	0.5
Lateral saturated hydraulic conductivity of 4 layers (cm h^{-1})	11, 4.75, 5.3, 2.2
Soil Temperature	
Thermal conductivity function coefficient (W $m^{-1o}C^{-1}$)	a=0.55, b=1.96
Phase lag for daily air temperature sine wave (h)	9
Rain/snow dividing temperature (°C)	-2
Snowmelt base temperature (°C)	-3
Snowmelt coefficient (mm °C d^{-1})	2
Critical ice content (cm^3 cm^3)	0.2
ET monthly factors	
Jun.= 1.1, Feb.= 1.15, Mar.= 1.1, Apr.= 1.1, May= 1.1, June= 0.9, July = 0.4, Agu.= 0.5, Sep.= 0.7, Oct.= 0.7, Nov.= 0.9, Dec.= 1.1	

The liquid dairy manure application rate was based on the crop N requirement and on the assumption of 50% N availability from the manure applied during the current years (Tortora et al. 2007), in addition to soil nutrient status and any nutrient credits from previous manure applications. Then 40 and 25 ton/ha liquid dairy manure for wheat and soybean were used, respectively. Liquid dairy manure samples were collected each year from the manure storage pit prior to application and analyzed for nutrient content by the Nova Scotia Department of Agriculture and Fisheries Laboratory, Truro, Nova Scotia.

Data Measurements

Water samples were collected from the drainage water discharging into the tipping buckets in capped 50 mL centrifuge tubes for NO3--N. From Jun 2003 to July 2003, the nutrient was gathered manually. From August 2003 onwards, sampling data was gathered using Isco model 6700 auto samplers (Isco, Lincoln, NE). The frequency of sample collection was based on the duration of each flow event following the storm. Water samples were stored at 4oC until analyses were performed.

Shallow groundwater samples were collected every two weeks or one day after a significant rainfall event (greater than 13 mm), whichever occurred first. All samples were transported in coolers the same day they were collected and stored at 4°C until analyzed, usually within a week.

Model Inputs

DRAINMOD inputs include climate data (daily max/min temperature and hourly precipitation), soil properties, drainage volume-water table depth relationship, upward flux, infiltration parameters, crop parameters, and drainage system parameters (Skaggs 1980, Workman and Skaggs 1994). The drainage volume, upward flux and infiltration parameters were calculated by an internal DRINMOD subroutine, which used the soil water properties of each layer of the soil to produce values of volume drained for water table positions ranging from the surface to the bottom of the soil profile (Skaggs 1980). Climate data includes hourly rainfall and daily max/min temperature that were collected at the Truro station and used in the DRAINMOD model. Potential evapotranspiration was calculated during simulation using the Thornthwaite equation.

Model Calibration

The objective of the calibration process was to minimize the difference between measured and simulated data. DRAINMOD-N II was manually calibrated using monthly drainage outflow and nitrate concentration of 2003-2004, while the monthly drainage outflow and nitrate outflow data in 2005-2006 were used for model validation.

The simulated monthly drainage outflow and nitrate concentration outflows were compared with the observed data for both model calibration and validation. Monthly observed and simulated drain outflow and concentration were compared using statistical parameters including: average absolute deviation (AAD), relative root mean square error (RMER), coefficient of determination (R^2).

The AAD value shows the overall magnitude of deviation of simulated values from observed ones as given by Janssen and Heuberger (1995):

$$AAD = \frac{\sum_{i=1}^{n} |O_i - P_i|}{n} \tag{1}$$

where Oi is the i_{th} observed values, P_i is the i_{th} predict value, for a total number of events "n".

The Relative root mean square error is suggested by El-Sadek et al. (2001).

$$RRMSE = \frac{\sqrt{\sum_{i=1}^{n} (O_i - P_i)^2}}{O_{avg}} \tag{2}$$

Where O_{avg} is the mean observed value.

R^2 is also used to compare observed and predicted values (El-Sadek et al. 2001, Fernandez et al. 2006) and it is expressed as:

$$R^2 = \frac{\left(\sum_{i=1}^{n} (O_i - O_{avg})(P_i - P_{avg}) \right)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2 \sum_{i=1}^{n} (P_i - P_{avg})^2} \tag{3}$$

Where P_{avg} is the mean predicted value.

Results and discussion

Hydrology

DRAINMOD was manually calibrated by comparing observed and simulated drainage outflows. During the calibration process, and in order to obtain the optimal agreement between the predicted and observed system variables, the model input parameters were changed. Calibration parameters were selected based on previously cited literature and adjusted on a trial-and-error basis using daily and monthly drain flow.

The calibration parameters consisted of soil hydraulic parameters (saturated hydraulic conductivity, lateral saturated hydraulic conductivity (cm h-1) and factor α (cm-1)), monthly ET adjustment factors, drainage coefficient, and maximum surface storage (He et al. 2002, Singh et al. 2006, Wang et al. 2006).

Simulated and observed subsurface flows for monthly hydrographs during the calibration period (2002-2003) are shown in Figure 2. As shown in this figure, DRAINMOD simulations are closely matched with observed monthly drain outflow. The statistical indices calculated from the simulated and observed monthly outflow for the calibration period were 0.71 mm, 1.08 mm and 0.92 for AAD, RRMSE and R^2, respectively. The statistic values showed a good agreement between observed and simulated monthly drain outflows.

Monthly drain outflow data of 2005-2006 were used to validate the DRAINMOD model hydrology. To validate the calibrated model, the monthly predicted and observed drain outflow during the period of 2005-2006 were compared (Figure 3). The overall RRMSE in the predicted monthly drain outflow was 1.09 mm and the monthly values of R^2 and AAD were 0.83 and 1.85 mm, respectively, showing a close agreement between predicted and observed drain outflows during the validation years.

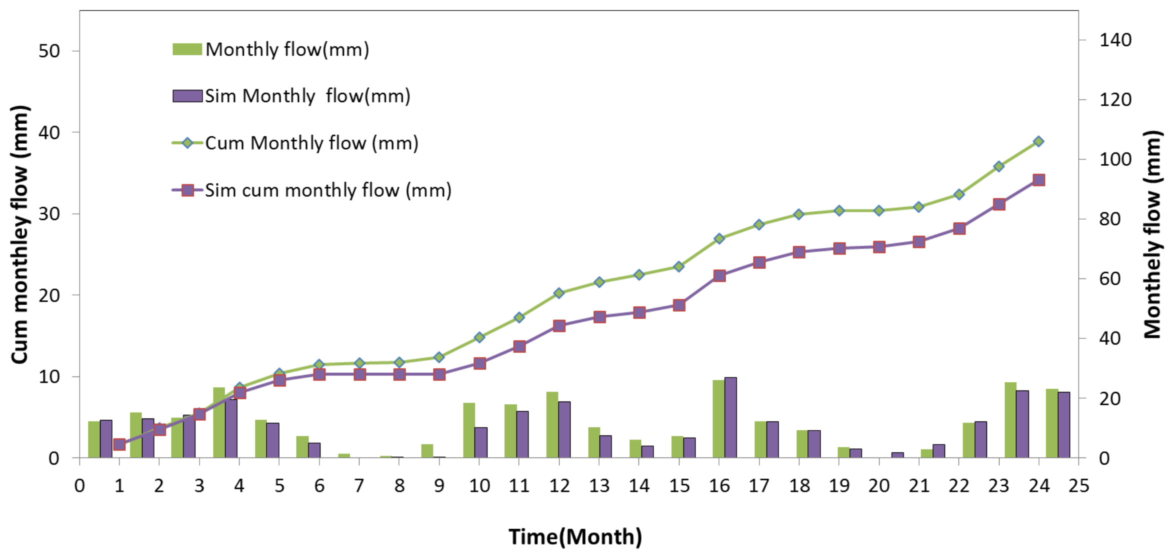

Figure 2. Simulated vs. observed daily drain outflow for calibration years (2003-2004)

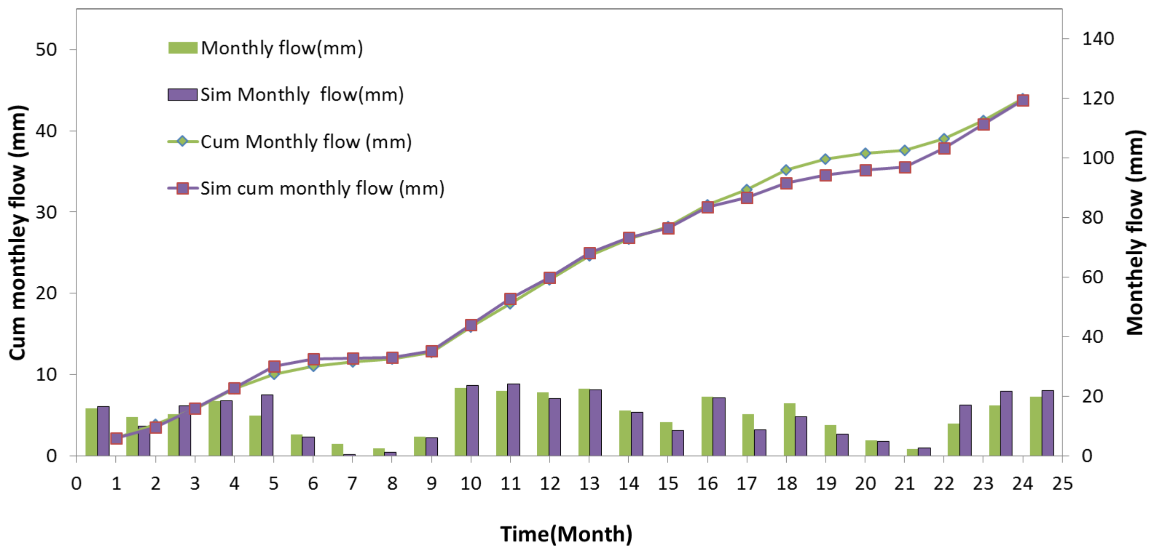

Figure 3. Simulated vs. observed daily drain outflow for validation years (2005-2006)

Nitrate

Several Nitrogen-related parameters are required for the DRAINMOD-N II simulation including crop management, N transport and transformation, and organic matter parameters. After calibrating the hydrological portion of the model, the nitrogen component was calibrated. The calibration process consisted of a trial and error testing of input values that resulted in the best agreement between simulated and observed monthly nitrate losses from the tile systems in the field. The range of parameters tested was taken from values found in the literature (Breve et al. 1997, Breve et al. 1997) and are summarized in tables 2, 3 and 4.

The DRAINMOD-N II was calibrated using the field measurements monthly drainage nitrate concentration taken during the study period. The Calibrated parameters and their ranges were selected based on a previously conducted calibration for DRAINMOD-N II (R.W. Skaggs, M.A. Youssef, G.M. Chescheir, DRAINMOD: model use, calibration and validation Trans. ASABE. Am. Soc. Agric. Biol. Eng., 55 (4) (2012), pp. 1509–1522 ISSN 2151-0032)). In order to measure the efficiency of the calibration, statistical measures were calculated using the calibration result data versus observed data. The RMSE and AAD value of the monthly NO3-N losses for the years f 2003 and 2004 were 1.42 and 0.46 mm, respectively, and R^2 for this period was 0.92. The low values of RMSE and AAD and high R^2 for all the calibration cases indicate a good fit between the simulation results and field observations.

Table 2. Initial transport parameters and NH4+ distribution coefficient used in DRAINMOD-N II.

Input parameter	Value
Longitude dispersivity (cm)	5
Tortuosity	0.5
Tolerance	10−4
Minimum time step (day)	0.001
Concentration in rainfall (mg l^{-1})	
NO_3–N	0.45
NH_4–N	0.55
NH_3–N concentration in air (mg l^{-1})	0
NO_3–N initial concentration in soil (mg l^{-1})	
0–100 cm	8
NH_4–N initial concentration in soil (mg l^{-1})	
0–100 cm	0

Table 3. Initial transformation parameters used in DRAINMOD–N II.

Input parameter	Nitrification	De-nitrification
Michaelis–Menten parameters		
Vmax (µg N g^{-1} soil day^{-1})	30	2
Km	10	40
Optimum temperature (°C)	20	35
Threshold water-filled pore space	–	0.77
Optimum water-filled pore space range	0.5–0.6	–

Table 4. Initial organic matter parameters used in DRAINMOD–N II.

Input parameter	Kdec (day^{-1})	C/N ratio (day^{-1})
Litter pool		
Surface structural	1.06849×10^{-2}	150
Surface metabolic	4.05479×10^{-2}	15
Surface microbes	1.64384×10^{-2}	8
Below-ground structural	1.34247×10^{-2}	150
Below-ground metabolic	5.06849×10^{-2}	15
SOM pools		
Active	$2.0000 \times 10_{-2}$	15
Slow	$5.4795 \times 10_{-4}$	20
Passive	$1.2329 \times 10_{-5}$	10

According to figure 4, the monthly simulated NO3–N losses portray a good agreement with the field measurements. The results show that NO3–N losses were strongly dependent on outflow rates following the typical behavior. As shown in figure 4, the accumulated model results tend to be slightly higher than field observations during wheat season. During soybean season, the highest monthly NO3–N drainage losses occurred during November and December.

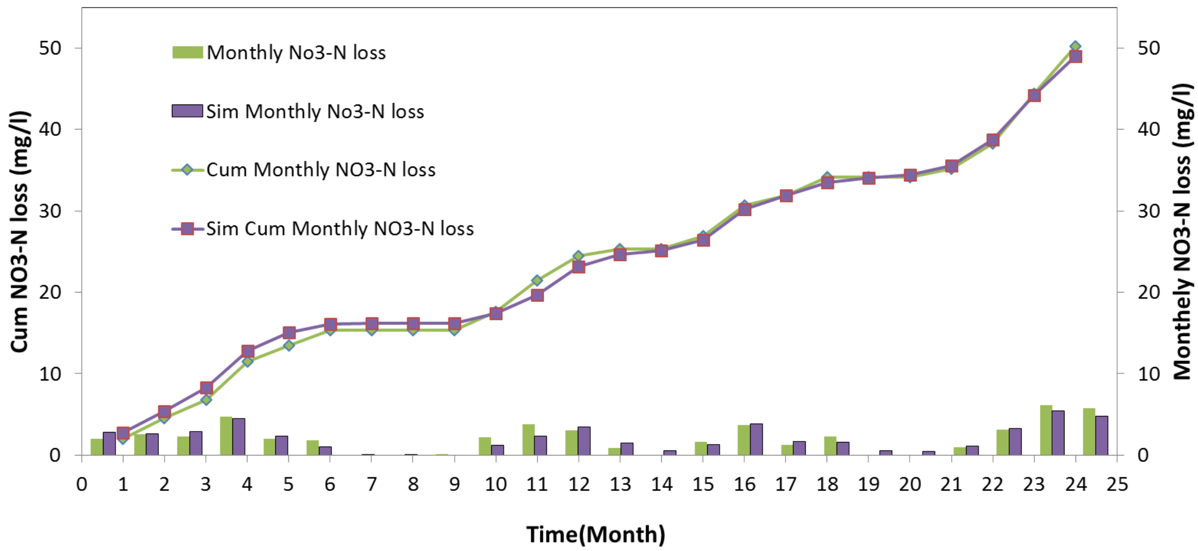

Figure 4. Observed and simulated monthly and cumulative NO3–N losses in subsurface drains for calibration period (2003-2004)

DRAINMOD-N II model was validated using the data obtained from the experimental years of 2005-2006 for this plot. According to figure 5, the results visually show a good agreement between the field measurements and the simulated results for monthly and cumulative NO3-N loss. The statistical analyses for NO3-N concentration in both years was reliable. The RRMSE, AAD, R^2 value of the monthly NO3-N losses for years 2005 and 2006 were 1.43 mm, 0.51 mm and 0.79, respectively. High R^2 values and low RRMSE and AAD showed that DRAINMOD-N II could be used successfully in simulating nitrogen-N concentration in a no-till area. Low RRMSE values indicated that the differences between the observed and simulated nitrate-N concentrations in no-till field was found to be small in both years. According to figure 5, the monthly DRANMOD-N II model results tended to be higher than field observations during wheat season and lower during the soybean season.

The results of this study demonstrated the potential of DRAINMOD-N II for simulating N dynamics in no-till fields. However, more rigorous testing of the model should be conducted before its extensive use.

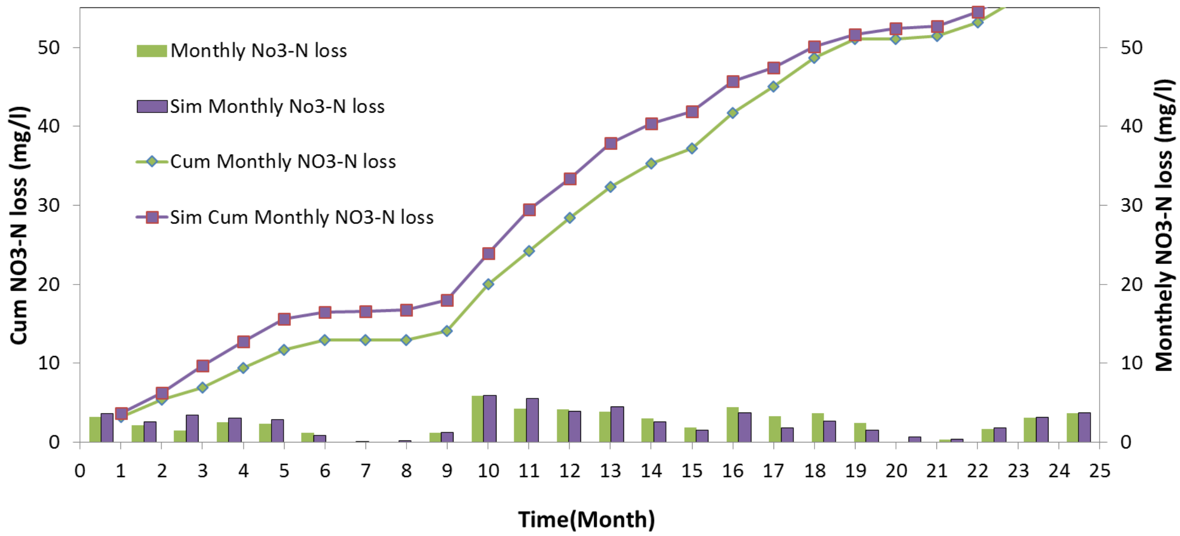

Figure 5. Observed and simulated monthly and cumulative NO3–N losses in subsurface drains for validation period (2005-2006)

Conclusion

The nitrogen simulation model, DRAINMOD-N II, was field-tested using four years of data from an experimental no-till field located in Truro, Nova Scotia, Canada, from 2003-2006. The test site was a no-till field with artificially drained agriculture and very poorly drained soil under natural conditions. In this study, the field was planted on the basis of awheat-soybean rotation and managed using free drainage, . DRAINMOD-N II model was successfully tuned up during calibration using data sets for cultivation periods between 2003 and 2004. Subsequently, the verification of the model shows a good agreement between the observed and simulated data. The statistical goodness-of-fit measures represented by the average absolute deviation (AAD), relative root mean square error (RMER), coefficient of determination (R^2) for the DRAINMOD-N II verify the good match between the model results and field observations. The consequences of this study demonstrate the capability of the DRAINMOD-N II to simulate drainage rate and nitrogen losses from no-till fields.

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IMPACT OF DRAINAGE EFFLUENTS ON GROUNDWATER QUALITY-A CASE STUDY FROM LAHORE PAKISTAN

Ghulam Zakir Hassan[1,*], Faiz Raza Hassan[2], Saleem Akhtar[3]

Abstract:

In Pakistan, approximately 80% the population in large cities do not have access to clean water. Lahore the provincial capital is the second largest populated city of Pakistan with an estimated population of 10 million people and an area of 1014 km^2. It is located on the alluvial plain of the Indus Basin on the left bank of the Ravi River. The Water and Sanitation Agency (WASA) is pumping groundwater at a rate of 1400 MCM per annum to meet the domestic needs of the city. Different drains are discharging domestic, industrial and agricultural effluents in the River and polluted water of the River is leached to underground reservoirs. To evaluate the impact of this pollution on underlying groundwater, an experimental setup has been developed in 2010 along the River. Fifty piezometers in the shape of three batteries perpendicular to the River, one just on the River edge, the 2nd at a distance of 500 ft. and the 3rd at a distance of about 1500 ft from the River bank have been installed on both sides of the River at three sites, covering a length of about 60 km of the River. Each battery consists of three piezometers at 50ft, 100ft and 150ft depth below ground level. The four dimensional (along the river, across the river, vertically downward and with respect to time) trends of groundwater levels and quality are being monitored and evaluated. The analysis of data observed so far indicates that groundwater quality is deteriorating with the passage of time especially at the Shahdra Bridge site (near Lahore). It has been further observed that pollution in the River Ravi is contributing to the deterioration of groundwater quality. Fluctuation of groundwater levels measured using a river gauge indicates that the River is hydraulically connected with the aquifer and is recharging it. Groundwater levels in the aquifer of Lahore are falling at an average rate of 2.5 ft. per year mainly due to excessive pumpage and less recharge due to urbanization. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near the city and improves at the depth below the natural surface. Sub-soil strata at most of the sites are generally sandy except a thin layer of clay/silt in the upper layer at 50 ft. The slope of groundwater seepage line at Shahdra on the left side of the River is steeper as compared to the right side due to excessive pumpage of groundwater in the city area. Keeping in view the current situation some possible measures for the management of groundwater have been recommended in the current study.

KEY WORDS: Groundwater, Piezometers, Effluents, Ravi River, Artificial recharge, Lahore.

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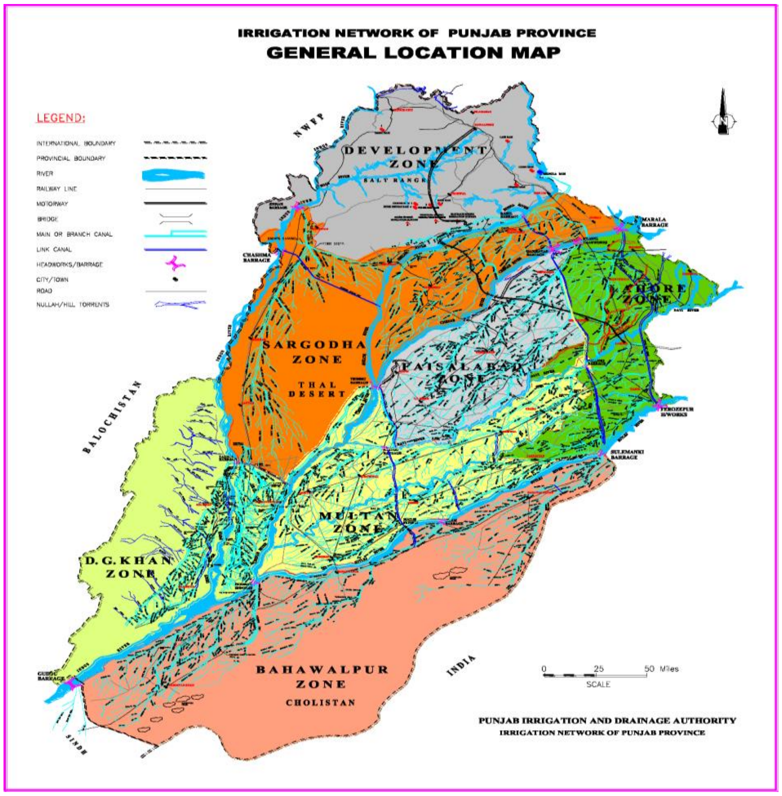
Introduction

Background of Irrigation and Drainage Network

Pakistan is bestowed with a largest contiguous irrigation canal network, major part of which lies in Punjab Province. This network (Figure 1) was started to be constructed by British during early nineteen century. The continuous expansion of the irrigation system over the past century significantly altered the hydrological balance of the Indus River Basin (IRB) in Pakistan (Hassan and Bhutta, 1996).



Headworks/Barrages	13
Main Canals	24
Length of Main Canals and Branches	3993 Miles
Length of Distributaries and Minors	19191 Miles
Length of Inter River Link Canals	528 Miles
Off-take capacity of Main Canals	1.2 Lac Cs
Off-take Capacity of Link Canals	1.1 Lac Cs
Total Outlets	58000
GCA	23.35 m.a
CCA	20.78 m.a

Figure1: Irrigation network in the Punjab province

Table 1: Salient features of SCARPs

Province	Project area in M. Acres	Surface Drains in Km.	Tile Drain Km
Punjab	9.141	2956	800
Sindh	5.306	7187	976
NWFP	0.603	773	5781
Baluchistan	0.177	322	-

This situation created the need of drainage of agricultural lands in the country. Although some drainage was installed before World War II, little attention was paid to the growing waterlogging and salinity problems. To alleviate the twin menace of waterlogging and salinity, Water and Power Development Authority (WAPDA) was established in 1958 and Salinity Control and Reclamation Program
was conceived, planned and implemented by adopting surface as well as subsurface drainage projects in the country. First Salinity Control and Reclamation Project (SCARP-I) was implemented in 1960-63. Almost 61 such projects have been completed and salient features of SCARPs (Table 1).
In addition WAPDA also replaced 1472 tubewells and developed about 5363 private tubewells for groundwater development in Punjab. Parallel to subsurface drainage program a large network of surface drain of about 10,000 Km has led in the province to carryout surface and surface effluents. Surface drainage network of Punjab (Figure 2).

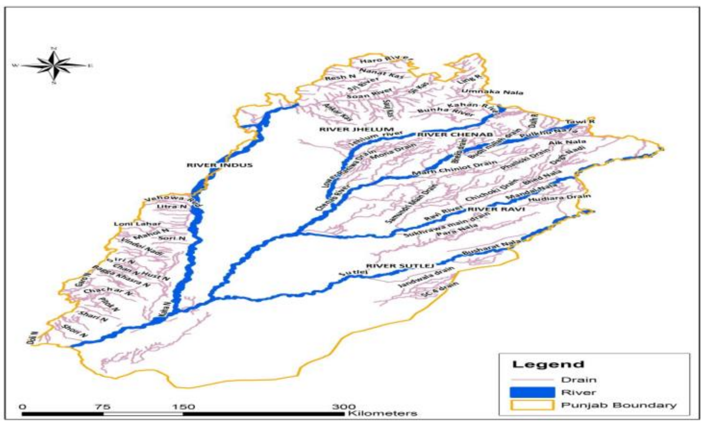


Figure 2: Drainage Network of Punjab

Table 2: Drainage Network of Punjab

Sr. No.	Name of Irrigation Zone	Number of Drains	Total Length of Drains (Km)
1	Lahore	277	2108
2	Faisalabad	222	2420
3	Multan	44	1351
4	Sargodha	383	3087
5	DG Khan	61	677
6	Bahalwalpur	20	340

Keeping in view the importance of irrigation and drainage projects in Pakistan, Asian Development Bank (ADB) in 2004 has classified these projects under the subsector agricultural and natural resources under their sector and thematic classification system which were previously clustered with rural development projects (ADB, 2008).
When this system of canal irrigation was put in operation, the problems of waterlogging become the major challenge which led to the parallel system of drainage network. During pre-irrigation era, watertable in different doabs (the land between two rivers) in Punjab province (Figure 3) was very deep at about 160 m (Ahmed. N, 1995). Seepage from the irrigation system and percolation from irrigated fields caused the watertable to rise continuously, reaching critical conditions for a substantial area especially in the Punjab province. This led to the dual menace of waterlogging and salinity and crops were seriously affected over a wide area.

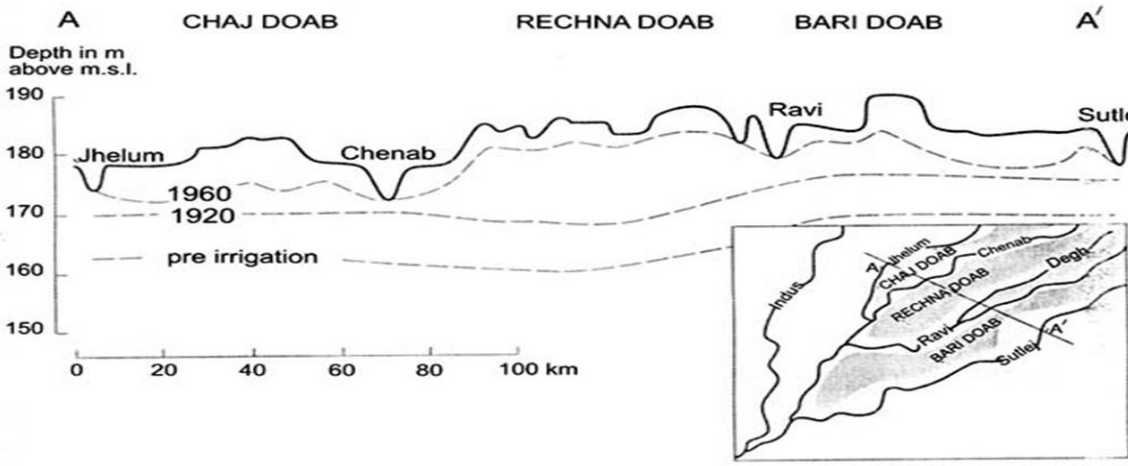


Figure 3: Groundwater table rise in Punjab along section AA/ (Ahmed N. 1995))

Issues of Drainage in Rural Areas

Increasing demands of food and fiber resulted in extensive use of fertilizers, insecticides, herbicides and other chemicals which ultimately wither leach down directly to groundwater or flow into surface drains. These agricultural runoff carry out salts and other hazardous materials to the drainage network where a major part is leached down to the groundwater. Area Treated with Pesticides (Figure 4). The 2nd largest issue of groundwater is its continuously deteriorating quality which is of more concern as it deals directly with human health.

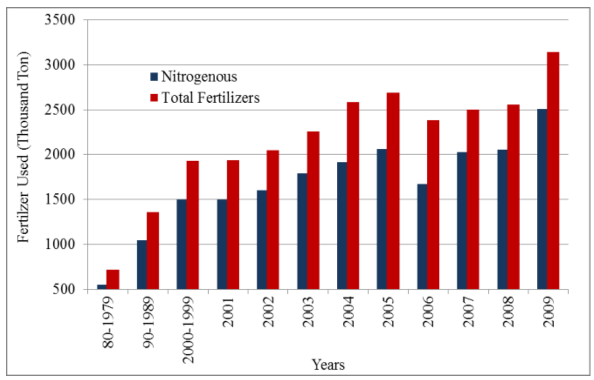


Figure 4: Area Treated with Pesticides

Sources of groundwater pollution normally are manmade intervention on earth surface and in certain cases the salts in bed rocks. Most of the pollutants effluents like industrial, agricultural, municipal etc. are in liquid forms which leach down to groundwater. Some other are in solid form like solid waste heaps through which pollutant leach down to subsurface soil and then to groundwater. Some pollutants are in gaseous form like vehicular and industrial emissions, which return back to soil surface in drains via acidic rains and percolate down to groundwater through unsaturated zone. Use of Fertilizers in Punjab (Figure 5).

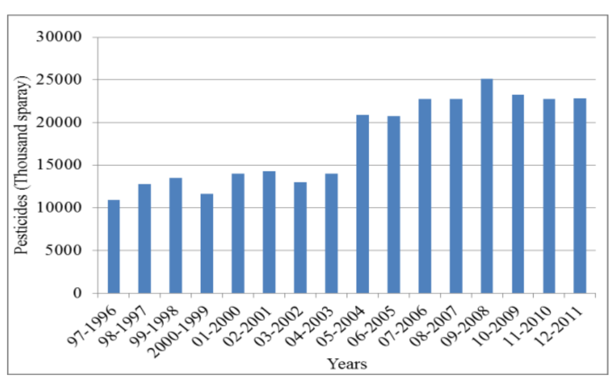


Figure 5: Use of Fertilizers in Punjab

Industrial effluents supplement the pollution load in these drains as most of the industries are throwing their waste waters into drains or even in some cases to canals directly without any treatment as two examples of industrial effluents (Figure 6).

Figure 6: Un-treated industrial Effluents

(IRI, 2009) and (IRI, 2013) conducted a field survey and investigation study by installation of sixty exploratory boreholes in the field at various critical sites in Punjab to explorer the groundwater quality and soil stratification to observe the impact of surface drains and other potential threats for groundwater. Wherein it was observed that surface water bodies especially drains are playing a vital role in contamination of groundwater. (IRI, 2012) conducted a groundwater investigation study in Faisalabad area using MODFLOW (flow and solute transport) where tile drainage and surface drainage networks are functional and groundwater is brackish for which one of the causes is heavy industrial pollution in the area. Well-field for supply of drinking water to Faisalabad city was proposed accordingly near the River away from the area of influence of industrial drainage network.

In 1959 a salinity control and reclamation project (SCARP) was started in a limited area, based on public tube wells, to draw down the watertable and leach out accumulated salts near the surface, using groundwater for irrigation. Different projects were executed to install various types of drains like surface drains, subsurface drains/tiles drains, vertical drainage (tubewells) to mitigate the hazards of waterlogging and salinity. By the early 1980s, some thirty such projects were started to control the menace of waterlogging and salinity in the country. By 1993 the government had installed around 15,000 tube wells. Private farmers, however, had installed over 200,000 mostly small tube wells, mainly for irrigation purposes but also to lower the watertable.

Issues of Drainage in Urban Areas

In urban localities, inefficient sewerage system and lack of waste water treatment plants has resulted the discharge of waste water directly into drainage system/surface water bodies. Unfortunately, this drainage system articulates with the rivers-canal system and consequently becoming the main source of surface and ground water pollution. The consequences of shrinking good quality irrigation water resources have forced the farmers to use drainage water for irrigation. As such use of drainage water is augmenting environmental and health implications in addition to groundwater and surface water pollution (Hamid et al., 2013). More than 200 million people in the world are using different forms of wastewater (treated, partially treated, untreated) for irrigation purposes (Raschid-Sally and Jayakody, 2009). According to another estimate, 10% of the total world's food production is based on wastewater irrigation (Corcoran, 2010). A survey conducted

by International Water Management Institute (IWMI) revealed that in Pakistan 32,500 hectares of land are directly irrigated with wastewater i.e. 26% of crops especially vegetables are being produced from wastewater (Baig et al., 2011).
The mobilization of heavy metals in soil through ground water and surface water is known to have potential toxic impact on environmental quality and human health as well (Iqbal et al, 2016). Moreover, the presence of heavy metals in soil and water beyond the permissible limits may render soil non- productive and may cause bio-accumulation of heavy metals in human beings (Singh et al., 2006). It may lead to a significant accumulation of heavy metals, thus influencing the food quality and safety through their ultimate entry in the food chain via plants and aquatic life (Muchuweti et al. 2006). Groundwater quality in the aquifer is deteriorating with the passage of time and sweet water is becoming rare and out of reach of the common farmers who are dependent on groundwater for their livelihood. (Hassan et al, 2014).

Material and methods

Description of Study Area

Lahore city, is the capital of Punjab province, has a population of about 7.2 million and plays an important role in the country's economy being hub of industrial activities. Major source of water supply in Lahore for domestic as well industrial uses is groundwater. Due to tremendous urbanization and industrialization in the city, pressure on groundwater has increased manifolds. The city is situated on the bank of Ravi River. Flows in the river have decreased continuously since 1960. A number of drains carrying domestic and industrial effluents are entering into the river. A reach of about 60 km of the river has been selected to investigate the impact of various effluents in drains and river on groundwater. Map of study area (Figure 7).

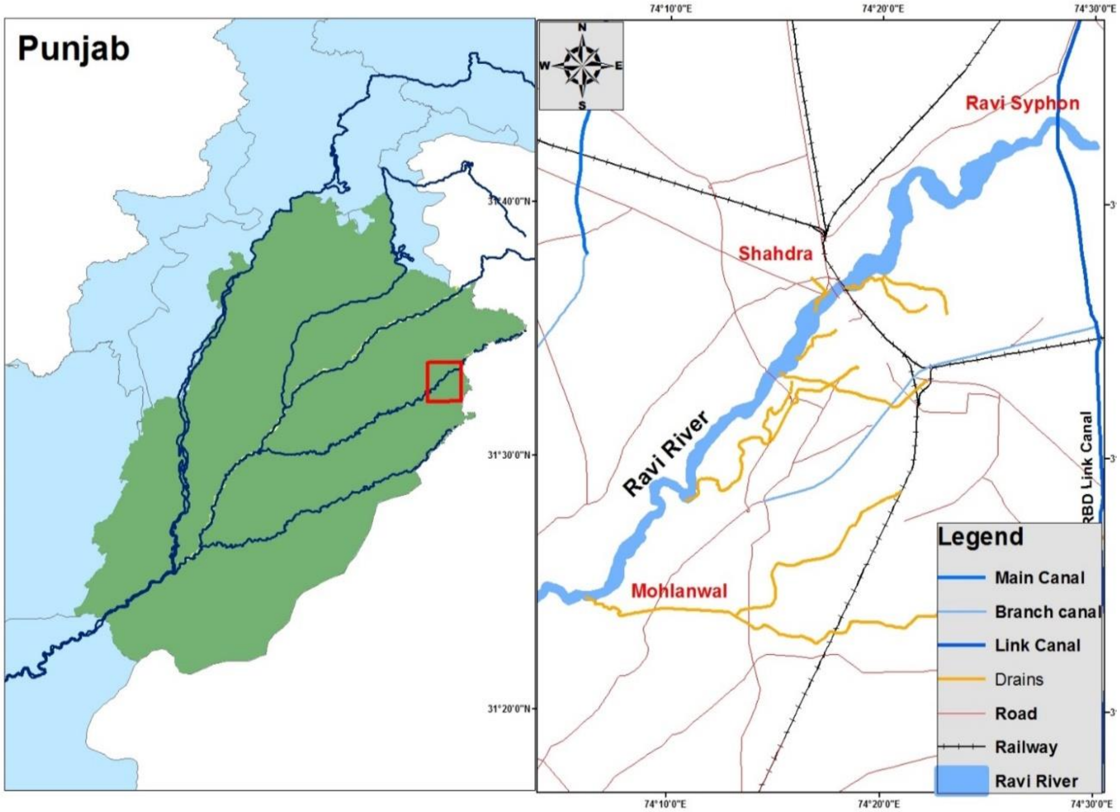


Figure 7: Map of study area

Population growth has a direct impact on depletion of groundwater resources. Abstraction of groundwater increases as population grows and over-exploitation of aquifer results in decline of groundwater levels. Temporal trends of depth to watertable and population growth in Lahore (Figure 8). Major consumers of groundwater in Lahore (Figure 9).

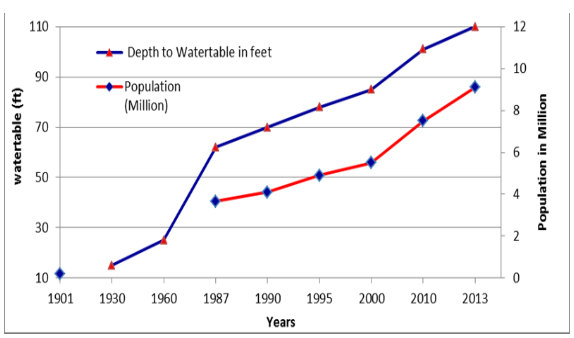


Figure 8: Trends of Population and Watertable Depth in Lahore

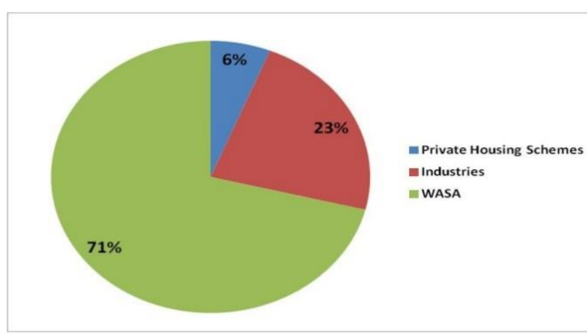


Figure 9: Major Groundwater Consumers in Lahore

An important aspect of the research study is to develop a link between quality of surface water bodies (Ravi River & drains) and its impacts on groundwater quality in the underlying aquifer. Ravi River has been polluted and is being polluted due to indiscriminate discharge of untreated municipal waste water and industrial effluent into it. Historic Ravi River discharge at Shahdra Bridge (Figure 10) and waste water effluents being thrown in the River (Figure 11).

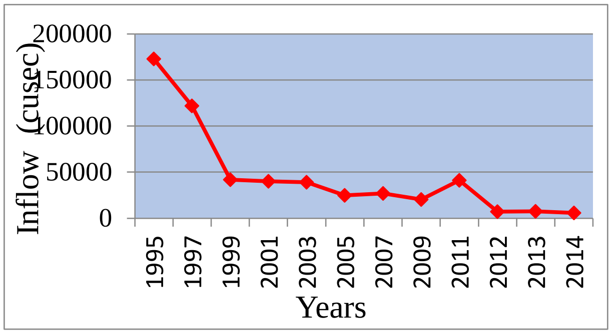


Figure 10: Discharge reduction in Ravi River

Figure 11: Waste water effluents in the Ravi River

Low flows in Ravi River have resulted in lowering in groundwater level in Lahore and it adjoining area. On one side recharge to the aquifer has decreased tremendously and on the other side the ecosystem in the river has suffered badly and river has become a "sludge carrier". (Hassan et al, 2013) during a study found that pollution in surface water bodies is affecting the groundwater quality in the underlying aquifer in Lahore city. They recommended to allow/arrange minimum flow in the River at least to meet the requirements of dilution of pollutants and to treat the wastewater before throwing it into the river.

Water and sanitation agency (WASA), Lahore has installed 480 tubewells of different capacities at a depth of ranging from 150 to 200 m for supplying water to the citizens of Lahore which are extracting about 1170 cusec of groundwater per day for drinking purpose. In addition to WASA tubewells, a large number of private tubewells installed in housing schemes are roughly pumping

100 cusec water daily. Water is also being pumped by industries at the rate of approximately 375 cusec (Hussain & Sultan, 2013). In this way total extraction of groundwater in Lahore becomes 1645 cusecs. Over exploitation of groundwater causes many serious environmental concerns like salt water intrusion, increase in pumping cost, increase in installation cost of tubewells, land subsidence, land sliding, development of sinkholes etc.

Urban population in the Lahore is increasing at an alarming rate of 4% per year which is leading towards a continuous increase in domestic sewage. This sewage coupled with street runoff is a severe threat to groundwater as a part of it ultimately leaches down to groundwater. It was estimated that discharge of waste water of Lahore city into Ravi River was about 990 cusecs in year 2006 (Saeed and Bahzad, 2006) and now has crossed to 3,304 cusecs through drains and various pumping stations (Figure 12) without proper treatment (Hussain & Sultan, 2013).

A survey of drains entering into the River has been carried out which has revealed that six (06) main drains are entering into the River which are throwing about 3304 cfs of wastewater in the River.

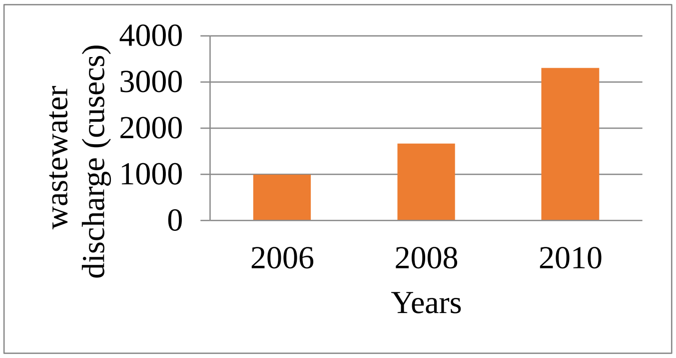


Figure 12: Effluents being thrown into the Ravi River

Monitoring Network and Survey

Three sites along Ravi River namely Ravi Syphon, Shahdra Bridge and Mohlanwal has been selected for installation of piezometers keeping in view the different factors including but not limited to distance from the River, availability of bench mark, safety of the piezometers, site approach, willingness of farmers and protection of piezometers from rainfall and irrigation water etc. Fifty piezometers along the River on both sides in the shape of triangular battery of three piezometers (9 on each side of the River at) at three selected locations were installed. In each battery, three piezometers were installed up to a depth of 150, 100 and 50 ft. respectively. Schematic layout of the piezometers installed three at sites (Figure 13). Three batteries of piezometers perpendicular to the River have been installed on one side of the River at all three sites. First battery has been installed on the edge of river bank, 2nd battery at a distance of about 500 ft. away from the river edge and 3rd battery at a distance of about 1000 to 1500 ft. from the River edge. A complete network of piezometers has been installed to monitor the 4th dimensional trend of changes in groundwater levels and quality, which are along the river, away from the river, below the natural surface level (NSL), and with respect to time. Monitoring network along the River has been laid on permanent basis which is to be used for long-term observation of changes in groundwater levels and quality and impact of pollution in River on groundwater.

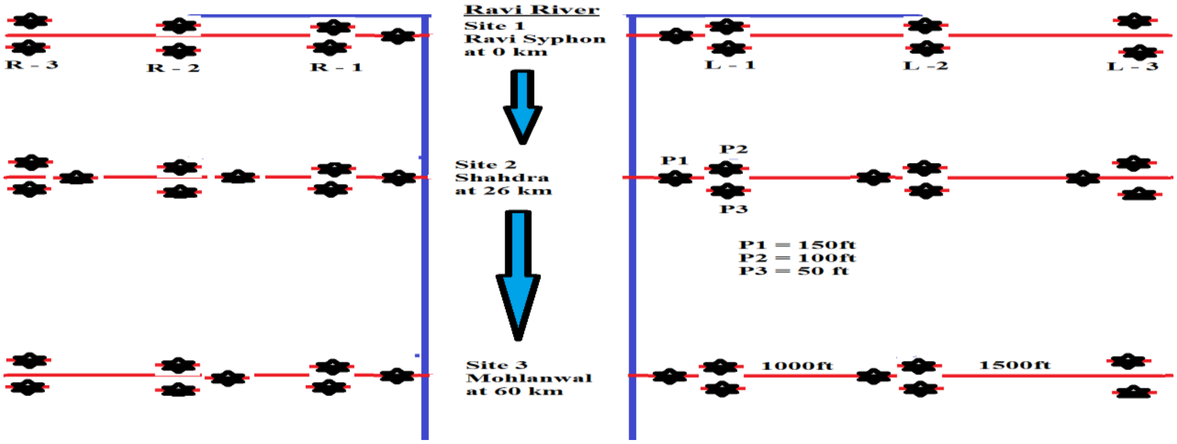


Figure 13: Layout of Ravi River Showing Locations of Piezometers

As mentioned already, Lahore has become hub of industrial activities in the country. A large number of industries are discharging wastewater into sewerage system and surface drains without treatment. Domestic and industrial effluents contain organic and inorganic pollutants, which deeply percolate to groundwater. Flow in Ravi River especially during the winter is remarkably insufficient to dilute and wash off wastewater pollution (Hassan et al, 2016). The environmental profile of Pakistan indicates that about 40% of deaths are related to waterborne diseases spread by water pollution, mainly due to the sewage and industrial wastewater contamination to drinking water distribution systems. Map of major drains entering into the Ravi River and schematic layout these drains are shown in Figures 14 and 15 respectively.

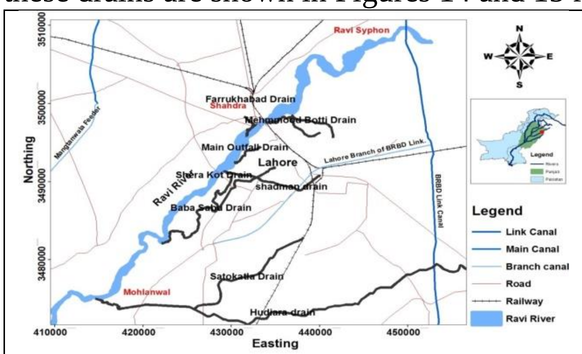


Figure 14: Map of Major Drains entering the Ravi River

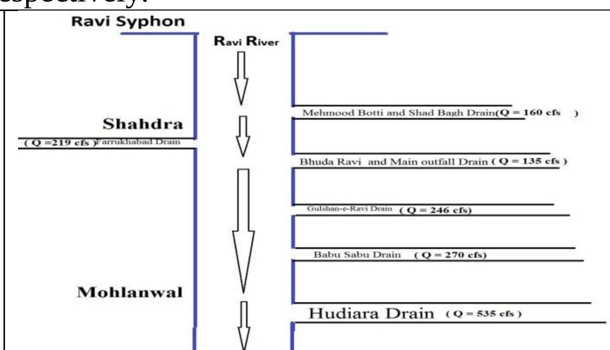


Figure 15: Schematic Layout of Major Drains entering into the Ravi River.

Results and Discussions

Major target of the study is to monitor and evaluate the impact of pollution in Ravi River due to surface drains on groundwater in the underlying aquifer. For this purpose a network of piezometers was installed along the River. Samples of water from following different sources have been collected and analyzed to arrive at conclusions.

i) Wastewater (drains entering the rivers)
ii) Groundwater at different depths/locations (from piezometers)
iii) Surface water (River water)

Waste Water Quality (Drains)

Water samples from these drains were collected and analyzed. Effluents of these drains are deteriorating the quality of groundwater along the River. The water quality determined from the drain samples (Table 2). More value of EC (2440 µs) from Farrukhabad Drain has been observed during 2012 that is adding polluted load into the River. The results represented indicate that pollution load in drains are increasing with the passage of time and enhancing pollution in the river and groundwater. A network of surface drains in Lahore city carries wastewater from various sources and ultimately enters the Ravi River. These are earthen channels which cause the leaching of various pollutants directly to groundwater. (Hassan et al, 2013).

Municipal Solid Waste (MSW) consists of household waste, commercial waste and institutional waste. Unscientific dumping of solid waste always poses serious environmental problems on groundwater. Leachate produced at landfill contains thousands of complex components and it becomes part of groundwater after infiltration. Lahore city, three sites have selected for dumping of solid waste. Groundwater is suspected to be contaminated due to unscientific, unsafe, unplanned and traditional selection of these sites. At least three-quarters of the total waste generated (3800 tons/day) in Lahore is dumped at these sites without proper treatment. According to a previous study, it was found that most of groundwater samples collected from nearby these landfill sites contain pollutants and their concentration level in groundwater is higher than prescribed by Pakistan Standards and Quality Control Authority (PSQCA) and concentration of Arsenic in drinking water is higher than WHO criteria (Akhtar & Zhonghua, 2013). It was reported in the Daily newspaper (20 May, 2008),that according to United Nations Environmental Program (UNEP)'s data about 47% drinking water in Lahore city was contaminated due to presence of various hazardous toxic elements (Manan, 2008).

Excessive and uncontrolled use of chemical fertilizers, pesticides and herbicides promotes contaminated agricultural run-off. This not only pollutes the surface drains but the water trickling down to lower layers of soil causes a severe contamination of the natural aquifer in surrounding areas of Lahore. Over abstraction of groundwater prompts recharge from the surface water drains, which themselves are severely contaminated. Chemical analysis of drain water samples 2016 (Table 3).

Table 3: Quality of Drainage Water entering the Ravi River

Sr. No.	Name of Drains	EC (µs) (2011)	EC (µs) (2016)	Increase in EC (%)
1	Mehmood Botti Drain	1550	1700	10
2	Farrukhabad Drain	2176	2290	5
3	Main Outfall Drain	2012	2100	4
4	Gulshan-e-Ravi Drain	1794	1850	3
5	Babu Sabu Drain	1520	1600	5
6	Hudiara Drain	2394	2460	4

Groundwater Quality

Groundwater quality at downstream from Ravi Syphon to Lahore city has deteriorated. It has been observed that the color of groundwater near Lahore city has varied from colorless to yellowish and its odor is now to objectionable with turbidity ranging from 2 to 4 NTU. Heavy metals have also been found in the groundwater samples and the concentration of lead (Pub), Nickel (Ni) and number of E. coli levels exceeded the permissible limits of drinking water quality (Ayesha, 2010). Municipal landfills are considered another sources which have a serious threat to urban environments and a great source of pollution especially groundwater (Akhtar and Zhonghua, 2014).

To develop the link between wastewater in river and groundwater in the underlying aquifer, water samples from all 50 piezometers installed along the river, away from the river and at different depth were taken through a specially designed sampler. The samples were analyzed. Electrical Conductivity (EC) of groundwater at all sites has been adopted as a parameter to compare the results. The results are graphically plotted in Figures 16-21.

Results indicate that groundwater quality at Ravi Syphon on both sides of the River at all depths (P1=50 ft., P2=100 ft. and P=150 ft.) is good and is not deteriorating with time. This indicates that groundwater quality perpendicular to the river from Left side (L_1, L_2, L3) or right side (R_1, R_2, R_3) is good and can be used as bench mark for comparison of groundwater quality.

The data analysis at Shahdra site (near the city) reveals that EC values at 50 ft. depth are more while the value at 150 ft. depth is lesser on both sides of the River which indicate groundwater improves vertically downward. Groundwater quality at 50 ft. depth at R_3P_3 and L_3P_3 is deteriorating.

At Mohlanwal site, EC values of piezometer installed at 50 ft. depth are more as compared to those at 100 ft. and 150 ft. depth on left side while lesser on right side of the river.

Results indicate that quality of groundwater at 50 ft. depth is deteriorating with the passage of time at Shahdra. Overall results of analysis of groundwater samples along Ravi River indicate that the quality of water is deteriorating, moving downstream from Ravi Syphon to Lahore.

Result of analysis indicates that groundwater quality is deteriorating more at Shahdra (as compared to that of Ravi Syphon and Mohlanwal) due to entrance of effluents through different drains into the river. The data at Shahdra site along both sides of the river indicate that quality of shallow water at depth of 50ft at R3 and L3 is deteriorating more with the passage of time.

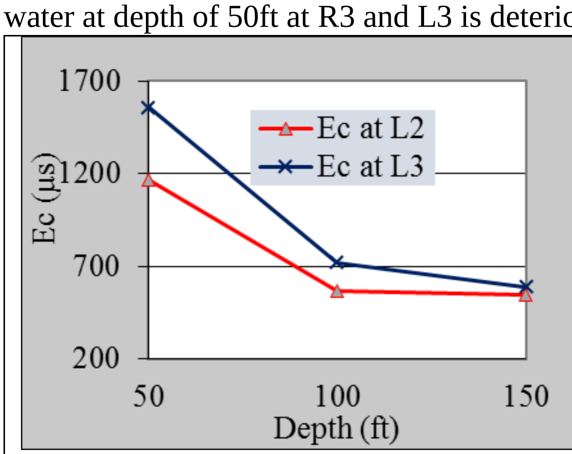


Figure 16: Ec (µs) at Shahdra site vertically downward for the year (2016)

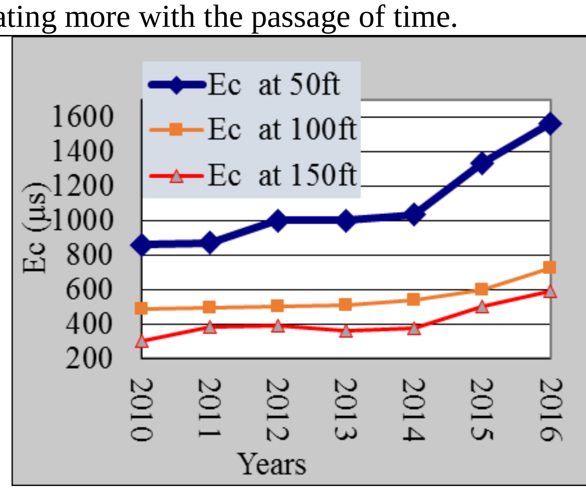


Figure 17: Ec (µs) at L3 Shahdra site w.r.t to Time

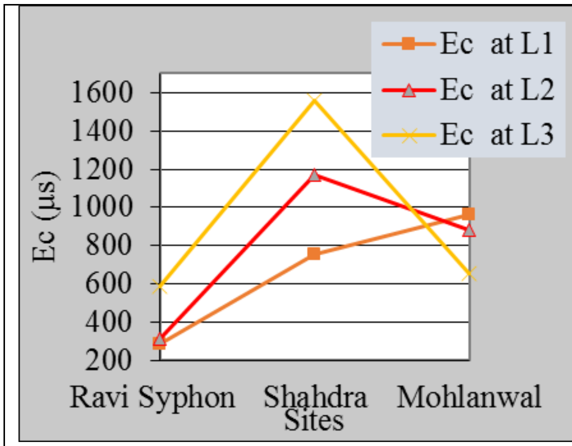


Figure 18: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

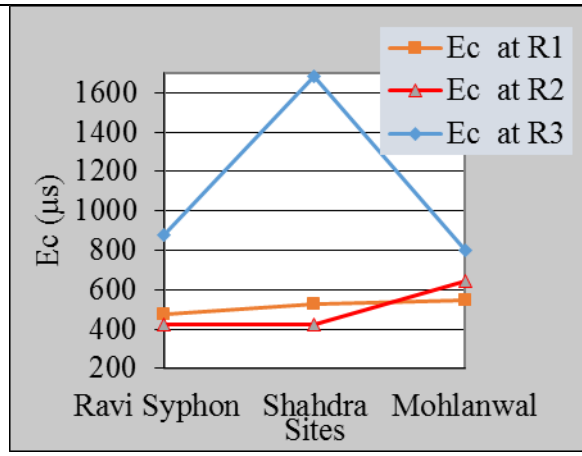


Figure 19: Ec (µs) along River from Ravi Syphon to Shahdra and to Mohlanwal at a Depth of 50 ft. for the year 2016

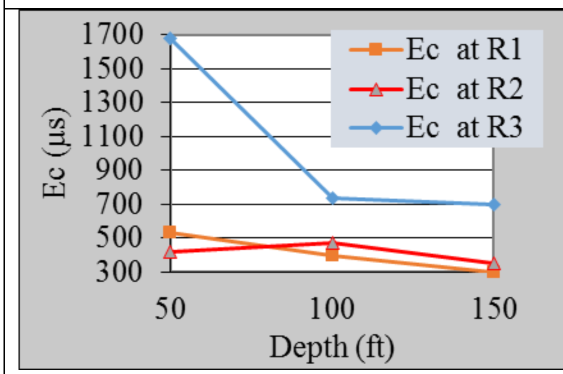


Figure 20: Ec (µs) at Shahdra site vertically 2016 downward for the year (2016)

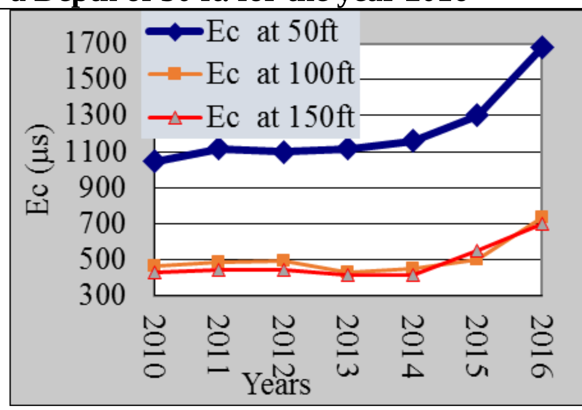


Figure 21: Ec (µs) at R3 shahdra site w.r.t to Time

Broadly speaking these all are the surface pollutants and flood waters can play a significant role in washing away and diluting these hazardous materials. Flood water contributes significantly towards recharging the aquifer and washing the pollutants. For example during flood 2014 average rise in watertable observed in Rechna doab was 2.57 ft. (IRI, 2015).

Conclusions

i. Pollution entering the Ravi River is ultimately affecting adversely the quality of underlying groundwater and the River has become a source of pollution for groundwater reservoir (due to low flows and throwing of untreated effluents in it).

ii. It is found that there is rise of about 3 -10% in EC value over a period of 5 years.

iii. Quality of drains water entering the River is deteriorating with the passage of time and consequently similar trends have been observed in River water quality

iv. Groundwater quality in the aquifer is deteriorating with the passage of time and sweet water is becoming rare and out of reach and quality improves with the depth below land surface.

v. Groundwater quality deteriorates moving downward from Ravi Syphon to Mohlanwal and is the worst near Shahdra (near the city)

vi. Ravi River is contributing towards recharging the aquifer as groundwater levels fluctuate with the river gauge.
vii. Quality of effluents in drains entering the River is deteriorating with the passage of time.
viii. There is lack of communication/coordination among different Government Departments/ agencies and the various stakeholders/consumers

Recommendations

- Production of all pollutants should be reduced or minimized at source through scientific research and tools.
- Education, awareness and motivation campaigns for all stakeholders can play a vital role
- Formulation of long term policy framework/ legal framework and comprehensive master planning to guard against fast polluting groundwater reservoir.
- Treatment of industrial and municipal effluents before throwing into the River
- Harvesting of rainfall in separation from industrial and domestic wastes
- To strengthen the monitoring network for drainage system to evaluate their impacts
- Installation of treatment/recycling plants for sewerage and industrial effluents as well as for solid waste in the city at appropriate locations.
- Artificial recharge through rainfall-runoff modeling at identified potential sites and to explore feasible sites in parks, playgrounds and other natural depressions.
- To maintain minimum flow in Ravi River for dilution of pollutants and enable it to act as source of recharge.
- Industrialists should be provided with scientific solution to recycle or treat the effluents at source instead of throwing it into nearby water body or injecting directly to groundwater which off-course is not less than a crime.
- Sever steps are required to be taken for control/mitigation of gaseous emissions.
- Regarding solid waste management we can go for use of geo-synthetic materials at landfill sites to avoid leaching of pollutants.
- Solid waste can also be used to obtain bio-energy.
- Treatment plants should be adopted to make the industrial, municipal, and agricultural waste waters useable some purposes like industries, irrigation etc.
- Farmers must be educated to use less toxic and in limited/required quantity fertilizers, pesticides, weedicides etc.

Acknowledgements

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IDENTIFYING AND DETERMINING POLLUTION LOAD OF AGRICULTURAL POLLUTANTS IN THE CATCHMENT BASIN OF KARUN AND DEZ RIVERS

N. Hosseini-zare[1,*], N. Shahinzadeh[2], D. Bahmaei[3]

Abstract

The impacts of climate change and human induced activities due to the development of urbanization, industries and agriculture are the biggest challenges in the field of water resource management in Iran, especially river water management in Khuzestan Province. Suitable soil and water resources in the Great Karun River basin, extensive areas of natural resources, favorable climate conditions and energy resources have led to the development of agriculture, industry, and population growth in the Karun and Dez Rivers margins. This study aims to identify, quantitatively and qualitatively review and determine the pollution load of agricultural drainages in the basin of Great Karun (Karun and Dez Rivers), determine the volume of drainage water and the impact on the quality of production resources. After field study, sampling (N=96) was done during four seasons in 2013-2014 in 24 input points of drainage water to water sources. The EC, pH, TSS, NO3-, DO, BOD, PO4-3, COD features, Cations, Anions and discharge were measured. Results showed that agricultural pollutants with a volume of 2,374 million cubic meters per year are causing pollution of types TDS and NO3- with 11862 and 65.51 tons per day, respectively. Pollution load of organic materials based on BOD and COD is 29.7 and 211 tons per day, respectively. Results also showed that, the Dez river reach has the largest share in terms of volume of drainage water and incoming pollution load. Moreover, the agricultural drainages of Shoeibieh, Haft –Tapeh Sugar cane, Ajirub and Salimeh, Karun (K), Myanab and Kharur within the Dez river reach, the drainages of Sardarabad (N) and Zahuabad within the Shatit reach and the fish-farming wastewaters within the Gargar river reach are among the most important drainages affecting the quality of water resources and agricultural lands in the downstream basin. Evidences show that in future the situation will be worse if proper measures are not undertaken.

KEY WORDS: Pollution load, Karun and Dez rivers, Soil and water resources, Agricultural drainages, Khuzestan

Introduction

Soil and water as the main elements in agricultural production are of crucial importance;therefore, any damage to them directly affects the quality and quantity of products and irreparably damages these resources (Hillel, 1997). The quality and quantity of these resources is associated with their

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exploitation and operation management (agricultural, urban, and industrial) (Jafarinejadi *et al*., 2010). Water consumers in the agriculture sector are mainly the rural population, and due to their economic and social characteristics which are based on the traditional exploitation of resources, optimal water exploitation management has not progressed much in this sector (Hosseini-Zare, 2004). Currently, water resources exploitation in non-agricultural systems such as in the case of industries and urban wastewater discharge is the same as it used to be in industrialized countries in previous centuries in the West (Hosseini-Zare, 2004). The pollution of soil and water resources has become a serious threat to human societies, environment, and natural ecosystems (Gyawali *et al.*, 2012). Fatouki *et al.* (2003) investigated pollution in the Keiskamma River in South Africa. Their results showed that the discharge of wastewater from the Keiskammahoek treatment plant was the most important point source of pollution load. The most important pollution loads of that river were related to salinity, nutrients, and oxygen-demanding compounds. Essien (2010) studied the pollution load of the Ikpa River in Nigeria and reported that urban development of the Uyo metropolitan center was the major contributor to pollution of the river. It was concluded that pollution was mainly due to the discharge of leachate, urban runoff, and sewage into the river. Deng *et al.* (2010) studied the total pollution load on the Yangtze River in China and examined the share of the pollution load. The total pollution load of COD and ammonia nitrogen, inorganic nitrogen, and phosphate was estimated. Their results show that pollution load resulting from inorganic nitrogen and phosphate is higher than the refinement potential of the system. Mehrdadi *et al.* (2006) studied the pollutants of the Tajan River in the Mazandaran Province and concluded that the Mazandaran Wood Industry, Paksar Dairy Industry, Antibiotic Production Industry of Sari, and Sari urban wastewater and agricultural activities are the most important pollution sources of the Tajan River basin which seriously threatens water quality. Therefore, the increase of water needed in various sectors including agriculture activities and irrigation and drainage networks, shrimp and fish farms, industries, urban development, and water transfer can have a huge impact on the water quality in the Karun River in the future (Karamouz *et al.*, 2004). The Karun and Dez drainage basin, with an area of 21,500 square kilometers, accounts for 33.8% of the Khuzestan Province area. Suitable soil and water resources in the basin and the wide and potential range of natural resources, favorable climatic conditions, and rich oil and gas resources has led to a growing development of agriculture, industry, aquaculture, population growth, and urbanization in the Karun and Dez riverbanks. This has caused various problems across most environmental areas such as the impact on water and soil receiver resources, increased pollution, and reduced natural capacity of the environment in the studied region (Khuzestan Environmental Protection Agency, 2006). The Greater Karun river system consists of the confluence of thetwo major rivers of Dez and Karun and is the greatest surface water system in Iran with an average, maximum, and minimum annual dischargeof 19,174, 38,323, and 7,915 MCM/year, respectively (The Khuzestan Water and Power Organization, 2013). This study aims at identifying and determining the pollution load of various pollution sources in the Karun and Dez basin which affects the quality of water and soil resources in the Khuzestan region.

Materials and Methods

The study area included the Karun River basin from its entry point into Khuzestan plain (Gotvand) down to Abadan and Khorramshahr and the Dez River from its entry point to the Khuzestan plain (Dezful) to Bande-Ghir, where it join the Karun River and forms the great Karun River. The Karun and Dez Rivers basin is the largest basin in the Khuzestan province in Iran which is located at geographical coordinates of 48° 10' to 52° 30' East longitude and 30° 20' to 34° 05' North latitude in the central Zagros Mountains. The Karun basin has an area of 62,417km^2. Awareness of the present condition, determination of the main pollution sources, and specification of the hierarchical structure of qualitative variables were among the methods used in this study to determine the pollution load.

In the next stage, the entry points of all pollutants, including agricultural drainage, industrial wastewater, and urban wastewater to rivers were determined using Global Positioning System (GPS) and recorded in Excel software along with other data. Twenty-four agricultural drainage systems, nine sources of industrial wastewater, and thirty-eight sources of urban wastewater located along the Karun and Dez rivers, including the wastewater emissions from cities of Dezful, Gotvand, Shooshtar, Ahvaz, Khorramshahr, Abadan, Veis, and Mollasani, were identified. Sampling was conducted over the hydro-year 2013-2014. Figure 1 shows the sampling locations. A Molinet (or volume measurement) was used for determining the discharge rate. Seventy-one samples were collected of which each sampling, amounted to 284 samples of pollution sources over four seasons. Samples were transported to the laboratory and were prepared. Qualitative variables, such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were determined as indicator parameters for the pollution load of organic materials. Qualitative variables such as total dissolved solids (TDS), Cl^-, SO_4^{-2}, and TSS were determined as characteristic indicators of soluble and insoluble solids. The qualitative variables of nitrate (NO_3^-) and phosphate (PO_4^{-3}) were also determined as characteristic indicator of the pollution load of nutrients. Then, the indicator parameters of the pollution load were measured. All steps including sampling, stabilization and transport of samples to the laboratory and the testing methods were as per the Standard Methods for the Examination of Water and Wastewater, 22nd Edition (2012). Contribution of pollution sources and prioritization of the various agricultural, urban, and industrial pollution sources in the pollution load entering the river, was calculated using SPSS20 and EXCELL based on the qualitative and quantitative obtained results of the indicator parameters.

Results and Discussion

The results of the descriptive statistics of parameters using calculations of the pollution load for various pollution sources were determined (Table 1). The results of the pollution load and the degree of importance of soil and water pollution sources of the Karun and Dez rivers basin in terms of pollution load by indicator parameters is shown in Table 2.

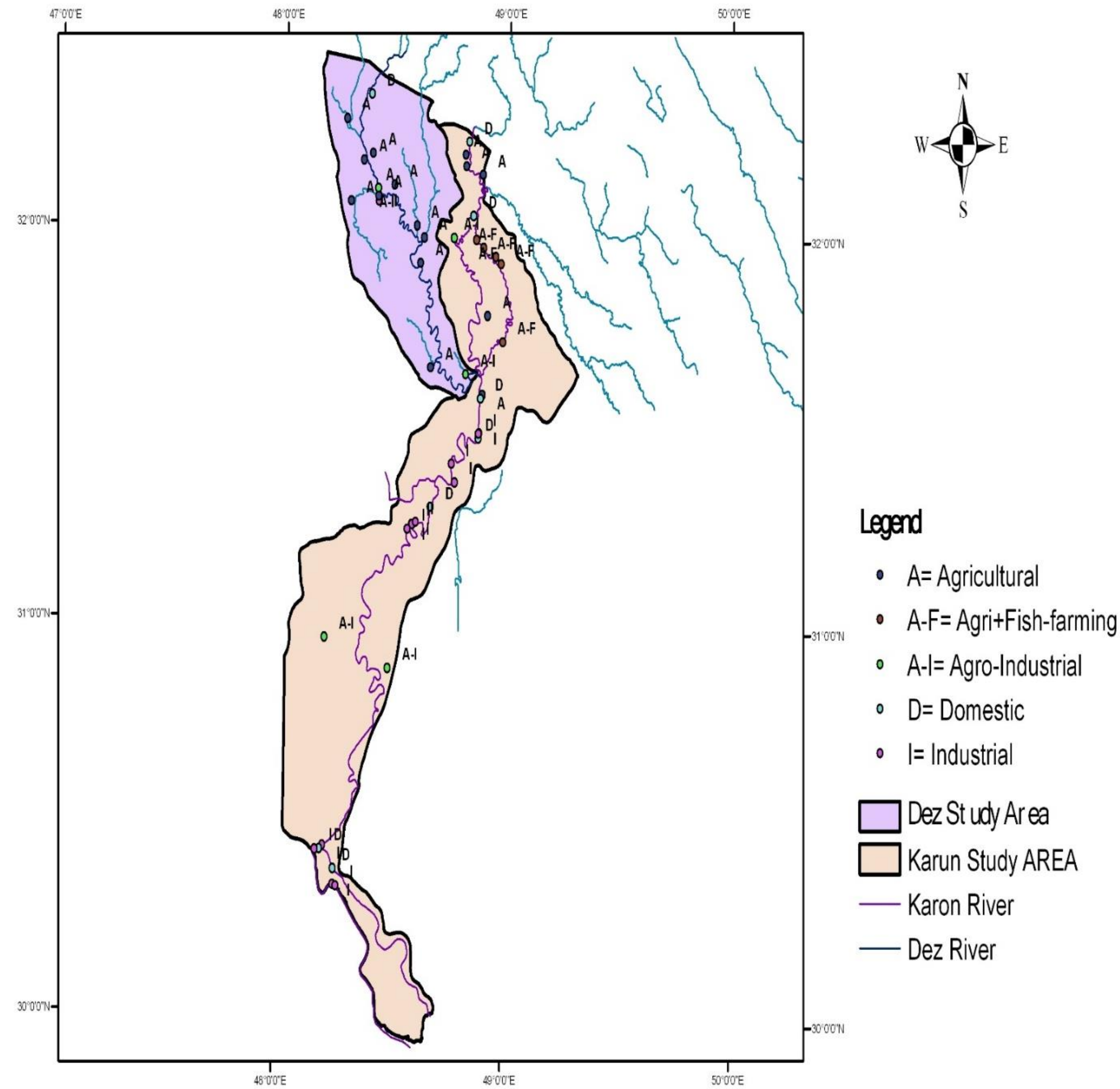

Figure 1. Location of the study area and pollution source

Table 1. Statistical characteristics entering Karun and of pollution load indicators of pollution sources Dez rivers in four seasons of 2013-2014 water year

Pollution Sources		TDS	EC	pH	TSS	NO_3	PO_4	DO	BOD	COD	Total coliform	Fecal coliform	NH_3
		ppm	µmho/cm	-	ppm	ppm	ppm	ppm	ppm	ppm	NO/100ml	NO/100ml	ppm
Agricultural Drainage	Number	24	24	24	24	24	24	24	24	24	24	24	24
	Mean	2221	3263	7.7	59	7.6	0.05	6.8	5.19	32.04	43115	16079	0.73
	Min	451	711	7.3	20	1.27	0.005	3.6	2.14	14.7	8650	2200	0.25
	Max	4882	6540	8.1	180	16.05	0.41	10.2	21.2	115	110000	56150	2.5
	SD	1465	2050	0.19	42.8	3.47	0.085	1.88	3.93	19.33	31348	14746	0.46
Industrial Wastewater	Number	9	9	9	9	9	9	9	9	9	9	9	9
	Mean	2169	3389	7.7	269	10.04	0.27	3.48	59.61	407	85222	31633	0.95
	Min	910	1297	6.9	40	3.47	0.01	0.20	21	68	15000	2000	0.25
	Max	3740	5750	8.5	1440	26.10	0.78	7.30	169	2200	110000	110000	1.5
	SD	850	1325	0.44	447	7.30	0.27	2.68	47.24	682	38228	33535	0.35
Urban Wastewater	Number	36	36	36	36	36	36	36	36	36	36	36	36
	Mean	2107	3291	7.8	255	8	5.1	0	86	209	45×10^6	28×10^6	21.9
	Min	630	981	6.9	24	3.72	1.5	0	29	66	2×10^6	0.25×10^6	5
	Max	4090	6390	8.4	593	19.07	8.5	0	205	509	500×10^6	319×10^6	41.3
	SD	1011	1581	0.45	103	2.9	2.4	0	40	104	95×10^6	64×10^6	10.25

Table 2. Pollution load of pollution sources and their priority in polluting (discharge is in m^3/sec, and the indicators are in Tons/day)

Pollution Sources	Discharge Rate			TDS			BOD			COD			NO3			NH3		
	m^3/sec	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank
Agricultural	75.3	87.3	1	11862	84.3	1	29.7	26.7	2	211	32.6	2	65.51	87	1	4.8	23.6	2
Urban	7.9	9.21	2	1638	11.6	2	53.51	48.2	1	130	20.1	3	5.08	6.75	2	15.25	75	1
Industrial	3.03	3.5	3	569	4	3	27.82	25	3	306.6	47.3	1	4.65	6.2	3	0.25	1.2	3
Total	86.23	100	-	14070	100	-	111	100	-	647.9	100	-	75.24	100	-	20.3	100	-

Table 2. (Continued) Pollution load of pollution sources and their priority in polluting (Discharge is in m^3/sec and the indicators are in Tons/day)

Pollution Sources	PO_4			Cl			TSS			SO_4		
	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank	Tons/day	%	Rank
Agricultural	0.28	9.9	2	2654	80	1	342	47.5	1	4722	89.4	1
Urban	2.5	88.34	1	537.7	16.2	2	178	24.7	3	424	8	2
Industrial	0.05	1.76	3	123.4	3.72	3	199	27.7	2	134.5	2.55	3
Total	2.83	100	-	3315	100	-	719	100	-	5280	100	-

Assessment of Pollution Load of Agricultural Drainages

Results showed that of the 86.23 m^3/sec pollutants discharge entering the Greater Karun system (Karun and Dez Rivers) before the Ahvaz region, 75.3 m^3/sec (87.3 %) is related to agricultural drainage. Moreover, the results revealed that the most important problem of agricultural drainage was the level of salinity in the drainage discharge. The total pollution load entering the Karun and Dez rivers on the basis of various agricultural, industrial, and urban pollution sources is presented in Table 2. Accordingly, from a total of 14,070 tons/day minerals and inorganic compounds (TDS) pollution load discharged into the water sources of the Karun and Dez Rivers, 11862.5 tons/day (84.3 %) is due to agricultural drainage. Based on the calculations of the pollution load, agricultural pollutants account for 211.16 tons/day (32.6 %) of organic matter based on COD (chemical oxygen demand) out of a total 647.92 tons/day entering the Karun and Dez rivers. In this regards, agricultural pollutants ranked second after industries. Agricultural drainage accounted for 29.7 tons/day (26.75 %) of organic matter based on BOD (biochemical oxygen demand) of out of a total of 111 tons/day entering the Karun and Dez rivers. Agricultural drainage ranked second in this regard. In terms of chlorides (2,654 tons/day), sulfates (4,722 tons/day) and nitrate (65.51 tons/day), agricultural drainage were the largest contributor of the pollution load entering the river, and since they have a significant discharge rate, pollution load as a result of agricultural drainages is very important. Afkhami (2004), Karamouz (2005), and Hosseini-Zare (2002) studied the pollution sources and their pollution load in the Karun and Dez rivers basin and estimated that the contribution of agricultural drainages in the pollution load of dissolved solids (TDS) and organic load based on BOD and COD as 70, 19 and 23.5 percent, respectively. Due to the significant development of agricultural and aquaculture activities and particularly the implementation and operation of the seven sugarcane industry development plans in the northern and southern regions of the city of Ahvaz in the vicinity of the Karun and Dez Rivers basin, the increased contribution and role of agricultural pollution sources in mineral and organic pollution load discharging into the river during this study as compared to other similar studies is quite predictable.

The Assessment of Pollution Load of Urban Wastewater

The results of inorganic and organic compound pollution load and other indicators of urban wastewater pollution and their comparison with agricultural drainage is shown in Table 2. Results show that the discharge rate of urban wastewater is 7.90 cubic meters per second and constitutes 9.2% of the total 86.23 cubic meters per second of measured discharge rate. Urban wastewater ranked second after agricultural drainage in this regard. Table 2 also shows that from a total of 111 ton per day of organic pollution load in terms of biochemical oxygen demand (BOD) entering the Karun and Dez Rivers, 53.51 ton per day (48.20 %) is due to urban wastewater. The share of agricultural drainage and industrial wastewaters was 29.7 and 27.82 ton per day of organic pollution based on BOD. Results also show that out of a total of 647.92 ton per day of pollution load based on COD, 130.14 ton per day (20 %) is related to urban wastewater. In the case of agricultural drainage and industrial wastewater, 306 and 211 ton per day, respectively, was estimated based on COD. The pollution load of industrial organic compounds was mainly related to the sugarcane-related industries such as paper mills and Silk companies located in the Haft-Tapeh region. Regarding the pollution load of dissolved salts, the total amount of dissolved solids (TDS) is calculated as 14,070 tons/day, and the share of urban wastewaters was calculated as 1638.5 tons/day (11.6 %). Another issue is the ammonia pollution load. Out of the 20.3 tons/day ammonia pollution load, 15.25 tons/day (75 %) was due to urban wastewater. By comparing the results in Table 2, which is based on the final results of the pollution load calculations, it was found that although the concentration of COD and nitrate is higher in urban wastewater as compared to agricultural drainage, the pollution load discharges into the river by agricultural drainage is 1.62 and 12.9 times higher than the urban wastewater respectively. This was due to the very high discharge rate of agricultural drainage as compared to urban wastewater. Regarding organic compounds based on BOD, as shown in Table 2, the BOD levels of urban wastewater is nearly twice the BOD levels of agricultural drainage. This indicates that microbial decomposition of organic matter in urban wastewaters was higher compared to agricultural drainage, and if a considerable volume of urban wastewater, in as such that when the urban wastewater of Ahvaz, enters the river, their oxygen demand would be much higher, which reduces water oxygen content more easily. Most organic materials in agricultural drainage are mainly byproducts of the sugarcane industries and made of cellulose and are thus resistant to microbial decomposition (sugar cane wastes). These material are often transported to the extremes of the river and become a source of organic material based on COD. Regarding control and prioritization of urban wastewater treatment, it can be said that according to the results, although the city of Ahvaz is the capital of the province and is highly-populated, its urban wastewater is directly discharged into the river at the rate of 400,000 cubic meters per day from the gateway of Ahvaz to the southern end of Ahvaz, Ahvaz has been identified as a major center of organic, microbial, ammonia material pollution load. The results of the present study is in agreement with studies conducted by the Environmental Department of Khuzestan (2002), Dezab Consulting Engineers (2001), and Hosseini-Zare (2002), which estimated 10.7%, 33%, and 14% share for TDS, BOD, and COD pollution load arises from urban wastewater, respectively.

Assessment of Pollution Load of Industrial Wastewater

Khuzestan is an agricultural production hub and is also considered an industrial hub due to the existence of large oil, gas, steel, carbon, petrochemicals, and electronic industeries as well as many smaller industries. Contemporary National Iranian Oil company's policies of, development and expansion of current oil fields and new excavations have severely affected the international wetlands of Shadegan and Hour-al-Azim, in addition to the polluting of water resources and dam reservoirs and agricultural land in the Karun and Dez rivers basin and the urban centers of the Province caused by the National Oil Companies unregulated activities. In recent decades, the Khuzistan Province has frequently witnessed failure and rupture in oil pipelines and oil spill pollution of soil and water resources in the various basins of the Khuzestan Rivers. In addition to the aforementioned issues, a reality the Khuzistan province has witnessed in recent years is that due to numerous economical and labor-related problems, and particularly problems caused by sanctions, many industries have closed and others are on the verge of closing. According to authorities, many industries are operating with 40 % capacity, for instance, Khuzestan Pipe Co, Ahvaz Sepanta Co., Ahvaz Sugar Refinement, Ahvaz Khorramnoush, Pasargad Chemical, Abadan Dairy Co., Soap factory. Yas Khorramshahr Co., Khorramnoush Khorramshahr Co., Dezful Sugar Co. This issue has led to large scale unemployment in the Khuzestan province. Unemployment and the necessity to earn a living has caused many to turn to agricultural and aquaculture activities regardless of the economic development capacity of Khuzestan. They have exploited water either by legal permits or illegally which results into the low quality of water and soil resources , causing serious challenges in the short-term and long-term. It has to be noted that sanctions and encouraging non-oil exports, including agricultural products with the goal of self-sufficiency and foreign exchange and overcoming sanctions have put additional pressure on water and soil resources, which has in itself deteriorated the quality of water resources on all levels and increased soluble salts and pollution in base resources. Results shows that industries related to the sugarcane industry, due to the cellulose nature of their materials, and related industries such as paper mill and Silk companies located in Haft-Tapeh area, with a significant organic pollution load of BOD (21.9 tons/day) and COD (285 tons/day), has had the greatest effect on the quality of water, and consequently, soil resources to date.

Conclusion

The important factors that destroy the quality of soil and water resources and increase the pollution load entering the Karun and Dez rivers can be summarized as follows: Human factors including development in various aspects, such as increasing population, urbanization, development of economic sectors, including agriculture and aquaculture, industrial and issues of inter-basin water transfer, problems caused by sanctions, including bankruptcy and closure of many industries and a rising unemployment rate, and thus, many activities of unemployed people in the agriculture and aquaculture sector , along with natural factors such as climate and climate change and reduced precipitation and consequently reduced runoffs and incidence of droughts. However, human factors, including soil and water resources management, are the most prominent causes of the current situation. Results showed that the major problem of soil and water resources in the Great Karun basin in the Khuzestan Plain is caused by minerals and soluble salts resulting from agricultural activities and the vast areas under cultivation. The discharge of drainage water to River systems is a common practice in Iran. This practice seriously decreases the quality of irrigation water used by farmers in the lower reaches of the river system. Agricultural drainage belonging to the sugarcane industry located in the northern and southern regions of Khuzestan is about 110,000 hectares. These Agricultural drainage along with the Seasonal and high water consumption cultivation of crops , such as the cultivation of paddies in the Karun and Dez rivers basin, and the development of aquaculture are the main sources of water and soil pollution resources in the studied area. The Dez River in the Haft-Tappeh region is considered as a vulnerable and susceptible area regarding its natural assimilative aspect due to the organic pollution load discharged by the sugarcane industries and the related industries, such as paper mill and Silk companies based on biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Results also showed that the city of Ahvaz, as the highly-populated capital of the province, is due to the discharge of urban wastewater from the gateway of Ahvaz to the southern end of Ahvaz, one of the major sources of organic pollution load based on biochemical oxygen demand (BOD) and microbial and ammonia pollution load. There is a clear trend of water quality deterioration as the water moves from upstream to downstream areas. The water quality in the upstream region was found to be good with salinity levels in the range of 0.500 to 0.650 dsm^{-1}. The water quality gradually deteriorated in the Khuzestan Plain as a consequence of the confluence of pollution resources. The water quality at the lower reaches of the river system deteriorated to the extent that the salinity levels of the river water reached between 2.5 to 6 dsm^{-1}. Water quality deterioration has a major effect on the development of salinity and sodality in the irrigated land located in the lower reaches of the basin.

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APPLICATION OF BIO-DRAINAGE SYSTEMS FOR THE SUSTAINABLE AND OPTIMAL USE OF IRRIGATED LANDS AND THE PREVENTION OF THE SALINITY AND OVER-DRAINAGE OF ARABLE LAND

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Abstract

Sustainable agriculture in irrigated lands requires a natural or artificial drainage system which will extract the surplus water and salt from the soil. In many regions the natural drainage system fails to be efficient enough and artificial surface or sub-surface drainage systems must be implemented which in themselves are not only costly but also cause environmental problems in the area itself. It is believed that in such areas other methods for the transferring of salt and excess water off the land should be applied. One of the modern methods applied currently is that of bio-drainage which along with dry drainage and Argo-forestry are used for the reducing of environmental damage to drainage sites. In this paper, the author shall be focusing on the application of bio-drainage in the Khuzestan region. The main objective was the sustainable and optimal use of irrigated land in order to prevent the over drainage and salinity of the arable lands in the region. In contrast to artificial drainage systems which rely on mechanical equipment, in bio-drainage systems plants are used for the controlling of salinity and the retaining of the static equilibrium. Plants with the capability of dynamic absorption and transpiration pump groundwater upwards and release it to the atmosphere. This is an economical and assured method for the resolving of drainage problems in arid and semi-arid regions. The efficiency of this method in the controlling of salinity and excess water depends on variables such as the climate of the region, the soil characteristics, type of crop, irrigation method, and the chemical quality of the water used for irrigation. This method is often successfully applied in zones which have a high static equilibrium along with high rates of transpiration. Studies have validated its effectiveness in retaining the static equilibrium in various zones, yet its effectiveness in the decreasing of the salinity of the soil over a long period of time is debatable. It is believed that this method could prove to be a means of diminishing the effects of saline water on soils, and act as a retardant until more effective salinity mitigation measures are put into place. The amount of land required for the creating of bio-drainage systems is less than ten percent which in comparison to the amount of land required for the creating of an artificial drainage system shows a negligible difference. In the development of this type of drainage system one should consider the following; first of all the plants selected should have the capability to thrive in such an environment and the amount of water they consume and their transpiration index should be high. The plants utilized should be beneficial and have sufficient yields while being

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saline resistant. The root dispersion should be vertical and deep in order to tap groundwater sources. More over the plants selected should match the crop patterns publically acknowledged by farmers and the environmental effects of the plants should be carefully evaluated prior to implementation. This is largely due to the fact that the best way to protect and preserve such plants is through public awareness.

KEY WORDS: Bio-drainage, Irrigated land, Saline soils, Static equilibrium, Soil characteristics.

Introduction

It can simply be said that drainage is the process of eliminating the excess water and salts from the soil floor or depth. The aim of drainage in agriculture is to prepare a suitable environment for the plant root to grow (concerning ventilation and salinity). In a more comprehensible definition it can be said that drainage is the natural or artificial elimination of the extra water from an area that is one of the fundamental subjects of engineering hydrology. When the ground is irrigated the level of the groundwater table rises so the ventilation in the root becomes hard. Also concentration of salts make soil saline. Issues caused by the lack of ventilation in soil:

1- Decrease in the breathing of root and living beings;
2- Decrease in permeability and slow movement of the salts;
3- Formation of toxic compounds in soil (performing revival operations instead of oxidation);
4- Decrease in production of food in soil

Sustainable agriculture in irrigated lands depends on the existence of a natural or artificial drainage system that eliminates the extra salt and water from the soil. Natural drainage is insufficient in many areas and creating artificial drains in either open or underground forms, beside the environmental issues, become very costly.

Vertical and horizontal methods of drainage have been used for many years as traditional and standard methods of controlling phreatic surface and salinity. Although these methods have many advantages for beneficiaries, they have some problems too. Modern methods of drainage include bio-drainage, dry drainage and agro forestry drainage.

All plants need water to grow. Since natural precipitations could not always meet the water needs of plant, rest of the plant need for water is resolved through irrigation. Agricultural development in many countries has often been concurrent with development in irrigation. In average, agricultural products from a unit of an irrigated area are two times more than that of a rain-fed area. Irrigation, undoubtedly, plays an important role in protecting world population concerning food supply, clothing, bio-energy and industrial needs and its negative impacts on natural resources have been revealed from which salinity of the irrigated land and their becoming to wetlands can be stated.

Today roughly one third of the irrigated lands of the world is threatened by wetland dangers in a way that two to four million hectares from the world lands are excluded from the production cycle annually. There is no doubt that in the future also, because of so many losses due to low efficiency and using low quality water, new drainage problems will rise. In many places of the world managerial solutions has been presented for resolving drainage problems but most of these solutions are based on engineering approaches such as deep open drains, vertical drains (pumping ground water) or underground drains. These systems, basically, require maintenance and exploitation and also a high initial investment for creating such drains is needed. Furthermore, the output water from these drains is often saline and sometimes polluted and its pumping to the surface water (rivers, lakes, ponds,…) results in environmental issues. So other methods of controlling phreatic surface that are low cost and environmentally accepted are preferred. Bio-drainage is introduced and discussed in this article and its technical aspects, advantages and limitations are studied.

Bio-drainage: the main goal of this method is sustainable and optimized use of irrigated lands and prevention of fertile lands from being drained and saline. While artificial drainage depends on mechanical tools, bio-drainage controls salinity and phreatic surface with the help of plants. Ground water is pumped to the atmosphere by the plants by means of the transpiration pull. This method is introduced as a low cost yet secure treatment to solve drainage problems in dry and semi-dry regions. These methods, generally, are more affordable and eco friendly. Bio-drainage technology, if implemented correctly, can lower the groundwater level resolving the issues related to flood and canals leakage.

Common plant species in bio-drainage

Selecting plant species in bio-drainage depends on environmental conditions. For example, species resistant to salt are suitable for saline condition while species that consume much water are appropriate for controlling penetrated water with low salt and canal leakage.

- Tamarix troupii
- Acasa tortilis and Acasia nilotica
- Eucalyptuses specially Eucalyptus Camaldulensis

Tamarix: is an old tree. Since its root can get to surface water of the ground, it has been said to live more than 1000 years in some places in the tropics. This tree height reaches to 10 to 15 meters. The tree belongs to Tamarix family and grows in different places of the world including Iran.

Eucalyptus: belongs to myrtle family which is originally from Australia and constitutes dense forests in that country. The tree reaches a height of 145 meters with a trunk perimeter of 25 meters.

some Australian researchers have claimed, in an article titled "natural gold particles in the leaf of Eucalyptus and its relation to discovery of underground resources of gold" published in scientific journal Nature, that Eucalyptus tree is capable of absorbing the gold laid in the ground depth and transferring it to the surface of the ground hence making mine discovery possible.

Materials and methods

This method of drainage is an unstructured method and purposes of the underground drainage are fulfilled through growing plant (mainly unfruitful ones). Choosing the type of plants to grow (several years or permanent) should be done considering the resistance to salt or preferably halophytes. To implement this method of drainage trenches are allocated to grow water intensive plants in the proximity of arable areas. This kind of plants makes a lower aquatic potential in soil face due to their high transpiration. So underground drains that have a higher aquatic potential move toward the aforementioned trenches and the water table level decreases in farming areas and, in fact, drainage is accomplished in a biotic procedure.

In the studied associated with bio drainage some items have to be considered such as water and salts balance, water level required for growing plants (unfruitful ones), need for water of the plants practiced in bio drainage method, quality of the groundwater and the extend of the impact of the trenches made in agricultural areas. According to the studies, Tamarisk, Acacia, Mimosa and Eucalyptus are the appropriate trees for this method of drainage.

Results and discussion

In normal conditions indices of a hydrological system such as precipitation, evaporation, transpiration, soil moisture supply changes and drainage are in balance. High precipitation in some periods may temporarily increase drainage flow and raise the phreatic surface or moisture supply but finally, after a period of 5 to 10 years, the balance will be restored.

Plants play an important role in water balance indices (evaporation, transpiration, moisture supply). When agricultural plants or trees replace natural plant cover, the region aquatic balance changes the leakage to groundwater table may increase or decrease compared to its previous status. Indeed, the development of irrigated agriculture generally followed by an increase in water leakage into the groundwater table. As an example, in Australia the depth of penetration in semi-dry regions was measured before and after change in using method. The degree of penetration before the change, in which the area was covered with native eucalyptuses, was less than 0.1 millimeter per year and after the change and growing agricultural plants, the penetration dramatically changed and increased about 5 to 30 mm per year.

The driving force in bio drainage is of plants water consumption. So, cultivation of fast-growing tree species like eucalyptus during feeding (irrigation or precipitation), decreases the penetration of water into groundwater table and when irrigation or precipitation stops, that results in lowering of phreatic surface. Initial studies conducted in Australia suggest that the amount of transpiration and groundwater consumption of trees of low phreatic surface areas (5 to 8 meters beneath the surface of ground) is very high and is 3 to 6 times (1200 to 2300 mm per year) more than yearly transpiration of pasture species (400 mm).

In 1998, Morris and co-workers reported that the amount of two types of eucalyptus (Grandis, Camaldulensis) in shallow and saline water table was about 300 mm per year. They also claimed that trees ability to drain groundwater away from the soil with a low hydraulic conductivity declines when phreatic level decreases. Other studies also were conducted on different types of eucalyptus concerning transpiration. Their water needs were suggested to be almost equal.

Salt balance is also one of the basic factors that contribute to the growth and water consumption of plants. The salt that is transferred to root area, if not water-washed, absorbed or eliminated by the plant, will kill the plant.

Characteristics of plants root are very effective in water consumption efficiency. Plants with deeper root, besides having more access to water, consume more water and can lower the surface several meters.

During the penetration of irrigation water or rain water into the groundwater table, existence of trees with deep roots reduces the chance of penetration of water into the water table.

Bio-Drainage in rain-fed regions

The main problem with Bio drainage in rain-fed or humid regions is that plants water need is usually low in winter or precipitation season. So drainage takes place with a delay in a way that soil is saturated in winter and unsaturated in summer. With Bio drainage in rain-fed lands is designed according to the following different purposes:

Feed control

In high and rain-fed lands the input water stream usually under the root in upstream areas toward downstream and is drained into groundwater table. This makes the downstream areas saline. The process in which depth penetration of upstream is reduced to solve the drainage problem in downstream is called feed control.

In Australia plant cover or growing agricultural trees in the upstream has been the most important measure to control salinity. In this situation, planting trees in a small part of the upstream areas is enough. But plant cover in upstream has also negative impacts. If the evaporation ability of the new plants is great, it may make the land dry, decrease the flow of rivers and wells or making them go dry.

Preventing or blocking groundwater flow

By planting trees in some points in downslope, where water has rather a good quality, groundwater flow toward downstream is reduced so the drainage problem of downstream is partly resolved. The location for planting also is of great importance. That depends on status and construction of layers, upstream slope, feeding quantity, groundwater quality and the depth of phreatic surface.

Draining increase

Lands with low phreatic surface are often the places where drainage of groundwater takes place. In case that these lands have exits and their canals are drained into rivers, salt balance will be kept. But if no exit exists or if there is no penetration of groundwater into lower depths, then salinity of the lands will be inevitable. In these conditions the stability of bio-drainage system is found to be uncertain. Today in Australia, it is generally believed that bio-drain in downstream and smap lands finally results in salinity unless ordinary drainage systems are applied to control the salinity.

Bio-Drainage in irrigated lands

Irrigated lands work as feeding surfaces during irrigation and penetration of water into soil. They also operate as draining surfaces at irrigation intervals when evaporation-transpiration takes place. Bio-drainage in irrigated lands is designed according to the following purposes:

- Control of phreatic surfaces
- Prevention of canal leakage
- Composite system (ordinary drain + bio-drain)

In condition that salt accumulation of salt in root area limits the growth of bio-drainage plants, engineering solutions seem to be essential for system stability. In these situations, a combination of ordinary drainage and bio-drainage systems may be helpful.

Design principles

The following items have to be considered in development of bio-drainage systems:

1- Water balance: bio-drainage plants are supposed to be able to absorb groundwater enough for them to feed so that the phreatic surface beneath the root is maintained.
2- Cultivation surface: bio-drainage cultivation surface needs to be small as much as possible since the basic purpose of agriculture (especially in irrigated areas) is to grow valuable crops.
3- Salt tolerance: the plants used for drainage purposes have to be salt tolerant as groundwater is usually more saline than irrigation water; with an increase in salinity to 8 ds/m water consumption is reduced to half.
4- Cultivation arrangement: plants must be cultivated in blocks or ridges with certain distance so that phreatic level between them and in irrigated areas below the depth of plants root. Since access

to trees is more possible in roadside areas and borders, these places are recommended for planting bio-drainage trees.

5- Salt balance: the development of irrigation projects without considering drainage leads to the salinity if lands. The keep balance of salt, cultivated plants should be able to absorb salt and they have to be removed after a harvest. This can be fulfilled only in case that the salinity of irrigation water is very low.

6- Economic aspects: management of the exploitation of bio-drainage trees and plants differs from that of valuable farming plants. The income from bio-drainage plants is earned several years later than the initial investment (the cost of planting and preservation).

And the most important item is:

7- Public acceptance: growing new plants like trees will affect the social status of a village. New markets may arise. Careful safety attention for these trees is different from that required for ordinary plants (illegal rescission or cutting trees for firewood; and a fire may ruin the results of several years in a day). To resolve the issues and prove that the interests of bio-drainage system are gained as much as possible, active contribution of local communities to develop and plant bio-drainage trees is highly important.

8- Salt balance, an important issue in drainage.

No biological system can survive without a salt equilibrium. Salinity balance is one of the important issues that must be studied before considering bio-drainage as a managerial technique. Salt absorption by plant is slight compared to the total salt that enters the root through irrigation water. Studies have shown that only 1 to 1.5 percent of the total salt that enters the soil is removed from the soil by the plant.

Lambert (1981) calculated the amount of salt removal from soil by eucalyptus as 400 kg per hectare that is equal to percent of the salt entered the soil through the irrigation water.

So plants ability to eliminate salt from root area is not encouraging and other techniques such as salt washing and other drainage methods have to be used simultaneously.

Bio-drainage system lifetime

The experiences regarding bio-drainage in different places of the world belong to the recent years and no report confirming the long-term performance of these systems has been received. The lifetime of these projects is estimated at 10 and maximum of 15 years according to researches (1385). The main cause that makes these systems inefficient after 10 years of operation is the salinity issue.

Some other items:

In Gandhi's stream project in Ragestan, India, planting eucalyptus trees wetland areas near the irrigation stream caused groundwater surface to lower 15 meters in a period of 6 to 7 years. Drilling

performed in an area of trees to a depth of 10 meters showed that eucalyptus roots extend to a minimum depth of 10 meters.
Kapoor (2003) found bio-drainage helpful for water with salinity below 12 ds/m.

Akram (1385) claimed that maximum water and soil salinity that can be controlled in bio-drainage method is 5 ds/m. environmentally friendly bio-drainage methods by far have a better performance in a situation that restricting layers are so deep.

Conclusion:

1- Bio-drainage is very effective in resolving swamp issues in irrigated and rain-fed lands, having a desirable performance in areas with high phreatic surface and evaporation rate.
2- Plants ability to eliminate salt from root area is not so desirable. So they are helpful for postponing the transfer of salt to root area or in case of low salinity of irrigation water.
3- When salt accumulation of salt in root area limits the growth of trees, engineering solutions are essential for system stability. A combination of ordinary and bio-drainage systems can help.
4- If the area is more humid and water needs are low, then bio-drainage is found to have higher efficiency.
In similar reaserch Akram et al. (2008) applied the SAHYSMOD model in order to determine the sensitivity of the various elements influential on irrigation and their effect on bio-irrigation schemes, and obtained the following results:

- The major constraint of bio-drainage in arid and semi-arid regions is salt balance and the accumulation of salt in tree plantation strips. The sustainability of the system, however, is questionable except where the irrigation water is quite suitable and/or in humid regions with high annual precipitation
- In saline environments, hybrid systems that combine bio-drainage and conventional engineering-based technology will be needed to achieve sustainability.
- The effectiveness of the system is higher where the neighboring strips are narrower
- In most cases salinity of crop strips in bio-drainage is independent from the hydraulicconductivity of the soil
- A bio-drainage system could not be expected to be considered successful in areas where the barrier depth is too shallow
- Bio-drainage is very sensitive to the amount of applied water. The higher the water applied, the lower is its effectiveness in both water table and salinity control in plantation strips. A bio-drainage system could not be expected to be considered successful in areas where the barrier depth is too shallow,

- Sustainability can only be achieved where some sort of salt removal mechanism is included in the system.

The obtained results approximate the results obtained in conventional irrigation schemes.

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ASSESSING SENSITIVITY OF PADDY RICE TO CLIMATE CHANGE IN SOUTH KOREA

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Abstract

Paddy rice constitutes a staple crop in Korea. This study conducted a sensitivity analysis to evaluate the vulnerability of paddy rice to future climate change, and compared temporal and regional characteristics to classify regions with unfavorable water balances. The ratio of consumptive use and effective rainfall (REIP) was used as a sensitivity index. Weather data from 1971 to 2010 and future climate change scenarios RCP 4.5 and 8.5 were used to evaluate the sensitivity. The results showed an overall increase in water requirements and consumptive use. The REIP values were small for every period, except the 2040s, 2060s, and 2080s under scenario RCP 4.5, and the 2040s and 2080s under scenario RCP 8.5. Both climate change scenarios showed high sensitivity in the regions Jeollabuk-do, Jeollanam-do, and Gyeongnam-do. However, regions Gyeonggi-do, Gangwon-do, and Chungcheongbuk-do had low sensitivity as compared to other regions. The REIPs were used to categorize sensitivity into four categories: low consumption-water rich, low consumption-water poor, high consumption-water rich and high consumption-water poor. The Gangwon-do region had the highest number of regions that changed from the low consumption-water rich category to the high consumption-water poor category, making it a priority for measures to improve its adaptive capacity for climate change.

KEY WORDS: Climate change, Irrigation, Paddy, Sensitivity, Water vulnerability.

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Introduction

Global warming is a worldwide phenomenon, and the rise in temperature and unpredictable changes in precipitation pose serious risks to agriculture (parry et al., 2007). The average temperature on the Korean Peninsula has risen by 1.5 °C in the past 100 years and, consequently, the crop calendar has changed and the traditional water management practices have being challenged. The slightest change in climate can easily cause changes in crop growing environments and cause serious problems for agricultural water resources in areas with great seasonal and regional deviations.

Rice comprises 90% of staple grain production in Korea and is the staple food source for over 60% of the global human population. Since rice is sensitive to weather conditions, changes in climate can drastically affect its growth and yield. Many studies have examined the changes in growth and irrigation patterns of paddy rice due to climate change. For example (Li et al., 2016) simulated rice yield and growth processes based on RCP 4.5 and 8.5 scenarios and showed that temperature increase would cause earlier vegetative periods and reduced crop yield. In Korea, (Chung. 2009) used the HadCM3 GCM model and data from A2 and B2 to analyze agricultural water demand in the Nakdonggang region; the results predicted a decrease in unit duty of water and irrigation demands. (Yun et al., 2011) used the A1B scenario to analyze changes in reference evapotranspiration and water requirement; results showed an overall increase in both aspects. (Lee et al., 2012) used a crop growth model that implemented various climate change scenarios, and showed a decrease in future consumptive use and increase in crop yield of paddy rice. (Yoo et al., 2012) used a high-resolution climate scenario, RCP 8.5, to analyze the changes in paddy irrigation requirements and unit duty of water for different irrigation districts. The results predicted variation between different irrigation districts and seasons, but on average, the actual crop evapotranspiration would increase and, thus, the paddy water requirement and unit duty of water would increase.

These studies above show that climate change threatens agricultural water security, and that the most immediate threat to future agriculture is climate change. Thus, it is essential to study the potential future risks and vulnerability caused by climate change to prepare for this threat, to promote agricultural production, and help prepare solutions, prioritize policies, and technologies. Vulnerability to climate change is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (McCarthy et al., 2011). This study analyzed the changing trends in agricultural water demands and used a water balance model to evaluate the sensitivity of rice paddy fields. Furthermore, it used an index to compare the temporal and spatial sensitivity of paddy rice cultivation to climate change, and categorized 162 cities and counties throughout the country according to the sensitivity type of paddy.

Materials and methods

Figure 1 shows the procedures for generating a sensitivity index for climate change and conducting daily water balance analyses for 162 cities and counties in 10-year increments.
Daily low/high temperatures, daily rainfall, daylight hours, and relative humidity at weather stations throughout the country over the past 40 years (1971–2010) were collected from the Korea Meteorological Administration (KMA. 2014). The daily rainfall and daily reference evapotranspiration (the Penman-Monteith equation) for the future weather (2011–2100) was calculated using data from Representative Concentration Pathways (RCP) scenarios 4.5 and 8.5.

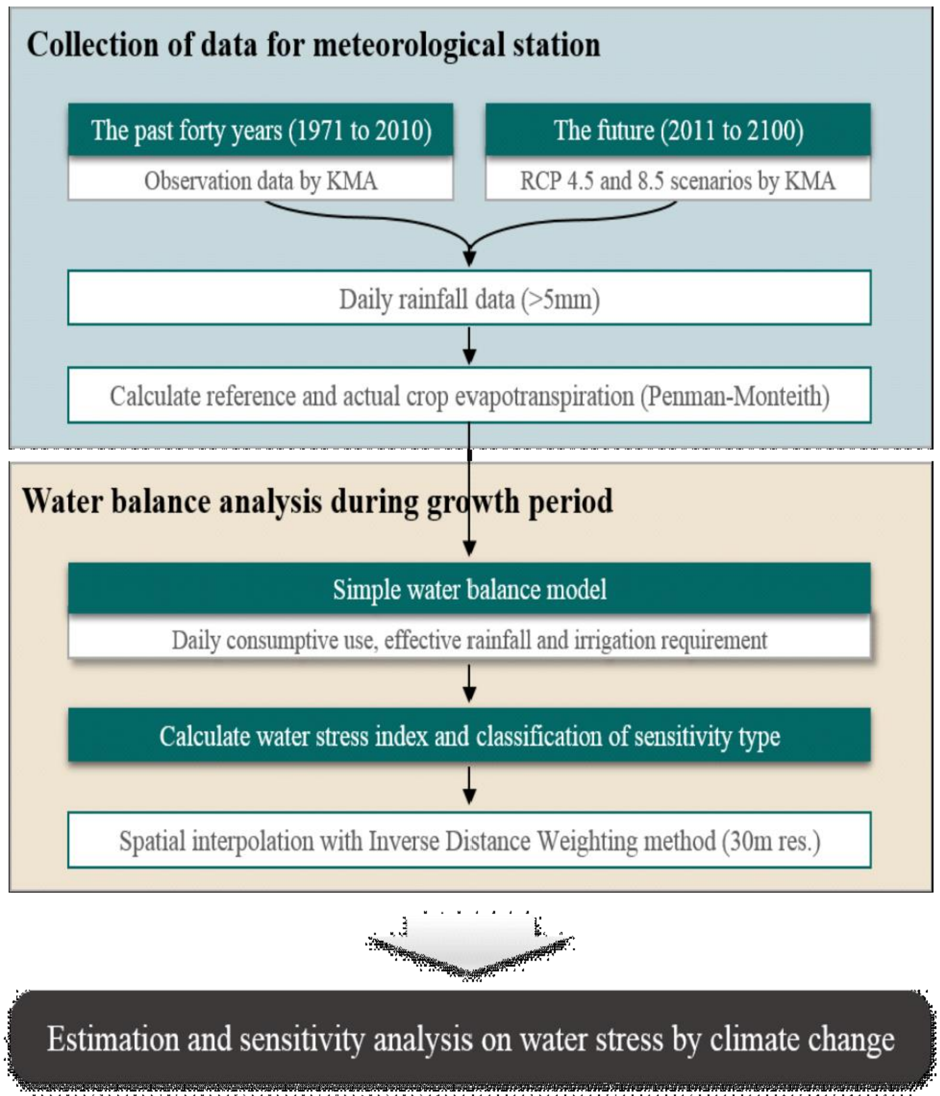


Figure 1. Procedures for evaluating sensitivity of paddy rice to climate change

Future climate change scenarios

The KMA provides climate change scenarios for South Korea based on RCP, using global and regional climate models. The dynamic downscaling technique is applied to the regional climate model (HadGEM3-RA) to generate climate change scenarios for the Korean Peninsula at a spatial resolution of 12.5 km. The study periods for the climate change scenarios are shown in Table 1. Periods were distinguished by the past (observed between 1971 and 2010) and the future (climate change scenarios, 2011–2100) and were divided into 10-year increments.

Table 1. **Past climate data and future climate change scenarios used in this study**

Period	No. of meteorological stations	Climate data	Source
1970s (1971–1980)	62	Observed	KMA
1980s (1981–1990)	68	Observed	KMA
1990s (1991–2000)	72	Observed	KMA
2000s (2001–2010)	81	Observed	KMA
2010s (2011–2020) to 2090s (2091–2100)	60	Climatic change scenarios (RCP 4.5 and 8.5)	KMA

Sensitivity index of vulnerability of paddy rice to climate change

Water balance analysis was used to predict paddy water requirements. Increase in crop evapotranspiration and decreases in effective rainfall are direct consequences of climate change that increase agricultural water demands (Jang et al., 2004). Equation 3 defines the Rainfall Effectiveness Index for paddy fields (REIP). A higher REIP indicates favorable water balance conditions with an adequate environment for cultivating paddy rice. A lower REIP indicates unfavorable conditions for growing paddy rice, and higher sensitivity to climate change.

$$REIP = \frac{\sum ER}{\sum CU} \tag{3}$$

where CU is the crop consumptive use which is defined as the sum of actual crop evapotranspiration and deep percolation, and ER is effective rainfall.

Categorizing climate change sensitivity of paddy rice

The REIP was calculated for all fields. The sensitivity to climate change may be different for two cases that have the same REIP value. Hence, this study categorized climate change sensitivity into four types, according to the magnitudes of REIP relative to a baseline, and analyzed regional characteristics. In this study, the baseline was limited to an average during 1971 to 2010. Regions where the future consumptive use was lower than the baseline consumptive use were categorized as Low Consumption (L), those where it was higher as regions of High Consumption (H). Regions where the future effective rainfall was lower than the baseline effective rainfall were categorized as Water Poor (P), those where it was higher as Water Rich (R). Second, categorization of consumptive use and effective rainfall were combined to analyze different regions according to the four sensitivity types: low consumption-water rich (LR), high consumption-water rich (HR), low consumption-water poor (LP), and high consumption-water poor (HP) (Figure 2).

Results and discussion

Temporal changes in paddy water requirements

Table 2 shows the irrigation requirement calculations throughout the paddy rice growth period for future climate change scenarios. The effective rainfall was highest in the 2000s, while consumptive use was lowest. The net water requirement was highest in the 1970s, when consumptive use was also the highest, but was the lowest in the 2000s, when effective rainfall was highest.

Temporal changes for each climate change scenario were assessed relative to the average values over the last 40 years (1971–2010). The average consumptive use for the baseline period was 536 mm, and the predicted future values for RCP were about 576 mm on average. For RCP 8.5, the average simulated value was almost 595 mm (11% increase). The annual precipitation during the cultivation period increased in all periods, relative to the baseline, except in the 2010s and 2030s..

The average effective rainfall for the baseline period was 493 mm. The predicted values for the 2030s, 2060s, and 2090s, were 492 mm (0.2% increase), 578 mm (17.2% increase), and 489 mm (0.8% decrease), respectively, for RCP 4.5, and 470 mm (4.6% decrease), 499 mm (1.2% increase), and 570 mm (15.7% increase), respectively.

The average net water requirement for the baseline period was 556 mm. The predicted values for the 2030s, 2060s, and 2090s were 602 mm (8.3% increase), 496 mm (10.9% decrease), and 620 mm (11.5% increase), respectively, for RCP 4.5, and 626 mm (12.6% increase), 616 mm (10.8% increase), and 590 mm (6.2% increase), respectively, for RCP 8.5. Specific trends were not identified due to complex effects involving increased actual crop evapotranspiration and effective rainfall.

Table 2. Results of annual precipitation, consumptive use, effective rainfall, and net water requirements for paddy fields under RCP scenarios in South Korea.

Period	PR (mm)		CU (mm)		ER (mm)		IR (mm)	
Period	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1970s	748		547		472		583	
1980s	876		539		498		559	
1990s	890		536		488		562	
2000s	954		522		515		521	
2010s	**851** (-1.8%)	918 (5.9%)	576 (7.4%)	549 (2.4%)	**473** (-4.1%)	492 (-0.3%)	605 (8.7%)	571 (2.6%)
2020s	939 (8.3%)	893 (3.0%)	555 (3.5%)	575 (7.2%)	485 (-1.6%)	**467** (-5.2%)	584 (4.9%)	623 (11.9%)
2030s	865 (-0.2%)	**848** (-2.2%)	594 (10.7%)	579 (7.9%)	492 (-0.2%)	470 (-4.6%)	602 (8.3%)	**626** (12.6%)
2040s	1,066 (22.9%)	1,057 (21.9%)	550 (2.6%)	581 (8.4%)	541 (9.7%)	549 (11.4%)	534 (-4.0%)	548 (-1.6%)
2050s	990 (14.2%)	996 (14.9%)	573 (6.9%)	600 (11.9%)	518 (5.1%)	508 (3.0%)	569 (2.3%)	602 (8.3%)
2060s	1,235 (42.5%)	869 (0.2%)	564 (5.1%)	627 (16.9%)	578 (17.2%)	499 (1.2%)	496 (-10.9%)	616 (10.8%)
2070s	1,018 (17.4%)	1,093 (26.1%)	600 (11.8%)	605 (12.9%)	506 (2.7%)	532 (7.9%)	609 (9.4%)	594 (6.8%)
2080s	1,062 (22.5%)	1,150 (32.7%)	566 (5.5%)	597 (11.4%)	533 (8.2%)	551 (11.7%)	538 (-3.2%)	571 (2.6%)
2090s	886 (2.2%)	1,127 (30.0%)	**611** (13.9%)	**641** (19.5%)	489 (-0.8%)	570 (15.7%)	**620** (11.5%)	590 (6.2%)

※PR: Precipitation, CU: Consumptive use, ER: Effective rainfall, IR: Net water requirement

※ Percentage to the baseline (the average of 1971–2010) in parentheses

Regional changes in the sensitivity index of paddy rice

This study categorized 162 cities and counties throughout South Korea, including Jeju Island, into 9 regions (U1, U2, M1, M2, M3, L1, L2, L3, and L4) to observe regional changes in the sensitivity index (Figure 3)

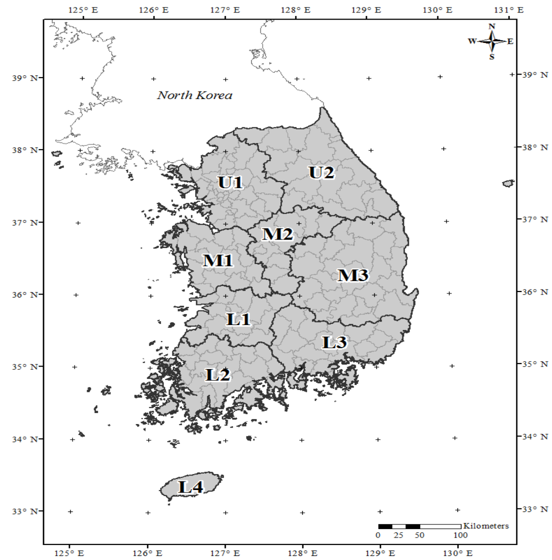


Figure 2. The 9 regions corresponding to provinces (U1: Gyeonggi, U2: Gangwon, M1: Chungcheongnam, M2: Chungcheongbuk, M3: Gyeongsangbuk, L1: Jeollabuk, L2: Jeollanam, L3: Gyeongsangnam, and L4: Jeju).

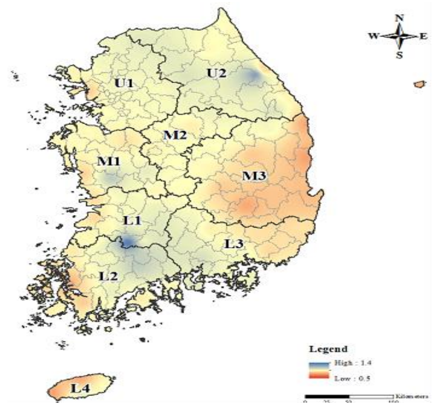
The temporal distribution of climate change scenarios RCP 4.5 and RCP 8.5 did not show significant statistical differences (Table 3). However, categorization of regional REIPs for all periods showed larger deviation for RCP 4.5 than RCP 8.5. Thus, regionally, it was predicted that RCP 4.5 has a larger deviation for sensitivity to climate change, compared to RCP 8.5.

Table 3. Temporal and regional averages and standard deviations of Rainfall Effectiveness Index for Paddy fields.

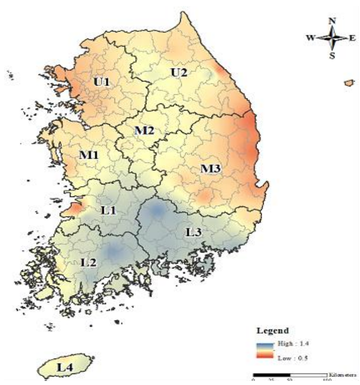
Period	RCP 4.5		RCP 8.5		Region	RCP 4.5		RCP 8.5	
Period	Avg	Std	Avg	Std	Region	Avg	Std	Avg	Std
2010s	0.91	0.078	0.97	0.087	U1	0.85	0.093	0.84	0.049
2020s	0.96	0.117	0.90	0.050	U2	0.91	0.091	0.89	0.042
2030s	0.90	0.092	0.88	0.056	M1	0.91	0.080	0.89	0.076
2040s	1.06	0.073	1.02	0.088	M2	0.98	0.089	0.95	0.069
2050s	0.98	0.061	0.93	0.083	M3	0.99	0.089	0.96	0.041
2060s	1.11	0.090	0.88	0.081	L1	1.04	0.089	0.97	0.062
2070s	0.93	0.072	0.95	0.059	L2	1.02	0.094	0.97	0.092
2080s	1.03	0.063	1.00	0.071	L3	1.09	0.081	1.05	0.070
2090s	0.88	0.083	0.97	0.091	L4	0.97	0.094	0.97	0.086
Avg	0.97	0.081	0.95	0.074	Avg	0.97	0.089	0.95	0.065

※ Avg: Average, Std: Standard deviation, bold: the minimum REIP

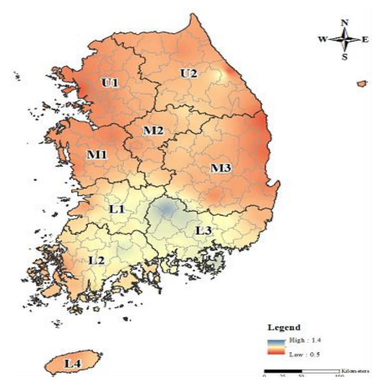
As shown in Figure 4, the L3 region was considered to have overall favorable water balance conditions in both future climate change scenarios. Regions L1 and L2, which are both major rice producing areas in South Korea, also showed less vulnerable to climate change, more than other regions. Conversely, U1, U2, and M1 had the lowest REIP for both RCP 4.5 and RCP 8.5, which indicated a need to improve the adaptive capacity for climate change in these regions.



(a) Baseline (1971-2010)



(d) 2040s under RCP 8.5 scenario



(e) 2060s under RCP 8.5 scenario

Figure 3. Spatial distribution of the REIP under different RCP Scenarios: (a) distribution of average REIP during the baseline period (1971–2010); (b) the 2060s with the most favorable REIP under the RCP 4.5 scenario; (c) the 2090s with the least favorable REIP under the RCP 4.5 scenario; (d) the 2040s with the most favorable REIP under the RCP 8.5 scenario; and (e) the 2060s with the least favorable REIP under the RCP 8.5 scenario.

Categorization of climate change sensitivity types

Climate change scenario RCP 8.5 showed an increase in the number of cities and counties classified as water poor regions during all periods (Figure 5). The average number of cities and counties classified as LP and HP in the future was 42 and 42, respectively. The 2010s and 2030s had the highest number of cities and counties classified as either LP or HP. Of most concern, was the 2040s and 2090s, where the numbers of HP cities and counties was highest, even when compared to scenario RCP 4.5. The lowest number of LR regions was during the 2060s and highest during the 2040s. For scenario RCP 8.5, the average number of cities and counties of each type were in the order of HR (26.3%) > LP (25.8%) > HP (25.7%) > LR (22.2%), showing HR with the highest weight, unlike the baseline, and showing LR with the least weight. Scenario RCP 8.5 had the highest percentage of cities and counties categorized as HR at 25.3%, contradicting the results of RCP 4.5. However, the number of cities and countries for each sensitivity type did not show a big difference between RCP 8.5 and RCP 4.5.

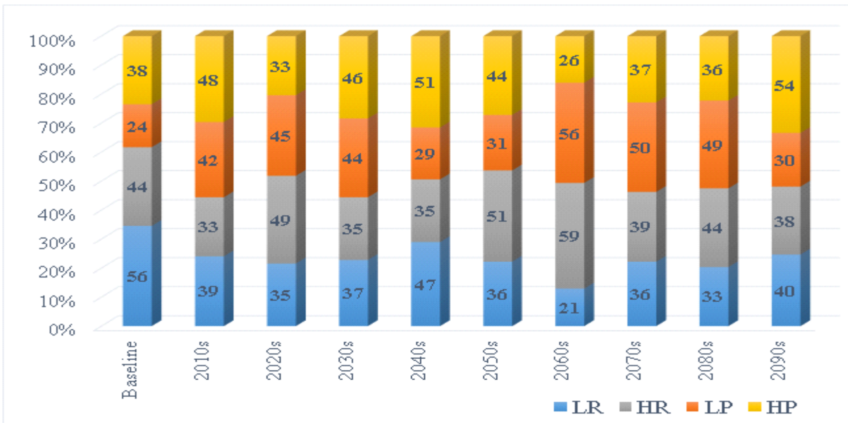


Figure 4. Regional distribution of sensitivity types for scenario RCP 8.5. The 2030s had the highest number of water poor regions and the 2010s and 2030s had the highest number of LR regions.

Regions that change from LR (the most favorable) to HP (the most sensitive type) in the future are a priority for measures to adapt to climate change. Conversely, regions that change from HP to LP are predicted to experience the least adverse effects of climate change. Figure 6 shows that regions that changed from LR to HP in the climate change scenario RCP 4.5 occurred most often during the 2030s with 27 cities and counties, and the least often during the 2060s, with only 7 cities and counties. Furthermore, from 2011 to 2100, there were 34 cities and counties that changed from LR to HP, and there were 22 for U1, 4 for U2, and 4 for M1 (Figure 10). RCP 8.5 had the most cities and counties in the 2010s (29), followed by the 2090s (27). However, the 2020s and the 2080s had 5 and 6 cities and counties, respectively, which changed from LR to HP, indicating that these periods are predicted to experience the least adverse effects of climate change. In all scenarios, U1 was the most sensitive to future climate change and is a priority for efforts to adapt to climate change. Twenty-two cities and counties improved from HP to LR for scenario RCP 4.5, and 34 cities and counties for scenario RCP 8.5. The M3 region is known as the driest region with the least rainfall and highest temperatures in South Korea.

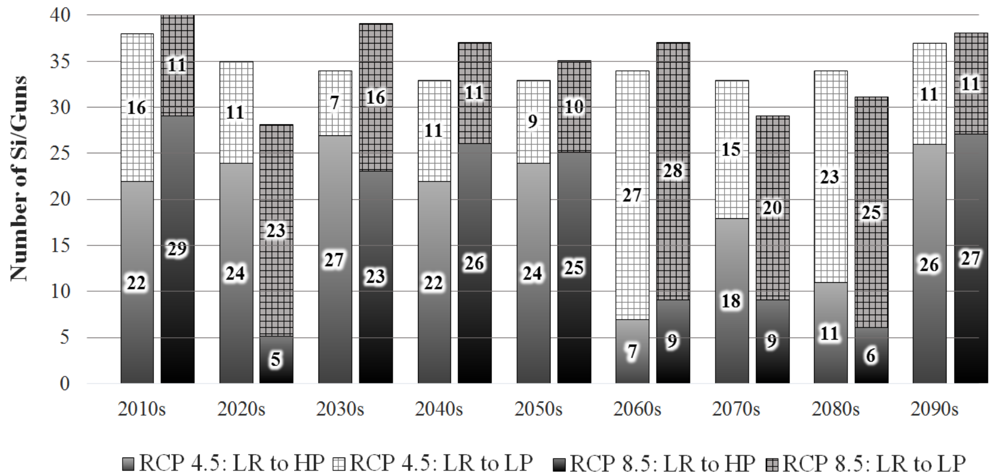
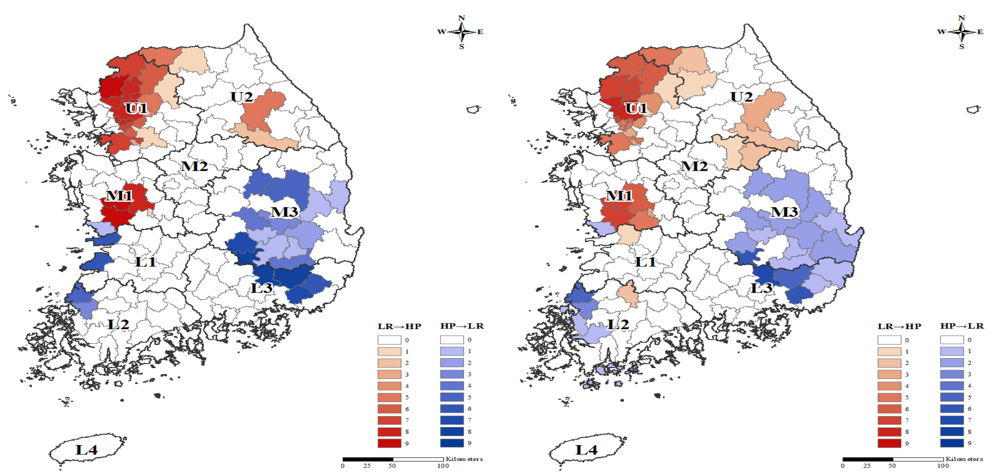


Figure 5. Comparison of changes in sensitivity types (LR to HP, HP to LR) with future climate change scenarios.



(a) RCP 4.5 Scenario (b) RCP 8.5 Scenario

Figure 6. Results of regional sensitivity changes according to RCP scenarios (Red: LR to HP, Blue: HP to LR)

Conclusion

This study predicted changes in the water balance of paddy fields using climate change scenarios RCP 4.5 and 8.5. Furthermore, an index was used to quantitatively express the sensitivity to climate change of paddy rice fields and categorize 162 cities and counties in South Korea into four types.

Scenarios RCP 4.5 and 8.5 both showed an increase in consumptive use. The increase for RCP 8.5 (average 10.9%) was higher than for RCP 4.5 (average 7.5%). The annual precipitation during the cultivation period increased compared to the present in all periods, except for the 2010s and 2030s. However, effective rainfall varied according to climate change scenarios and periods due to effects of rainfall days, rainfall intensities, and freshwater conditions of the field.

Sensitivity of paddy rice to climate change was evaluated using the ratio of consumptive use to effective rainfall (REIP). Higher REIP values indicated favorable water balance conditions, and low sensitivity to climate change, and vice versa. Compared to the REIP values over the past 40 years, sensitivity improved only during the 2040s, 2060s, and 2080s for RCP 4.5, and during the 2040s and 2080s for RCP 8.5. In the regional analysis, both climate change scenarios showed high REIP values for L3 regions, but U1 regions generally showed the lowest REIP values overall, which predicted an increase in sensitivity to climate change.

Cities and counties were categorized into four sensitivity types using the REIP: low consumption-water rich (LR), low consumption-water poor (LP), high consumption-water poor (HP), and high consumption-water rich (HR). In both RCP scenarios, the number of water poor regions (LP and HP) increased overall compared to the present. The number of cities and counties that changed from LR to HP over an extended period was highest in the U1 region, which indicated that this region should be a priority for measures to adapt to climate change. However, the M3 region showed a high number of changes from HP to LR, and was predicted to experience the least adverse effects of climate change.

This study predicted changes in agricultural water requirements from climate change and provided an index to quantitatively represent the water sensitivity of paddy rice.However, climate change scenarios include some degree of uncertainty and different information can be provided depending on the downscaling techniques or spatial resolution used (Chen et al., 2011and Oh et al., 2016). Therefore, sensitivity analysis can produce different results. In addition, since the changes in other factors, such as cultivation area or cropping system, from climate change were not considered (Li et al., 2009) future studies should address these aspects.

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MODELING THE IMPACT OF DRAINAGE DESIGN PARAMETERS ON THE AMOUNT OF NITROGEN LOSSES IN TILE-DRAINAGE SYSTEMS: A CASE STUDY FROM SOUTHWEST IRAN

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Abstract

Excessive soil nitrogen losses as a result of the inappropriate design of subsurface drainage systems have given rise to different environmental problems. The drain spacing and depth play a substantial role in the quality and quantity of the drain outflow into the environment. In this research, a simple but comprehensive simulation model using a system dynamic approach for the water and nitrogen cycle was used to simulate the impact of drain depth and spacing on nitrate and ammonium losses in sugarcane farmland at Imam Khomeini agro-industrial Company. Sixteen scenarios were modeled including the combination of four drain spacing (60, 70, 80 and 90 m) and four different drain depths (1.1, 1.4, 1.7 and 2.0 m) to compare the effect of drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses via the denitrification process and nitrogen uptake by the plant. The results indicated that through the increasing of drain spacing and the reducing of drain depth nitrogen losses in the form of denitrification and runoff would increase; and the nitrate and ammonium losses through the drainage water would decrease. Furthermore, the amount of applied urea fertilizer has a significant impact on the amount of nitrogen losses. So, based on the results the optimal tile-drainage system density in this region would be a drain spacing of 80 m and depth of 1m, in as such that the total drainage and runoff losses would be reduced up to an acceptable level. Therefore, the optimum design of subsurface drainage systems based on environmental criteria could aid in the control of nitrogen pollution on the farm-level.

KEY WORDS: Drain depth, Drain spacing, Nitrogen losses, Drainage water, Sugarcane, Imam Khomeini agro-industrial Company.

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Introduction

Artificial field drainage as a means to remove excess water in the root zone is now about 200 years old (Smedema et al. 2004), but estimating optimal drain spacing remains a challenging part of any drainage-scheme design (Shokri and Bardsley 2015). The environmental impacts of agricultural drainage have led to serious problems (Alibakhshi et al. 2013). Nitrate pollution is one of the main pollution for surface and ground water in agricultural areas. (Piccini et al. 2012; Shah and Singh 2016). The subsurface drain spacing and depth are two important parameters in designing drainage systems that play a determining role in the amount and quality of the drain outflow (Kalita et al. 2006). The inappropriate design of subsurface drainage systems would lead to the excessive loss of the soil nitrogen through drainage and runoff losses that cause environmental problems. The nitrate and ammonium pollutions in the agricultural watersheds with tile-drainage systems can be controlled by appropriate subsurface drainage systems designing to decrease the volume of drainage water and nitrate and ammonium concentrations in the drain outflow.

Nitrogen dynamics in Soil-Water-Plant-Drainage system is a complex process due to contribution of many interactions of the chemical, physical and biological processes. Thus, in order to model this complex relations in such a system we need a new tool. One of the most effective techniques for modeling complex systems is the System Dynamics approach.

The System Dynamics approach (SD) was first developed by Forrester (1961) for understanding of strategic issues in complex systems. Every SD is determined by interaction, information, interdependency, feedback, stock and flow diagram. In SD, the relation between behavior and structure of every dynamic system is based on the concept of information feedback and interaction of stock and flow variables (Simonovic 2000; Sahin et al. 2014; Neuwirth et al. 2015).

Today many simulation models have been developed for simulating nitrogen leaching and transformation in the plant root zone, the most important of them including LEACHN (Wagenet and Hutson 1989), ANIMO (Rijtema and Kroes 1991) and HYDRUS (Simunek et al. 1999). The problem of these models is number of input parameters and measuring some of them at the field-scale are really difficult or sometimes it is not possible. Moreover they cannot be used in artificial-drained farmlands for modeling of the drainage rate and the nitrate and ammonium losses from the drain pipes. This may be related to this fact that the hydraulics flow toward drains has not been taken into consideration.

The review of literature indicates that there is no study on modelling the effect of drain spacing and depth on nitrogen losses at sugarcane farmlands under subsurface drainage systems. The optimal designing of tile-drainage systems according to environmental criteria is the procedure that desirable economic and environmental results due to the ability to control pollution at the farm-level. It would be difficult and time-consuming to implement different drain depth and spacing at the farmland in other to investigate nitrogen losses from tile-drainage system. It can be achieved by simulating of different scenarios of drain spacing and depth. Therefore, the main objective of this research is the investigation of the impact of drain spacing and depth on the amount of nitrogen losses in subsurface drainage systems using a simple water and nitrogen dynamic developed model by the system dynamic approach and selecting optimal drain spacing and depth (optimal tile-drainage system density) based on environmental criteria (minimizing the nitrate and ammonium drainage and runoff losses into the environment) in a sugarcane farmland at Imam Khomeini agro-industrial Company.

Materials and methods

Description of developed model using system dynamics approach:

In order to simulate the scenarios of the impact of different drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses by denitrification process and nitrogen uptake by plant we used the developed modeled by Matinzadeh et al. (2016). Briefly, this model has two essential sub models of hydrological and nitrogen cycle. Output of hydrologic sub model include simulation of soil water content in different layers, upward flux, water table fluctuations and drainage rate from subsurface drainage system. On the other hand, output of nitrogen cycle sub model include simulation of fertilizer dissolution, nitrification process, denitrification process, ammonium volatilization, mineralization, immobilization, nitrogen uptake by the plant, soil particles adsorption, upward flux, nitrate and ammonium losses from surface runoff and subsurface drainage. The time scale of these hydrological and nitrogen variables are on a daily basis. Fig.1 shows the model structure (Stock and Flow Diagram) of developed model by Matinzadeh et al. (2016) with Vensim Professional software.

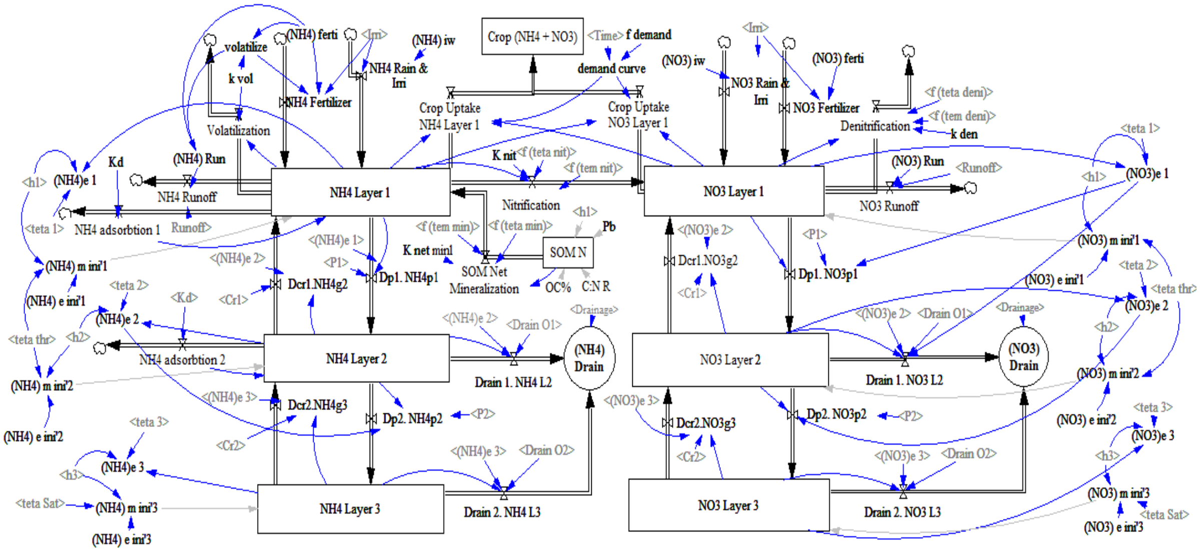

Figure 1. Developed model structure

For calibration and evaluation of developed model, we used the data measured from the study of Sadeghi-Lari (2013). These data measured from field B-129 with an area of 21 hectares that located in the Imam Khomeini agro-industrial Company at Khuzestan province of Iran. Therefore, this calibrated model was used to simulate the scenarios of the impact of drain spacing and depth on the amount of nitrogen losses from tile-drainage system in a sugarcane farmland at Imam Khomeini agro-industrial Company.

Research Area

Imam Khomeini agro-industrial Company is one of the seven sugarcane development Company that located in Khuzestan province, Iran. This region is part of the Khuzestan Shoeibieh Plain with the total area of 15800 hectares located in 40 km distance in the south of the city of Shooshtar and 50 km of the city of Ahvaz. The farmlands in sugarcane cultivations and industrial centers have been divided into fields of 21 hectares (i.e 250×850 m) and 25 hectares (i.e 250×1000 m) that include 480 farms. As well as, the subsurface drainage system parameter in this region is drain spacing 75 m and drain depth 2.1 m. The annual average temperature in the region is 24.5ºC, the average annual rainfall is 266 mm and the average annual evaporation is 2800 mm.

Tile-drainage system designing scenarios (drain spacing and depth)

The optimal designing of subsurface drainage systems plays the substantial role in reducing the concentration of nitrate and ammonium in drain outflow. Thus, spacing and depth of tile-drains are two essential parameters in designing subsurface drainage systems that have important role in drain environmental quality impacts. Therefore, in this research, 16 scenarios for subsurface drainage system designing have been implemented that include the combination of four different drain depths (1.1, 1.4, 1.7 and 2 meters) and for drain spacing (60, 70, 80 and 90 meters) to compare the effect of drain spacing and depth on the amount of ammonium losses through runoff, nitrate and ammonium losses through drainage water, nitrogen losses by denitrification process and nitrogen uptake by plant.

Results and discussion

The results of modelling 16 combination of drain spacing and depth scenarios have been presented in Table 1 and Fig. 2. As it can be seen in Table 1, by increasing the drain spacing, the nitrogen losses in the form of denitrification process and runoff will increase. This is because the increase of the drain spacing would reduce the drainage outflow and accordingly risen ups the water table level that leads to decreasing the infiltrated water into the soil and more water is discharged from the end of the farm due to runoff. Thus, denitrification process would increase because of waterlogging; and ammonium losses in the runoff would increase due to producing more runoff.

Moreover, with increasing the drain spacing, the amount of nitrate and ammonium losses by drainage water would decrease. The reason is that due to the generation of more runoff, less ammonium is infiltrated into the soil in one hand, and on the other hand because of reducing the drainage outflow and decreasing the leaching, the losses of nitrate and ammonium through drainage water will also decrease.

Meanwhile, Table 1 shows that with increasing the depth of drain, the nitrogen losses will be decreased in the form of denitrification process and runoff, since increasing the drain depth would lead to the increasing of the volume of the soil water storage, increase of infiltrated water into the soil. The result is that the drainage outflow will increase that leads to declining the level of the water table and reducing the runoff losses. Therefore, denitrification process would decrease due to the more aeration in the soil; and ammonium losses through the runoff would decrease because of decreasing runoff losses. The drain depth increase would add to the nitrate and ammonium losses through drainage outflow because of the less runoff generation, more ammonium enters into the soil, and due to the increasing of the leaching and the rate of the drainage outflow, nitrate and ammonium losses by drainage water will be more.

Table 1. Modeling nitrogen losses in different scenarios of drain spacing and depth (applied urea fertilizer was 450 kg/ha).

Drainage design		NH_4^+ runoff loss (kg/ha)	Drainage losses			Denitrification (kg/ha)	N crop uptake (kg/ha)
L (m)	D (m)		NH_4^+ (kg/ha)	NO_3^- (kg/ha)	Total N (kg/ha)		
60	1.1	50.2	20.9	91.2	112.1	97.8	123.8
	1.4	20.7	42.9	144.4	187.3	62.7	123.8
	1.7	9.7	48.8	162.9	211.7	49.5	123.8
	2	1.8	53.7	177.7	231.4	39.2	123.8
70	1.1	60.7	16.8	75.2	92.0	109.5	123.8
	1.4	28.6	38.6	125.4	164.0	80.8	123.8
	1.7	12.6	46.3	150.0	196.3	65.0	123.8
	2	4.5	52.5	170.7	223.2	46.3	123.8
80	1.1	77.1	12.9	55.9	68.7	118.2	123.8
	1.4	39.5	33.2	102.9	136.1	98.4	123.8
	1.7	21.3	41.8	130.4	172.2	80.5	123.8
	2	8.0	50.1	154.7	204.8	65.6	123.8
90	1.1	91.2	11.8	36.1	47.9	127.5	121.3
	1.4	60.5	27.1	80.6	107.7	107.1	122.5
	1.7	31.1	36.9	112.3	149.2	95.3	123.2
	2	16.1	45.5	136.3	181.8	81.1	123.6

To summarize, the highest nitrogen losses by denitrification process and runoff and the lowest total of nitrate and ammonium losses through the drainage water are in the combination of drain spacing and depth scenario of (1.1, 90 meters) that equal to 127.5, 91.2 and 47.9 kg/ha, respectively. The lowest amount of nitrogen losses due to denitrification process and runoff and the highest total of nitrate and ammonium losses through the drainage water are in the combination of drain depth and spacing scenario of (2.0, 60 meters) that equal to 39.2, 1.8 and 231.4 kg/ha, respectively. This modeling results of drain spacing and depth affecting on nitrogen drainage losses are similar to the field drainage experimental results that carried out by Darzi et al. (2013), Alibakhshi et al. (2013) and Darzi and Shahnazari (2014).

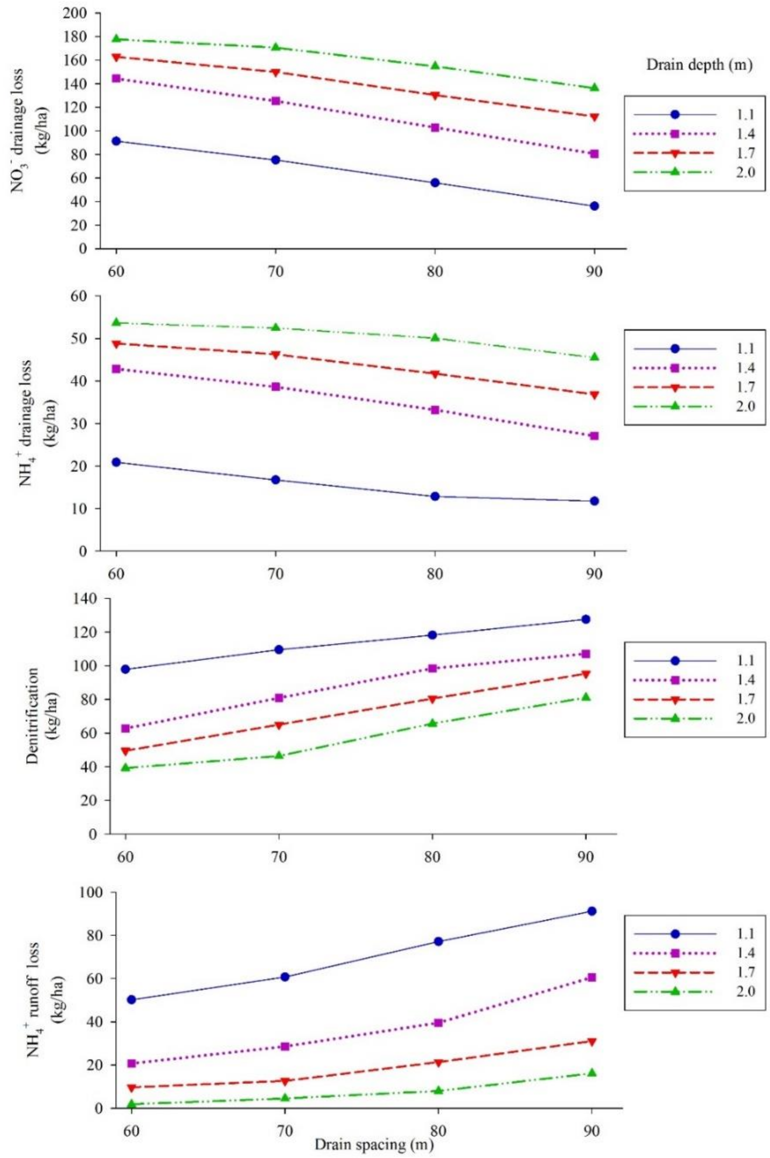

Figure 2. Modelling of nitrogen losses through denitrification, runoff and subsurface drainage system in different scenarios of drain spacing and depth (the amount of applied urea fertilizer was 450 kg/ha).

As it can be seen in Fig. 2, by increasing drainage system density (close spacing and more depth), the amount of nitrogen losses by denitrification and runoff will reduce and nitrate and ammonium losses through the subsurface drainage will increase. Therefore, the worst-case scenario in terms of nitrate and ammonium losses through drainage water is related to the highest drainage system density (scenario of 2.0 m depth and spacing 60 m). The worst-case scenario in terms of nitrogen uptake by the plant and nitrogen losses through runoff and denitrification is in the less density of drainage system (scenario of 1.1 m depth and spacing 90 m)

According to Table 1 and Fig. 2, nitrogen losses are high both through denitrification and runoff and also by tile-drainage system, and this is because of the excessive use of urea fertilizer in the Imam agro-industrial Company (applied urea 450 kg/ha).

Therefore, it is not possible to determine the optimal tile-drainage system density. Thus, to achieve this purpose, it is necessary first to apply the optimum urea fertilizer. The optimal drainage system density is a combination of drain depth and spacing that reduces the nitrogen losses through denitrification, runoff and drainage to the environment.

As mentioned previously, in order to determine the optimal density of tile- drainage system, it is necessary first to apply an optimized fertilizer in the farmland. Abbasi et al. (2015) and Matinzadeh et al. (2016) recommended 210 kg/ha of optimized urea fertilizer for the sugarcane in Imam Khomeini agro-industrial Company that should be applied during four split according to conventional fertilization timing in this area. Thus, 16 different scenarios of drain spacing and depth with 210 kg/ha of applied urea fertilizer were modeled to select the optimum tile-drainage system density. The results have been presented in Table 2 and Fig. 3.

Table 2. Modeling nitrogen losses in different scenarios of drain spacing and depth (applied urea fertilizer was 210 kg/ha).

Drainage design		NH_4^+ runoff loss (kg/ha)	Drainage losses			Denitrification	N crop uptake
L (m)	D (m)		NH_4^+ (kg/ha)	NO_3^- (kg/ha)	Total N (kg/ha)	(kg/ha)	(kg/ha)
60	1.1	23.2	8.3	31.6	39.9	45.6	123.8
	1.4	9.6	18.5	56.4	74.9	29.4	123.8
	1.7	3.7	22.4	63.6	86.1	23.6	123.8
	2	0.6	23.8	70.0	93.8	18.3	123.8
70	1.1	28.6	6.2	20.8	27.0	54.6	123.8
	1.4	12.5	16.6	50.1	66.8	38.1	123.8
	1.7	5.8	20.2	59.8	80.0	30.1	123.8
	2	1.3	22.9	66.7	89.7	22.8	123.8
80	1.1	38.0	5.3	15.5	20.8	61.5	122.3
	1.4	17.9	14.5	42.7	57.2	47.5	123.1
	1.7	9.2	18.3	53.8	72.1	38.1	123.6
	2	3.5	21.5	61.8	83.4	30.8	123.8
90	1.1	45.1	4.2	12.2	16.4	65.7	120.1
	1.4	28.0	12.2	34.8	47.0	52.2	121.3
	1.7	13.4	16.2	47.1	63.3	46.3	122.0
	2	7.0	19.5	56.0	75.5	38.9	122.4

As Fig. 3 shows, the trend of nitrogen uptake by the plant and nitrogen losses through denitrification, runoff and drainage to the variation of drain depth and spacing are similar to Fig. 2. So that through reducing drain depth and increasing drain spacing (reduction of tile-drainage system density), nitrogen loss in the form of denitrification and runoff would increase; and the nitrate and ammonium losses through the drainage water would decrease.

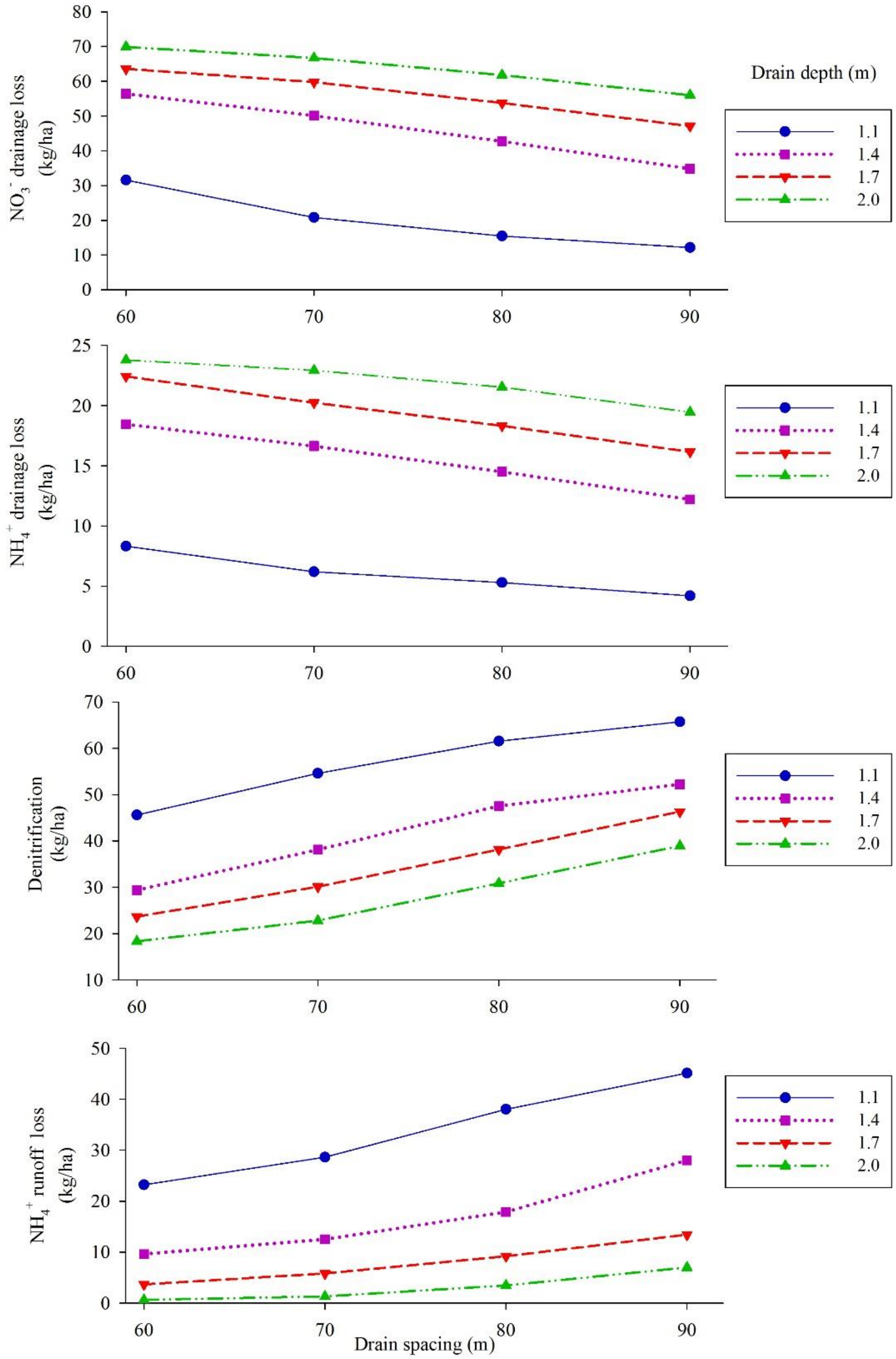

Figure 3. Modelling of nitrogen losses through denitrification, runoff and subsurface drainage system in different scenarios of drain spacing and depth (the amount of applied urea fertilizer was 210 kg/ha).

According to the results of this study and the environmental criteria, for reducing the nitrogen losses from the tile-drainage system, the depth of drain should be decreased and drain spacing should be increased. Therefore, in this area for the optimized density of subsurface drainage system the depth is 1.1m and the spacing is 80 m, so that the total tile-drainage losses of nitrogen would reduce to less than 25 kg/ha.

In this optimum density of the tile-drainage system, the total amount of nitrate and ammonium drainage losses compared to the current situation (236.8 kg/ha) would decrease by 71.3% for 450 kg/ha of applied fertilizer and 91.2% for 210 kg/ha of fertilizer. Therefore, this has a significant effect on reduction of nitrogen pollution load into the water resources and environment.

Conclusion

In this study, a simple but comprehensive developed model for water cycle and nitrogen dynamics was used to simulate the effect of drain spacing and depth (drainage design parameters) on nitrogen losses by system dynamic approach. The optimum designing of the tile-drainage systems according to environmental criteria can control pollution at the farm-level. The results of this research indicated that the more density of tile-drainage system would cause reduction of denitrification process, reducing nitrogen losses through the tail water runoff, increasing the drain installation costs and increasing nitrogen losses by the drainage water (increasing losses of fertilizer). On the other hand, less density in the subsurface drainage system would result in increasing denitrification process, increasing nitrogen losses by runoff, reducing the drain installation costs and reducing nitrogen losses through the drainage water (reducing losses of fertilizer).

Therefore, it is suggested to change the approach towards the criterion and principles of designing the tile-drainage systems to environmental standards.

Furthermore, this study recommends that in farmlands of Imam Khomeini agro-industrial Company, the drains should be installed at the shallow depth of the field (1.1 meter). This leads to reduce fertilizer losses and other pollutants.

Moreover, the system dynamics approach was found a powerful approach among available techniques that incorporates multidisciplinary research efforts and deals with the dynamic nature of the management problem for effective decision-making. The advantages of this approach include clear conceptualization, easy model adaptation, fast programming and accessible user interface.

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RECONSTRUCTION OF RECLAMATED AREAS DRAINED BY PIPE DRAINING SYSTEMS

Yuri G. Yanko[1,*]

Abstract

According to monitoring of drainage systems data, regardless depreciation guidelines, the main elements of pipe drainage systems are efficient and are able to significantly prolong effective work of systems with the help of pipe line flashing. Impartial assessment of drainage systems can be obtained on the basis of systematic monitoring which is part of extended monitoring of meliorated lands. On practice, monitoring is based on recognition observations and extraction of drainage pipes. In order to prepare planning documentation for repairing and reconstruction of pipe drainage systems, operating set of documents must be analyzed and afterwards detailed monitoring to be performed in accordance with approved methodology. Here with, reasons of soil water-logging and soil type units are being settled, areas with normal conditions and areas with not satisfied quality of drainage are being determined, conditions of exterior parts of drainage systems (soils, wells, filters) are being examined, and also areas for subsequent test drillings are being traced. While stripping of drainage pipes estuarial parts of reservoirs, draw wells and pipe connections, connections of drainage pipes and reservoirs are being examined, reservoirs and drainage pipes conditions, pore space of pipes, filtering materials and back filling are also being examined. Besides depth of drainage systems and their elevation are being determined in order to create measures to eliminate dysfunctions.

KEY WORDS: Land reclamation, Subsoil drainage, Humid zone, Reconstruction.

Introduction

Major part (more than 70%) of reclaimed lands in Leningrad region are drained by subsurface drainage. Common use of subsurface drainage for the purpose of drainage in Leningrad region started at the end of 1950-ies. To specify efficiency of subsurface drainage network in Leningrad region surveys and state estimation of subsurface drainage have been performed since 1980. Since 2002 survey of drainage systems with detailed description of all structural components has been performed in Leningrad region. The target of the survey is to receive objective information about

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status and operability of some drainage structural components, to find out deficiencies of structures on the base of this information and to introduce suggestions on these elements improvement.

Materials and methods

For 2002-2013 the drainage network survey has been performed at 35 sites with different soil conditions with total area of 2,380 hectares (ha). Total length of surveyed collector and drainage network is 995,049 meters (m), including 111,749 m of collectors, 883,300 m of drains and 59 drain wells and 545 mouths. Detailed survey of collector and drainage network status has been performed at 16 reclamation sites with total area of 1,012 ha; length of surveyed part of collectors is 38,921 m, drains – 183,594 m, 630 pits at collectors and 718 drains. At the same time description has been made of pipes cavity, joints of clay pipes, protective filtering material, trench filling material, connection of drains with collector, pipe connection in mouths and wells. Survey was mainly focused on the following statuses of main design parameters and structural components of drainage:

Slope and depth of collector and drainage network

In Leningrad region minimum permissible slope of 0.003% for regulating network is accepted. Minimal depth of drains in 1970-ies was 0.8 m and then was increased up to 1.0 m. Practically for all collection networks required slope is met; 19 sites without slope and 5 sites with adverse slopes (sites of Kupriyanovka and Kondokopshino) were found out. Inadmissible small depth of collectors imbedding was found out in 38 pits (6%) – sites of Sobolevka, Kupriyanovka, Kondokopshino. Significant part of regulating drain network is located at extremely small depths and part of drains (33%) is located at depth less than 0.8 m.

Drain pipes integrity

Practically all surveyed collectors are made of clay pipes with diameter of 7.5; 10 and 15 cm. While surveying drain systems several facts of drain pipe destruction were found out; these are facilities constructed later and destroyed mainly by linear facilities (cable networks, gas-pipe lines, etc.) – site of Pobedovka. At the site Plavuchi Most of Volokhovskoye CJSC smashed clay pipes were found; probable reason of destruction is an impact of frozen ground block during back filling of the trench. At the same time it is necessary to note that no cases of clay pipes destruction and layering were found due to their ageing. In 1980-ies use of corrugated polyethylene pipes with diameter of 63 millimeters (mm) with slot perforation increased. At all sites, where polyethylene drain pipes were penetrated, complete integrity of pipes was observed.

Joints of clay pipes

In compliance with norms and recommendations in regard to drainage systems used at the time of their construction optimal gap width between joints of clay pipes is 2 mm and permissible lateral tilt shall not exceed 1/3 of pipe wall thickness. Estimation of clay drainage joints was performed basing on such requirements. Joints of clay pipes are mainly tight:

- at collection network joints are tight in 560 cases (89%), in 70 pits gaps are found that exceed permitted rate (11%). It is explained largely by low quality of clay pipes with large diameter of 10 and 15 centimeters (cm)
- at regulating network joints are tight in 587 cases (97%), inadmissible large gaps are found in 16 cases (the gap was equal to 3-5 mm) – 3% of all open joints.

Inadmissible large gaps in joints of clay pipes at non-availability of protecting filtering material (moss digestion) were the main reason of drainage cavity siltation and decrease of its operability at sites of Kupriyanovka and Kondokopshino.

Protective filtering material (PFM)

Moss and later glass-fiber mat was used as protective filtering material up to 1970-ies. Glass-fiber mat used in the form of strips as PFM is still preserved; its normal status is guaranteed practically in all cases of its usage (433 joints at collectors – 70.5% of opened clay pipe joints). There are single cases of rooting at glass-fiber mat surface (Picture 1).

Picture 1. PFM penetrated by roots

Moss used for protection of clay pipe joints rotted and only in several cases moss remains are present; in majority of cases even traces of this material are absent (sites Chyornaya rechka LPOOS, Mykkolovo, Prirezka and a part of Kondokopshino site) – 228 pits at collectors – almost 37% of opened joints. Protective material was not found at drains in 46 pits (24% of surveyed sites). In eroded and unstable soils it is the main reasons for essential siltation of clay pipes cavity, especially with large gaps at joints. At the site of Mykkolovo clay drains were penetrated with plastic couplings that also did not provide protection from siltation – up to 25% of drain cavities are silted. During survey it was stated that all types of PFM are preserved at polyethylene pipes.

Mud fill of PFM by ocherous compounds was found out in mouth parts of single drains at the site of Agrofirma Rassvet CJSC (Picture 2).

Picture 2. Ochreous deposits at PFM

Status of trench filling material

Taking into consideration that drainage with depth filter has been used practically at the end of large-scaled reclamation projects at major part of drained lands the drainage systems is constructed with drain padding by soil. Water receiving capacity of such drainage strongly depends on status of trench filling material. Surveys performed in 1986 noted intensive compaction of subsoil, and it was considered at that period as one of the main reasons for significant efficiency decrease of subsurface drainage systems at low permeability soils. That is why during current survey status of trench filling material has been subjected to obligatory examination. Status of trench filling material has been surveyed in 708 pits. It was found out during survey that:

-loose trench filling material with soil traces is found out in 396 pits (56%);

- condensed trench filling material is found out in 276 pits (40%), including 61 pit where trench filling was practically the same as ground itself;

- in 36 pits drain trenches are filled with peat;

- in 3 pits sand depth filter has been penetrated with height of 0.2 m;

- in 3 pits sand depth filter has height of 0.8 m;

- in 1 pit at Kondokopshino site filtering elements of textile manufacture waste were found.

Compacted drain filling, especially at sites consisting of heavy soils (Kondokopshino, Sobolevka, Mykkolovo, Prirezka 1, Choyrnaya rechka), is one of the main factors witnessing efficiency decrease of subsurface drainage. Examples of dtrais disctructions are shwown on a Picture 3.

Picture 3. Silty clay drainage pipe

Drains connection with collector

Drains connection with collector has been mainly performed by holes overlapping in drainage and collector network. 84 drain connections with collectors were found out, 68 are performed by clay pipes overlapping with holes adjustment, 16 are connected by means of plastic connection angles. Connections are mainly well preserved; in major part there are supports by stone or clay pipe; place of connection is wrapped by glass-fiber mat; for 5 connection moss was used as PFM (moss remains are found), in 17 connections there is no PFM; in 2 cases clay pipes were used with prefabricated holes. Siltation of pipe cavity at place of connection is found out in 8 cases (7 cases at Kupriyanovka site, 1 case – at Kondokopshino site); a cracked clay pipe is found out at one connection.

Status of pipes cavity in collector and drainage network

State estimation of collectors and drains cavities has been made during pipe cavities opening in 1,339 pits, including 630 pits at collectors and 718 pits at drains. Data about cavity status of collector and drain network are specified in the Table 1. More than half of surveyed collection network has clean cavity of pipes (336 pits – 53%), in 163 pits deposit fills up to 25% of pipe cavity (26%), siltation of more than 25% of pipe cavity is found out in 63 pits and in 68 pits more than 50% of pipe cavity is silted. In 3 cases (at sites of Kondokopshino and Sobolevka) root mass penetrated to pipe cavity. In 131 cases siltation occurred in the result of PFM non-availability (including moss rotting), inadmissible big gaps in pipe joints or collector destruction. Weediness of collection pipe cavity is found out in 3 cases in mouth part. Pipe cavity of almost 80% of collectors is clean or silted less than per 25% and collection network is in rater well operable status. To recover operability of a major part of collectors washing and repair of mouths will be sufficient. Siltation changes of collection pipe cavity were evaluated by 4 pits located in lower 120 m part of collector. Pits were located in the mouth in each 25-30 m. These data prove that there are no essential changes in siltation degree along the collector length (except for mouth). Major part (87%) of regulating network also has clean pipe cavity or a cavity with insignificant siltation (up to 25%). Intensive siltation at Podobedovka site is induced by destruction of drainage network by the pipeline constructed later that cut drainage. At sites Experimental Field and Central Department joints of clay pipes are compacted; siltation is induced probably in result of moss rotting as moss was used for protection at eroded unstable soils that did not allow creation of natural soil filter at joints of clay pipes. Significant siltation of drains at Kondokopshino site is induced by inadmissible large gaps in pipe joints (3-5 mm). All drains, except for mouth part of single drains at the site Prigorod of AgroRassvet CJSC, performed of polyethylene pipes have clean non-silted pipe cavity. At the mouth of drains at the site of Sobolevka root corks were penetrated.

Drain wells

For subsurface drainage network of Leningrad region small area of drainage systems is the most specific feature. That is why drainage systems include rather small number of wells. At 15 reclamation sites with total area of 1,686 ha statuses of 59 drainage wells have been evaluated. All wells turned out to be back-drop manholes made of reinforced concrete rings with diameter of 1.0 m. Only two wells are blind (one well at Kupriyanovka site and one well at Sobolevka site), other wells are inspection. Only 8 wells (14 %) out of 59 were in normal status; other wells were silted and 30 wells (51%) were destroyed. In 11 wells pipe joints were damaged. Main reason of wells destruction is displacement (or breaking away) of the upper ring, holes around the well. Upper ring breaking away and displacement with seal failure is induced mainly by agricultural equipment running during field works and in some cases (in cohesive soils subjected to frost heaving) by deformation in result of frost heaving. Upper ring were absent in part of wells. Practically at all wells setting vessel is silted or filled with waste, there are no covers. Thus, it is necessary to note that practically all wells (92%) at drainage network are in unsatisfactory status being at the same time an essential factor of drainage efficiency. Considering typical reason of well destruction, it is necessary to change well structure.

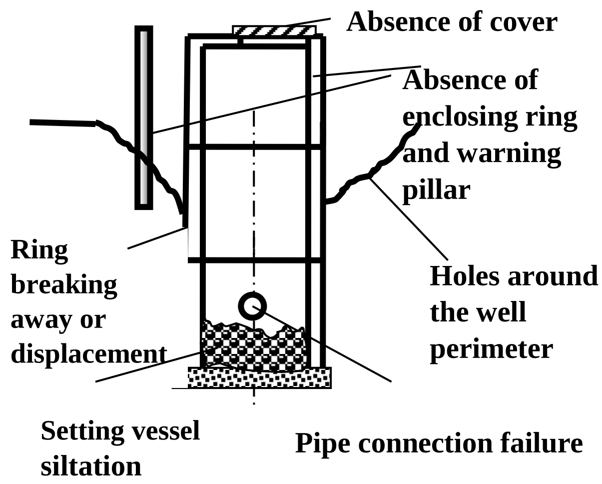

Figure. 1. Typical structure of drain well with specification of main deficiencies

Mouths

For the period of reclamation facilities survey 545 mouths were examined. The following facts were found out during the survey:
- 147 mouths are in normal condition (27%);
- 157 mouths are silted (29%);
- 241 mouths are destructed – mouth heads are displaced or absent;
- in 58 cases connection of mouth pipes with collector are damaged.

The biggest siltation degree and the biggest degree of root corks formation are specific for mouth part of collectors.

Excluding mouths of single drains at Prigorod site of Agrofirma Rassvet CJSC, ochreous formation at the mouth part was not found at the surveyed sites. At mouths of single drains at Prigorod facility ochreous formation at PFM is observed. Heads cut in to the bank are subjected to displacement most of all. Mouth walls mounted at the slope foot, as a rule, remain in better condition. It is necessary to note that washing of collectors in mouth part was not observed. Pipe joint failure indicates mainly use of short (less than 2 m) moth pipes.

Results and discussion

Even using just visual inspection without pipes disclosure is possible to determine factors affecting efficiency of pipe drainage systems, for example:

- afflux of drainage system by inlet channel or reservoir;

- distraction of pipe drainage system by later constructed facilities (line structures manly);

Some features of pipe drainage systems dysfunction these are requiring pipers disclosure:

- estuarial part of reservoir absence and allocation of drainage pipes on water-logged contours;

- water stagnation, wet spots or their traces presence on the territory drained by pipes.

Sludge setting of pore space of pipe drains is mainly occurs on unstable sandy and sandy clay soils. Pipes sludge setting causes decrease of intake and water transmission capacity in a drainage system. A pipe sludge setting around 30% decreases water transmission capacity on 40%, sludge setting on 70% causes decrease more than on 80%. Dependence of water intake capacity of pipe drainage on sludge setting level is presented on a Figure 2.

To improve efficiency of pipe drainage system is required to maintain in good conditions conductive channels receiving the drainage water, estuarial parts of reservoirs, dumb wells and pipe connections in dumb wells. In low water conductive subsoil water transmission of bulk filling is necessary to be estimated. Water transmission of bulk filling must be no less than 1.5 m per day. For areas where compaction and low water transmission capacity of bulk filling are found is recommended:

- carry out agroeliormative measures such us soil stratification and breaking up of compressed plough pan. Soil stratification depth must lay upper than drainage pipes layer;

- partial replacement of bulk filling with material of high filtering capacity by virtue of filtering stations and absorbing stations arrangement.

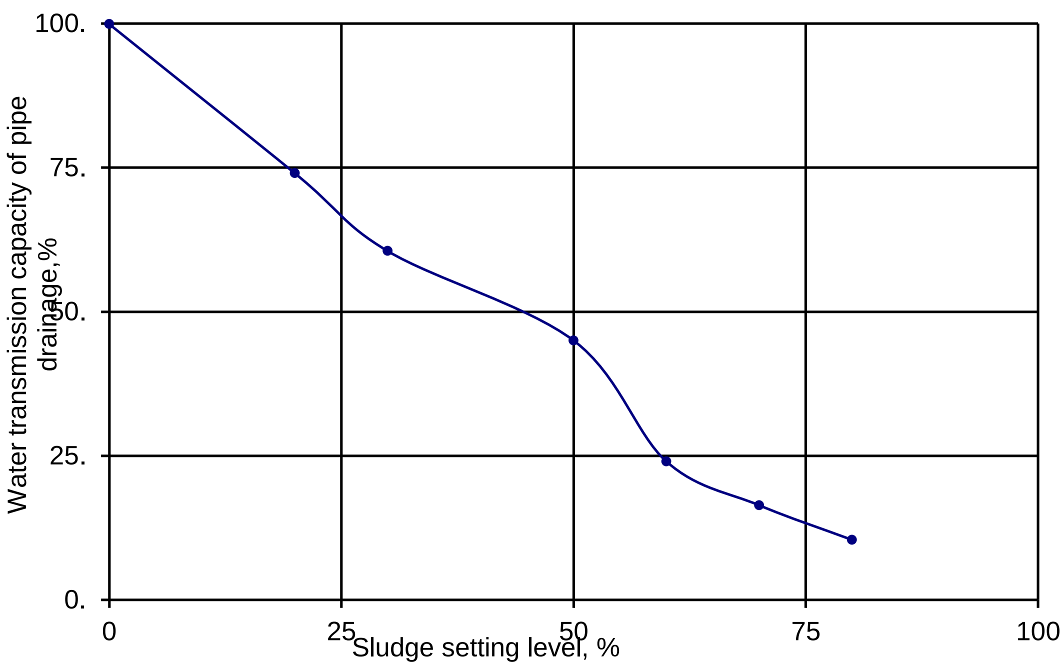

Figure 2. Dependence of water intake capacity of pipe drainage on sludge setting level

If drainage systems dysfunction caused by low-low cover thickness of drainage pipes, counter slopes of drainage lines, high-high gaps between clay pipes, displacement or drainage distraction then drainage functionality can be achieved only by reconstruction of damaged areas or by new drainage system creation. New drainage system arrangement must be preformed if sludge setting level of pipes exceeds 50% of dry mass. Pipe line flushing is the main measure of reconstruction of drainage systems. Pipe line flushing is recommended when sludge setting or chemical erosion cover more than 80 % of pipe section by the dry mass. Flushing of pipes is time-consuming process and efficient only in case if sludge setting found on no more than 30% of pipe section. Flushing provides cleaning of drainage pipe pores from clay sheet and rust and also provides restitution of water intake and water transmission capacity of pipes. Water pressure in a pipe should not exceed 20 mPas in order to prevent formed depth filter to be destroyed by manometric pressure. In other case pipe drain will be cleaned, but efficient field drainage will not be obtained. Capping mass in dependence on sludge setting intensity and pipe diameter is presented in a Table 1.

Table 1. Capping mass in dependence on sludge setting intensity and pipe diameter

Sludge setting intensity, %	Capping mass intensity,%	Capping mass volume / pipe diameter, м3/100 m			
		50 mm	75 mm	100 mm	150 mm
10	26	0,02	0,04	0,08	0,18
20	34	0,04	0,09	0,16	0,35
30	39,5	0,06	0,13	0,24	0,53
50	50	0,10	0,22	0,39	0,88
70	83,6	0,14	0,31	0,55	1,24
80	89,6	0,16	0,35	0,63	1,41

For development of design specifications and estimates for reconstruction and maintenance of pipe drainage systems is reasonable to carry out the development within two phases: the first one is field monitoring and dysfunctional pipes disclosure for listing of necessary documentation, and the second is project development.

Conclusion

1. One of the most efficient ways for rehabilitation of pipe drainage systems is pipes flushing with low pressure and considerable water expense;
2. To provide high long-term efficiency of pipe drainage system pipe flushing must be performed systematically.

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3

Topic 3:
Adaption of New Design Criteria in Favor of the Environment

EFFECTS OF VEGETATIVE BUFFERS ON SEDIMENT AND ITS ASSOCIATED POLLUTANTS TRANSPORT AND DEPOSITION

Sina Akram[1,*], Bofu Yu[2], Hossein Ghadiri[3]

Abstract

Silt and clay are primary carriers of adsorbed chemicals- especially phosphorus, chlorinated pesticides- and, most metals, and pathogens which are transported by sediment into aquatic systems. Sediments originate mainly from erosion of valuable topsoil of agricultural land. The control of agricultural pollution usually begins with measures to control erosion and sediment runoff.

Grass buffer strips impact overland flow hydraulics and consequently sediment delivery from hillslopes. Mathematical models facilitate the evaluation of performance of grass strips in reducing sediment delivery by simulating and predicting flow characteristics and sediment transport adjacent to and within grass strips. The GUSED-VBS 2 model has been developed to simulate flow, erosion and deposition processes in the upstream area and within grass strips.

The model is capable of estimating the proportion and amount of different sediment size classes in the outflow. The modified Green-Ampt equation was used to simulate infiltration. Gradually varied flow and a kinematic wave approximation were used to simulate flow characteristics upstream and within grass strips. The GUEST model was modified in order to use its basic approaches in the sediment transport module for grass strips. Model predictions agree well with measured data from a set of controlled experiments. The sensitivity analysis showed that the initial soil moisture and flow rate were the most sensitive parameters in predicting runoff loss. Increasing the slope steepness and flow rate dramatically decreased the efficiency of grass strips in reducing sediment concentration and sediment delivery.

Comparing the results of the model simulations for different prevalent scenarios showed that the backwater region upstream of dense grass strips is the main region for sediment deposition on low slopes. In agreement with the experimental observations, the model predicted the proportion of coarse particles to be higher in the deposited material upstream of grass strips compared with the deposited material within the grass strip. The efficiency of grass strips in reducing the concentration of sediment is much higher for coarser than finer particles. Grass strips can thus substantially decrease the delivery of fine particles if a significant reduction in runoff (i.e. infiltration) occurs within the strip. As no backwater forms on high slopes and the flow velocity is high in steep lands, particles will not have enough time to deposit ahead of the strip. Having long grass strips can amend the low trapping efficiency associated with extreme conditions such as high slope, wet soil and sparse grass strips by providing more opportunity for particles to settle and more runoff reduction. The new model is a tool to simulate transport and deposition of sediment along with its associated pollutants into the surface drains, rivers, lakes, wetlands and other receiving water bodies.

KEY WORDS: Model, Grass Strip, Sediment, Vegetated Strip.

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Introduction

Grass strips have been extensively tested and used to alleviate sediment and associated pollutants delivery to rivers (Abu-Zreig et al., 2004; Dabney et al., 1993; Hook, 2003; Parsons et al., 1994; Raffaelle et al., 1997; Rey, 2004). The two processes of increased roughness and infiltration enhance trapping of sediment particles upstream from and within grass strips (Akram et al., 2014; Deletic and Fletcher, 2006; Le Bissonnais et al., 2004; Schmitt et al., 1999; Shrestha et al., 2005).

A few models have been developed to predict the performance of grass strips in removing sediment. Although these models have helped decision makers, the models are not yet sufficiently accurate in some aspects and cannot explicitly describe the sediment transport and deposition processes in time and space.

The objectives of the paper are 1) to develop a new approach for predicting the fate of water and sediment in and around grass buffer strips, and 2) test the performance of this new model with two sets of controlled experiments, and 3) assess model sensitivity in order to clarify the effect and importance of various factors in the performance of grass strips. The highlight of this new model is the process-based simulation of the combined effect of buffer strips on sedimentation upstream and vegetation induced infiltration and sedimentation within the buffer strip. This has not been achieved in the papers reviewed above. The research by Hussein et al. (2007) which simulates the hydrology and sediment transport in the upstream section from grass strips is extended in this paper to include what occurs inside buffer strips. The model is based on Hairsine and Rose (1992) method, which assumes that soil erosion and deposition processes occur simultaneously.

Materials and methods

The model, hence called Griffith University Soil Erosion & Deposition-Vegetative Buffer Strips2 (GUSED-VBS 2), is a process-based model which simulates the deposition and erosion processes upstream and within grass buffer strips in single runoff events.

Following assumptions have been made in developing this model:

- The inflow is steady and subcritical.
- Deposition and re-entrainment (detachment of deposited sediment by overland flow) are the two main processes occur concurrently which change sediment concentration along the path.
- As the length of backwater is short and the permeability of bare soil is dramatically lower than vegetated ground, infiltration is neglected in the upstream region.
- Particles are trapped due to infiltration regardless of their size.
- Deposited mass due to infiltration settles on the soil top and does not percolate within.
- Vegetation is non-submerged.

Hydrology and sediment transport are modelled primarily in the upstream region. Water depth and sediment concentration of different particle size classes at the upstream end of backwater region in every time step are considered as initial conditions within buffers. Gradually varied flow equation is used to calculate flow characteristics upstream the grass strip:

$$\frac{dD}{dx} = \frac{S_0 - S_f}{1 - Fr^2} \quad (1)$$

where D is the water depth (m), x is the downslope distance (m), S_0 is the bed slope (m m^{-1}), S_f is the frictional slope (m m^{-1}), and Fr is the Froude number.

Change of sediment concentration over distance is calculated using the following equations:

$$q\frac{dc_\mathrm{i}}{dx} = -v_\mathrm{i}c_\mathrm{i} + Hr_\mathrm{max}\frac{v_\mathrm{i}c_\mathrm{i}}{\sum v_\mathrm{i}c_\mathrm{i}} \quad (2)$$

$$r_\mathrm{max} = \frac{F\sigma(\Omega - \Omega_\mathrm{o})}{g(\sigma - \rho)D} \quad (3)$$

$$\Omega = \rho g q S_f \quad (4)$$

where q is the unit flow rate (m^3 m^{-1} s^{-1}), c_i is the sediment concentration in size class i (kg m^{-3}), v_i is the fall velocity for size class i (m s^{-1}), H is the ratio of soil covered by deposited sediment to the whole area, r_{max} is the maximum rate of entrainment (kg m^{-2} s^{-1}), F is the available stream power available for entraining particles, σ is the wet density of sediments (kg m^{-3}), Ω and Ω_o are stream power and threshold stream power per unit area (W m^{-2}), and ρ is the water density (kg m^{-3}).

The distribution of particle size classes is to be given as input data to the model. Settling velocity for every class is estimated using Cheng method (Cheng, 1997):

$$v_\mathrm{i} = \frac{\left(\sqrt{25 + 1.2{d_*}^2} - 5\right)^{1.5}\vartheta}{d} \quad (5)$$

$$d_* = \left(\frac{(\sigma - \rho)}{\rho\vartheta^2}g\right)^{1/3} d \quad (6)$$

where v is the kinematic viscosity (m^2 s^{-1}), and d is the mean diameter of the particle size class (m). Cheng method is applicable to both laminar and turbulent flow regimes.

Deposition and entrainment processes change the bed elevation. The model is able to dynamically change the slope by:

$$\frac{dz}{dt} = -\frac{q}{\sigma(1 - \lambda)}\frac{dc}{dx} \quad (7)$$

$$S_0 = \frac{dz}{dx} \quad (8)$$

Where z is the bed level (m), $\boldsymbol{\lambda}$ is porosity, and t is time (s).

Equations 1 to 8 are identical to those used in Hussein et al. (2007).

The processes within grass strips are more complex. Infiltration intensifies particles settling; the infiltration rate is therefore also added to the settling velocity of each particle size class. The other complexity of the processes within the grass strip is that the flow is gradually varied, and unsteady.

Kinematic wave approximation is used in order to predict flow characteristics spatially and temporally along grass strip by the following equations:

The continuity equation:

$$\frac{\partial q}{\partial x} + \frac{\partial D}{\partial t} = -f \qquad (9)$$

Manning formula is used as the momentum equation:

$$q = \frac{1}{n} D^{5/3} {S_f}^{0.5} \qquad (10)$$

where f is the infiltration rate (m s^{-1}), and n is the equivalent Manning roughness coefficient inside grass strips.

The surface flow module is coupled with the Infiltration module which is based on modified Green-Ampt method:

The continuity equation:

$$\frac{\partial y}{\partial t} = \frac{f}{\theta_s - \theta_i} \qquad (11)$$

Darcy's formula is used as the momentum equation:

$$f = K_s \frac{|h_c| + y + D}{y} \qquad (12)$$

where y is the depth of wet front (m), θ_s is the water content of the soil while saturated, θ_i is the initial water content of the soil, K_s is the saturated hydraulic conductivity (m s^{-1}), and h_c is the capillary fringe pressure (m).

As the actual cross section area within a grass strip is lower than calculated one (due to the area covered by leaves and foliage), following equation is used to estimate the actual flow rate:

$$q_a = \frac{q}{(1 - Bl)} \qquad (13)$$

Where q_a is the actual flow rate (m^2 s^{-1}), and Bl is the fraction of cross section which is covered by stems and foliage.

Sediment transport processes are described by the following equation:

$$q_a \frac{dc_i}{dx} = -(v_i + f)c_i + Hr_{max} \frac{v_i c_i}{\sum v_i c_i} \quad (14)$$

Changes in topography over time within grass strips are calculated using the following equation:

$$\frac{dz}{dt} = -\frac{1}{\sigma(1-\lambda)} \frac{d(q_a c)}{dx} \quad (15)$$

Computational scheme and numerical solutions

Upstream the grass strip

The flow rate and sediment concentration upstream the backwater region are assumed to be steady and to be given to the model as input data. The water depth at the upstream edge of the backwater region is equal to the normal depth of the flow over the bare soil. The downstream depth of water in the backwater region is the normal depth of the steady flow over the grass strip.

The equations for predicting the flow and sediment characteristics upstream the grass strip (eqs 1 and 2) were solved using the fourth order Runge-Kutta method. As the downstream water depth which is equal to the normal depth of the flow within the grass strip is the control point for solving equation 1 and the concentration of particles of different size classes upstream the backwater were control points for equation 2, the two equations solved separately and results from equation 1 were used for solving the equation 2. The equations were solved at every time step taking the topography at the end of the previous time step as the initial condition for the next time step.

Within the grass strip

The sediment concentrations of different particle size classes at the entrance of the grass strip, which are the outputs of the "upstream" module, are taken as the upstream boundary condition for the "within the grass strip" module. The flow rate considering the infiltration rate at every time step at the lower edge of grass strip is a boundary condition for the numerical calculations. The water depth at the lower edge is equal to the normal depth of the corresponding flow rate over the bare soil.

The ordinary differential equation of the infiltration module (Eq 11) was solved using the fourth order Runge-Kutta method. The kinematic wave module was numerically solved utilising finite difference techniques. Fully implicit method was used to solve the kinematic wave partially differential equations (Eqs 9 and 10). Equation 14 was solved using fourth order Runge-Kutta method.

Model application and validation

The performance of the model in predicting the fate of water and sediment in and around grass strips was evaluated by comparing the model outcomes with the results of a set of experiments. conducted by Jin and Romkens (2001) in an experimental flume using artificial grass.

The tests were carried out in a laboratory flume evaluating the effects of different grass densities, bed slopes, flow rates, particle size distribution, and concentrations on fate of sediment upstream and within the vegetated area. Vegetation was simulated with polypropylene bristles which were inserted and glued in a staggered pattern. The surface was impermeable and infiltration effects were not tested. The length of grassed part and the upstream zone were 2.4 and 1.2 m respectively. Two different densities of 2500 and 10000 bunches of four bristles per square meter were used to see the effects of grass density on sediment retention. Three different particle size distributions of coarse sand, fine sand, and silt loam were used in a steady run-on to evaluate the effectiveness of grass strips in the fate of different particle sizes and combinations. Sediment was uniformly mixed in a tank and steady flow was distributed in the flume. Durations of the events were between 80 and 140 minutes.

Deposited sediments in the upstream area, upper half, and lower half of the grass strip were collected after every event. The collected samples were oven dried and sieved through a series of sieves to measure the fraction of different size classes in the deposited sediment. Run-on samples were also collected every two or three minutes at the outlet to measure concentration of different size classes in the pass through flow. More details can be found in Jin and Romkens (2001).

The parameters used to simulate the experimental conditions in the model are as Table 1.

The model results were compared with the observed data using different evaluation techniques.

The "Bias" of the model was calculated from the model predictions and the observations as:

$$\text{Bias} = \frac{\sum M_i}{\sum O_i} \quad (16)$$

where M_i and O_i are modelled and observed data respectively. The Bias criterion shows whether the model over-estimates or under-estimates the observations on average.

Table1. Model parameters and their values for Jin and Romkens (2001) experiment

Module	Parameter	Symbol	Unit	Values (Jin and Ramkens, 2001)
Hydrology	Buffer width	b	m	0.64
	Buffer length	L_{in}	m	2.4
	Upstream length	L_{up}	m	1.2
	Upstream Manning coefficient	n_{up}	s $m^{-1/3}$	0.015
	Grass Manning coefficient	n	s $m^{-1/3}$	0.075 in low density 0.12 in high density
	Width blocked by grass	Bl	-	0.01 for low density 0.04 for high density
	Flow rate	Q	L s^{-1}	1.45-7
	Surface slope	S_0	%	2-6
	Infiltration rate	f	m s^{-1}	0
Sediment	Kinematic viscosity of water	v	m^2 s^{-1}	10^{-6}
	Sediment concentration	c	kg m^{-3}	1.44-7

Effective excess stream power	F	-	0.1 in upstream area 0.002 in grassed zone
Water density	ρ	kg m^{-3}	1000
Sediment density			2630 for coarse sand 2630 for coarse sand 2520 for silt loam
Deposited sediment porosity	λ	-	0.4
Threshold stream power	Ω_0	kg m^{-3}	0.008

The observed data of grass strips of different conditions were also compared to the model predictions. The coefficient of model efficiency *Ec* (Nash and Sutcliffe, 1970) was calculated from the observations and model output as:

$$Ec = 1 - \frac{\sum(O_i - M_i)^2}{\sum(O_i - \bar{O})^2} \qquad (17)$$

Where $\bar{O}$ is the average of the observed values. The model efficiency measures the level of accordance between the modelled and observed values. *Ec* value of 1 indicates perfect agreement. The *Ec* value can be negative, indicating the model predictions are worse than those predicted with the average observed values

In addition, the root mean squared error (*RMSE*) was calculated as:

$$RMSE = \sqrt{\frac{1}{N}\sum(O_i - M_i)^2} \qquad (18)$$

Where *N* is the number of observations. *RMSE* quantifies the error in the modelled values in the unit of the original variable. *RMSE* equal to zero shows the perfect fit and the lower the *RMSE* value, the better the agreement. *RMSE%* (*RMSE/*$\bar{O}$) was also calculated to represent the relative magnitude of errors.

Results and discussion

The model was run for every scenario tested in the first set of experiments (Jin and Romkens, 2001) and Table 2 shows the performance indicators for this set of flume experiments.

Table 2. Model performance indicators for three predicted variables of importance to the effectiveness of vegetation buffer strips

Variable	Bias	Ec	RMSE	RMSE%
Water depth in grass strip (m)	1.07	0.95	0.01	8
Efficiency in trapping sediment (%)	0.99	0.58	12.70	-
Fraction of different size classes in the outflow (%)	1.01	0.67	6.62	69

As it is shown in Table 3 the model predicts the water depth within the grass strip with high accuracy. The model predictions for the efficiency of grass strips in reducing sediment concentration and the particle size distribution in the outflow are also quite accurate. Figure 1 shows the observed and modelled efficiencies for a total of 28 runs of the flume experiment.

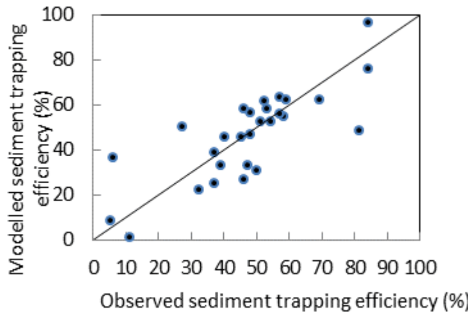

Figure 1. Observed versus modelled efficiency of grass strips in reducing sediment outflow

The distribution of different particle size classes in the deposited sediment upstream the grass strip for different inflow particle distributions is shown in Figure 2. The fraction of fine particles is less than that of in the inflow in both observed and modelled data. The model has predicted that there cannot be any deposition of particles finer than 106 µm in the upstream area, while it actually happened. However the fraction of particles finer than 106 µm in the observed deposited sediment upstream the grass strip was considerably lower than that of in the inflow. The proportion of coarse particles was higher than that of in the inflow in both observed and modelled data while the model over-predicts it in the upstream region.

Figure 3 shows the observed and modelled distribution of different particle size classes in the deposited sediment in the upper half of the grass strip for different inflow sediment types. The proportion of finer particles is higher in this area compared to the upstream region in both modelled and observed data. As the model over-predicted the proportion of coarse particles in the deposited sediment upstream the grass strip, consequently the predictions show lower fraction of coarse particles in the upper half deposited sediment.

High resistance of the grassed area and high infiltration capacity within the grass strip enhance sediment deposition upstream and within the buffer strips. Changes to the water profile because of the presence of grass strips reduce the flow friction slope and consequently the stream power. This increases the deposition rate comparing to non-grassed areas. Infiltration not only reduces the mass of sediment in the outflow, but also lowers the flow velocity by decreasing the flow rate, which enhances settling of particles.

As an illustration, Figure 4 shows a slope of 1 m in length with 50 cm upstream and 50 cm within the grass strip, and the modelled water surface and deposited sediment profiles in a hypothetical grass strip after 10 and 30 minutes of a runoff event over the slope. The particle size distribution is the same as the fine sand in Jin and Romkens (2001) test. As Figure 4 shows that the deposited sediment increases over time, the location where the maximum rate of deposition occurs migrates towards the grass strip. The length and depth of the backwater region upstream the grass strip increases over time. The reason is that the depth and length of deposited sediment in the upstream area increases in time. The rate of deposition in the grassed area is much lower comparing to the upstream region because of the high rate of deposition of coarser particles upstream the grass strip. The flow velocity is also higher within the grass strip than in the upstream section. Figure 4 also shows that the water depth decreases slightly downstream within the grass strip due to infiltration, and the decrease becomes less pronounced with time as infiltration is reduced from the 10th to 30th min.

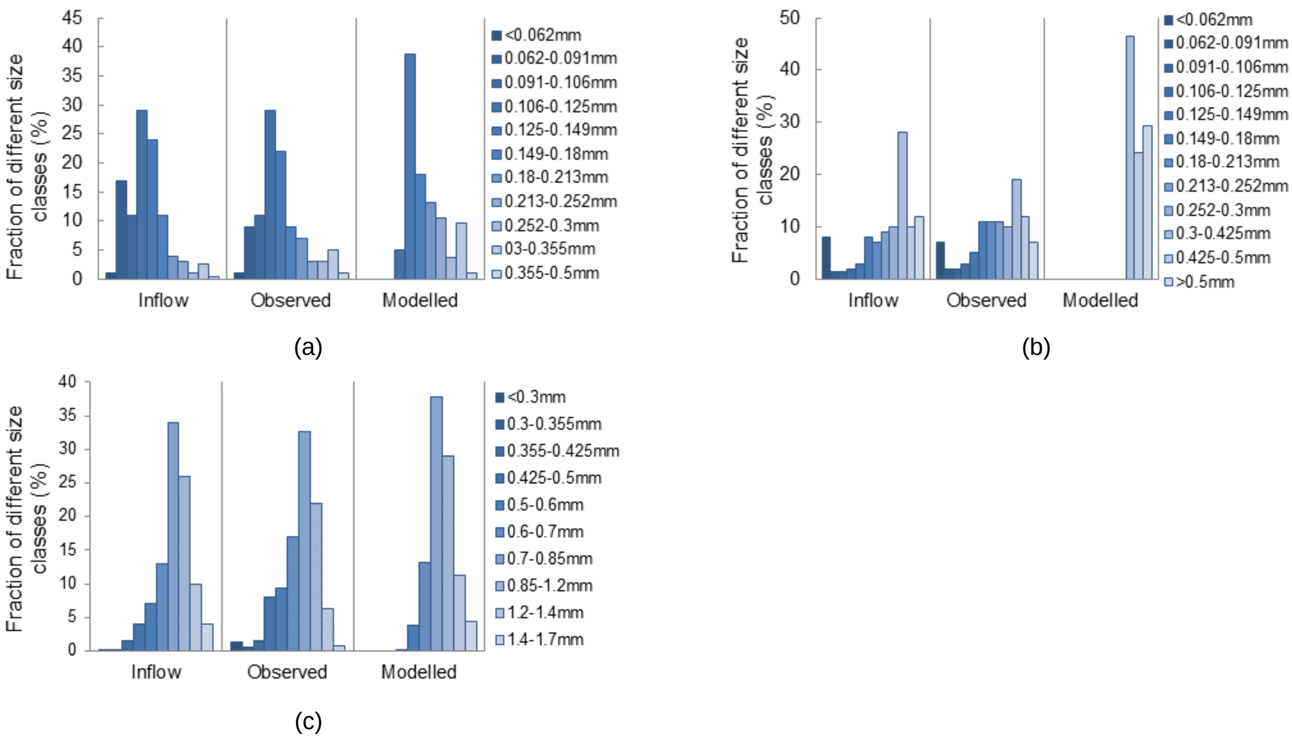

Figure 2. The proportion of different particle size classes in deposited sediment upstream grass strip. a) Run 02, b) Run 05, c) Run 07

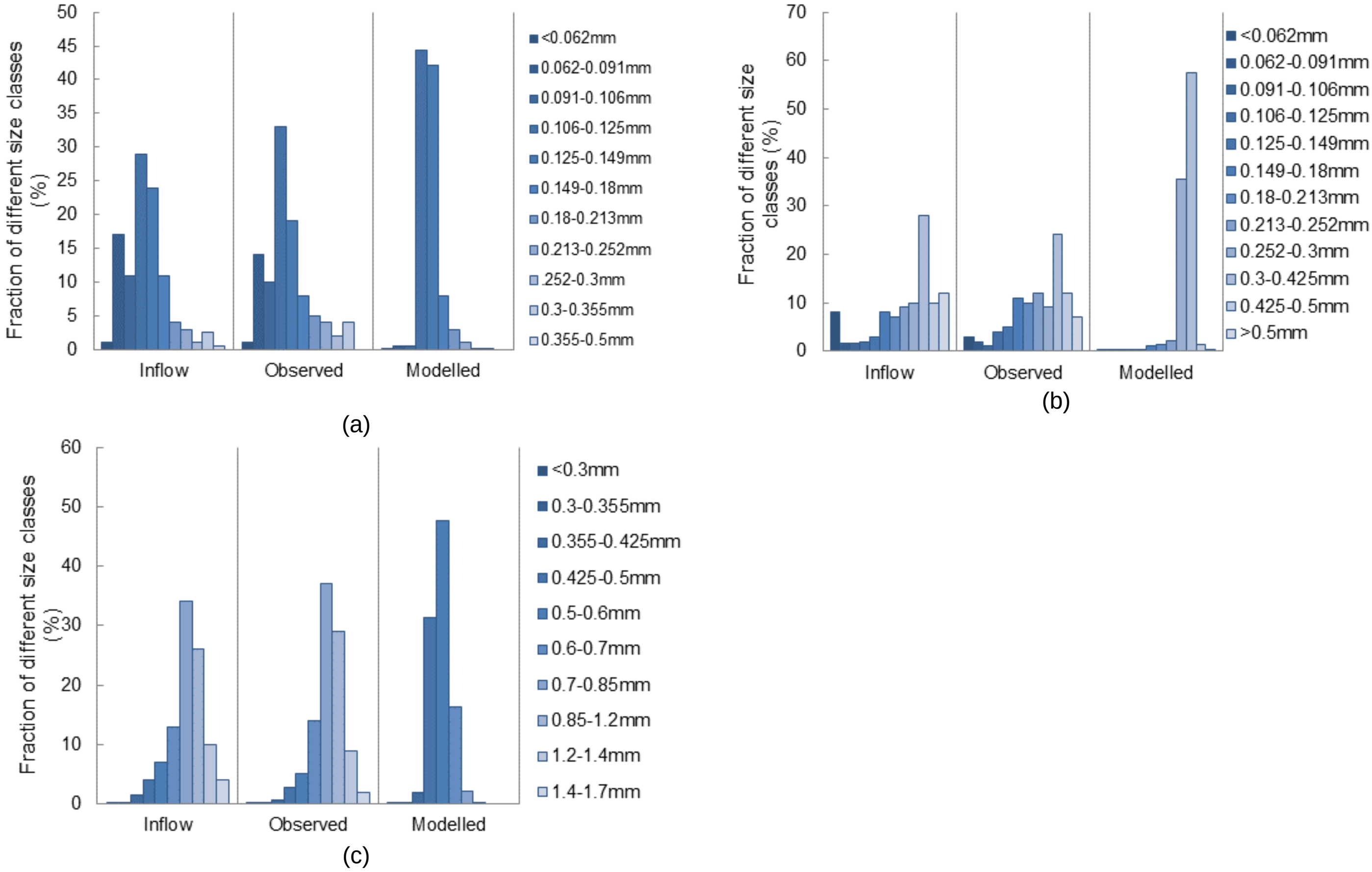

Figure 3. Distribution of different particle size classes in deposited sediment in the upper half of grass strip. a) Run 02, b) Run 05, c) Run 07

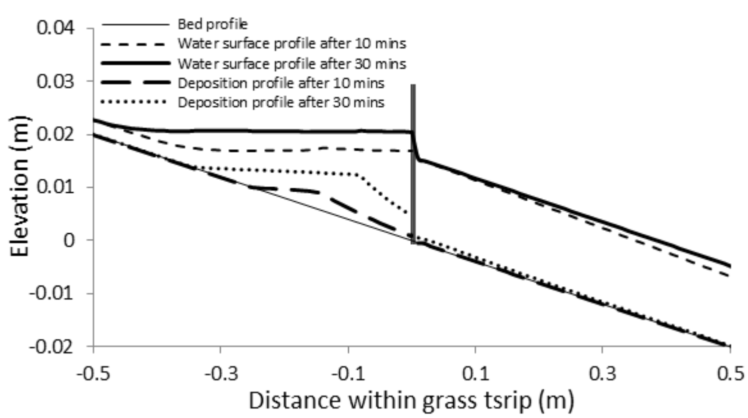

Figure 4. Simulated water surface and deposited sediment profile upstream and within grass strip with q=0.001 $m^2\,s^{-1}$, S_0=4%, n=0.2, Ks=10^{-5} $m\,s^{-1}$, θ_s=0.43, and θ_i=0.3

Sensitivity analysis was performed to estimate the uncertainty of the model outputs based on uncertainty in different input parameters. The ranges of input parameters for conducting the sensitivity analysis are presented in Table 3. The minimum and maximum values of these parameters all differ by a factor of 4 to allow a consistent comparison. The distribution of particle size classes is the same as the fine sand in the Jin and Romkens (2001) experiment. The fixed values of the parameters are presented in Table 3. Sensitivity of these 7 parameters was evaluated one at a time. When the value of a parameter was changed, the remaining parameters were held at these fixed values according to Table 3. In order to be able to compare the effectiveness of different parameters in reducing runoff, and sediment concentration and mass, parameters were normalised as following:

$$\acute{X} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (19)$$

where X' is the normalised factor, X is a model parameter, and X_{min} and X_{max} are the minimum and maximum values of this parameter respectively.

Table 3. Range of input parameters for sensitivity analysis

Parameter	q ($m^2 s^{-1}$)	Manning's n	L (m)	K_s ($m s^{-1}$)	θ_i	S_0 (%)	Duration (min)
Range	0.0005-.002	0.1-0.4	1-4	$2*10^{-5}$-$8*10^{-5}$	0.1-0.4	2-8	20-80
Fixed value	0.001	0.2	2	$4*10^{-5}$	0.3	4	40

The effect of different parameters on runoff reduction is showed in Figure 5. As Figure 5 shows the performance of grass strips in reducing runoff is most sensitive to the initial soil moisture. When the initial soil moisture is high the efficiency of grass strips in runoff reduction is dramatically lower comparing to initially dry soils. Figure 5 also shows that changes in flow rate effects the performance of grass strips in runoff reduction. As flow rate increases from low to medium or high rates, the volume of water infiltrates the soil dramatically decreases. The length of the grass strip is also as effective as the flow rate. The runoff reduction is considerably higher in long strips comparing to short ones. Slope steepness and hydraulic roughness did not have significant effect on runoff reduction, so are not illustrated in Figure 5.

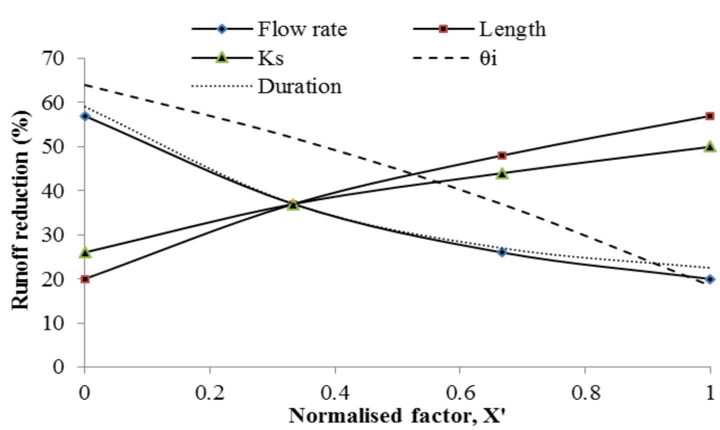

Figure 5. Effectiveness of different factors in efficiency of grass strip in runoff reduction

Figure 6 shows the sensitivity of grass strips in reducing sediment concentration in the outflow to variation in different parameters. Slope steepness is most sensitive to the reduction in outflow sediment concentration due to grass strips. As slope increases from 2% to 8% the backwater region upstream the grass strips tends to contract to an area close to the grass strip, hence limits the amount of deposition upstream, and leads to higher concentrations in the outflow. The rate of sediment deposition decreases in high slopes due to high flow velocities. Stream power is also higher in steeper fields and that enhances the re-entrainment process. The efficiency of grass strips also decreases dramatically as the flow rate increases.

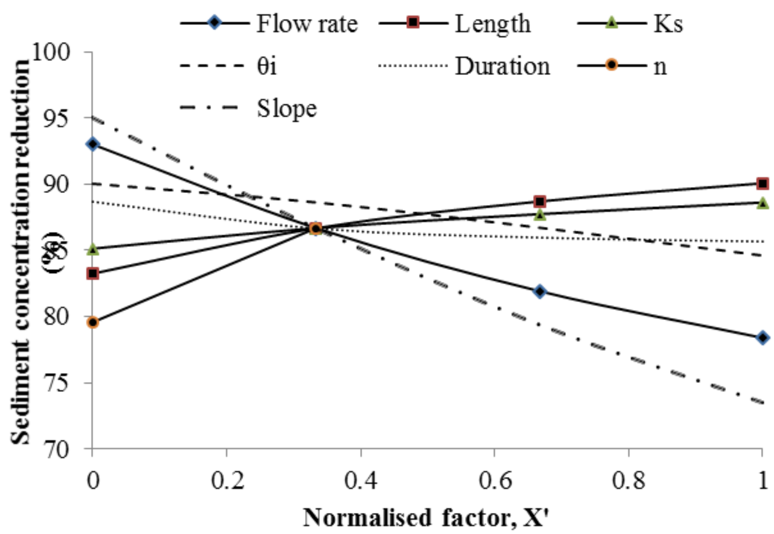

Figure 6. Effectiveness of different factors in efficiency of grass strip in reducing sediment concentration

Figure 7 illustrates changes in sediment mass reduction in grass strips in varied input parameters. Similar to Figure 6, slope is the most important factor in reducing sediment mass. The significance of flow rate in sediment delivery reduction by grass strips is almost as high as slope steepness as the efficiency of grass strips in reducing sediment delivery is considerably lower in high flow rates comparing to low flow rates. The effect of initial soil moisture is more pronounced in reducing the mass comparing to the concentration.

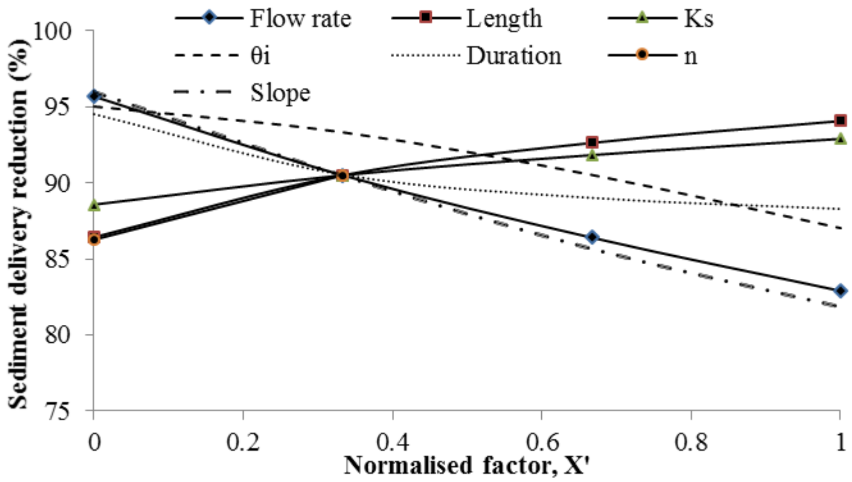

Figure 7. Effectiveness of different factors in efficiency of grass strip in reducing mass of sediment

Conclusion

A process-based model was developed in order to predict and simulate the fate of water and sediment in and around grass strip. As the size of sediment particles is very important in order to use the model for water pollution predictions, the model calculates the concentration and mass of sediment in the outflow for different particle size classes separately. The model consisted of hydrology and sediment transport sub-models. The two sub-models primarily model flow and sediment transport in the backwater area upstream the grass strip and these backwater simulation results specify the conditions of the grass strips upstream edge.

Modified Green-Ampt method is used to calculate the infiltration rate over time and distance. Gradually varied flow equation and kinematic wave approximation were used to simulate flow characteristics upstream and within the grass strip respectively. The Hairsine and Rose (1992) module for predicting water erosion and deposition in sheet flow is modified in order to be used in grass strip.

The model outputs were compared with a set of experiments carried out in controlled conditions. The model predictions of flow and sediment transport characteristics were accurate. The sensitivity analysis showed that the initial soil moisture of the grass buffer strip is the most sensitive parameter in predicting the runoff loss. Increase in the slope steepness and the flow rate dramatically decreases the efficiency of grass strips in reducing sediment concentration and delivery. The efficiency of grass strips reduces over time during events.

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COMPARISON OF THE BENEFIT FOR APPLYING SHALLOW DRAINAGE METHOD OF FOOD CROPS AND DEEP DRAINAGE OF TREE AT THE RECLAIMED LOWLANDS IN JAMBI-INDONESIA

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Abstract

This research focuses on the projection of an irrigated tidal peat-swamp in the Rantau Makmur village, Jambi, Indonesia, in order to assess the impact of peat losses due to the drainage system. Several drainages scenarios were considered carefully to find the best scenario suitable for the region. In order to quantify the impact of drainage, we developed a 3-D (x,y,t) EmSub model. The model can be used to estimate the CO_2 emissions due to peat oxidation, as well as the estimating of the subsidence based on soil consolidation and peat losses. Short-term simulation for 4 years showed a good agreement between the simulated subsidence and the observational data. Therefore, the utilization of this model for a long-term projection may be promising. The impacts from various scenarios are investigated using 100 years simulation. The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. Every plant has a different drainage depth. Two groups of plants have been introduced: 1) Tree crops (industry and forestry) which live on deep water table (acacia and palm oil); 2) Food crops which live on shallow water table (paddy). The simulations show that tree crops release abundant CO_2 emission and strong subsidence which lead to not-usable soils due to inundation. Therefore, profit/loss ratio of food crops drop significantly and is less than tree crops. In general, the model shows that tree crops group (acacia, palm oil, rubber, jelutong) contribute largely to CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit margins significantly. In particular, the highest rate of CO_2 emission and subsidence is triggered by acacias, which need a very deep water table. Detailed results and discussions of every plant are shown in this paper. This will help users and decision makers to choose the best scenarios for long-term land management planning in the study area.

KEY WORDS**:** Spatial model, Drainage, Peat swamp, Subsidence, CO_2 emission.

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Introduction

Previous study has shown that drained peat swamp could release significant CO_2 emission and cause rapid land subsidence due to peat oxidation (Hooijer et al., 2001). However, the method used for calculating the CO_2 emission is still under debate. This study, therefore, propose a numerical method to simulate groundwater flow in peat swamp and estimate the impact of various drainage scenarios. Aswandi et al [2015] have developed a groundwater model for a tidal peat swamp, which was coupled with open-canal system in 3-dimensional (x,y,t) frame. They named the model as Groundwater-Canal Flow (GCFlow) model. Based on their model, this study introduces a model for simulating CO_2 emission and land subsidence, so-called the Emission-Subsidence (EmSub) model. The EmSub model uses predefined water table map calculated by GCFlow model to estimate the amount of CO_2 loss and subsidence in various drainage scenarios. Based on estimated CO_2 emission and land subsidence, we evaluate the impact of drainage on food crops and various forest scenarios.

Materials and methods

Research site is located in an irrigated block in Berbak Delta, Jambi, Indonesia, with an area of ±100 ha bounded by two primary canals and two secondary canals (Figure 1). It is B/C typology class land where always inundated during high tide, or where the water will come only during high tide.

Figure 1: Research Site in the Berbak Delta, Jambi-Sumatera, Indonesia

In this research, two main models were developed. The first model is the GCFlow model, which has been developed in our previous study [Aswandi *et al*., 2015]. The second model is the EmSub model, which simulates CO_2 emission and land subsidence. Firstly, the GCFlow model is run for 365 days to get 1-year averaged water table. Outputs from the GCFlow model were used as input for 100-years simulation of the EmSub model. As the land subsides, drainability limit of the land is calculated which is used to reveal"age of usable land" and percentage of land condition in each year. Finally, we calculated the profit/lost ratio by comparing the crop productions and profit with CO_2 losses.

Model design

There two main components in the EmSub model, those are the CO_2 emission and the land subsidence. Note that the CO_2 emissions come from peat decomposition To calculate CO_2 emission, we use a proxy that relates annual average of CO_2 emissions rate per one meter of water table depth. Thus, this component uses the annual average of ground water table as the input. While the component of land subsidence (*hereafter* subsidence – S) consists of two sub-components; (a) subsidence due to oxidation of peat mass loss (S_E) and (b) physical compaction (also called consolidation) as a result of changes in effective stress in Terzaghi model (S_C). Therefore, total Subsidence (S) is sum of these two: $S = S_E + S_C$. (1)

Subsidence due to the loss of peat mass is converted from annual CO_2 emission rate based on the content of C and bulk density of peat. It uses annual CO_2 emissions as input. While the consolidation component uses the lowest ground water level as input.

The CO_2 emission and subsidence scheme

The model uses horizontal partitions on *X-Y* axis with an annual time-step. The CO_2 emission using the annual groundwater level as a proxy can be formulated as follows.

$$E_{i,j,k} = c\left(H_{top,i,jk} - H_{i,jk}\right), \quad (2)$$

$$H_{top,i,j,k} = H_{top,i,j,k-1} - S_{i,j,k-1}, \quad (3)$$

where E is the rate of annual CO_2 emissions due to peat oxidation, H_{top} is the elevation of the land surface relative to the averaged sea level (L) and S is the subsidence (L). In addition, the coefficient of CO_2 emissions rate in the peat land is defined as c ($ML^{-3}T^{-1}$) (M, L, and T are unit for mass, length, and time, respectively). i, j, k are the indices representing the column, row, and layer, respectively. Hooijer proxy explains that for each depth of the ground water level of 1 m, the rate of CO_2 emissions amount to 90 ton ha^{-1} per year, or 9 kgm^{-3} per year. The CO_2 emissions can be converted into components of subsidence (S_E) with the following equation,

$$S_{E,i,j,k} = \frac{E_{i,j,k}\left(\dfrac{M_C}{M_C + 2M_O}\right)}{\rho_{b,i,j,k} N_C}, \quad (4)$$

where M_C and M_O are the atomic weight of carbon and oxygen (kg/mol), respectively. Meanwhile, ρ_b and N_C are bulk density (L^3M^{-3}) and fraction carbon content of peat (MM^{-1}), respectively On the other hand, subsidence due to compaction (S_C) consists of primary and secondary consolidation components, which can be calculated with the following equation,

$$S_{C,i,j,k} = L_{0,i,j,k} \frac{C_c}{1+e_{0,j,j,k}} log\left(\frac{P_{0,i,j,k} + \Delta P_{i,j,k}}{P_{0,i,j,k}}\right) + L_{0,i,j,k} \frac{C_\alpha}{1+e_0} log\left(\frac{t}{t_0}\right), \quad (5)$$

where L_0 is the initial thickness of the peat layer, C_c and C_α are the indices for primary and secondary compression (no units), e_0 is the initial void ratio (LL^{-1}), while P_0 and ΔP respectively represent the initial effective stress and change in effective stress due to decrease in ground water level ($ML^{-1}T^{-2}$). Meanwhile, t and t_0 respectively represent the time parameter and the time at the beginning of secondary consolidation. The first term in the right hand side of represents primary consolidation, while the second term represents secondary consolidation. Primary consolidation takes place very quickly (in a few days or weeks), while the secondary consolidation is lasting longer over years. In our simulation, the primary consolidation is defined to zero because the first drainage was done in past years.

Effective stress is assumed as weight of peat mass minus buoyancy of groundwater. Effective stress increases when the water level decreases (deeper water table). Effective stress during pre-drainage (or pre-dredging) is calculated based on the lowest ground water level before the drainage, and it is written as

$$P_0 = \rho_b g L_0 - \frac{\rho_b}{\rho_s} \rho_w g H_0 , \qquad (6)$$

WhereP0 is the largest effective stress at initial pre-drainage or pre-dredging ($ML^{-1}T^{-2}$). g is the gravitational acceleration constant (LT^{-2}). ρ_b, ρ_s and ρ_w are respectively the bulk density of peat, the density of peat particles, and the density of water (ML^{-3}). H_0 is ground water level calculated from the water table to the bottom of peat (L).

During drainage, effective stress can increase due to lowering of water table and can be calculated as follows,

$$P = \rho_b g L - \frac{\rho_b}{\rho_s} \rho_w g \left(H_0 - \Delta H \right). \qquad (7)$$

P is the largest effective stress after drainage ($ML^{-1}T^{-2}$) and ΔH is the change in ground water level depth (L). By calculating the subsidence, the surface elevation can be simulated dynamically. Note that the simulated subsidence is used for estimating the surface elevation, the peat depth and the ground water level of the next year. Therefore, we may say that our model can simulate the spatial and dynamical process of the water table.

The age of usable land

The spatial-map of age of usable land can be calculated based on the output of elevation that has been simulated. First, we calculate gravity-drainability limit with Euclidian distance method which is controlled by the nearest boundaries of the river or the sea. Drainability limit (E_{dr}) is calculated as: $E_{dr} = E_b + 0.00002D$ (8)

Where E_b is the elevation of the nearest river or sea, D is the shortest distance to the boundary of the river or the sea, and the constant of 0.00002 is the gravity-drainability slope coefficient, which means 2 cm/km. If the elevation is lower than E_{dr}, then the land is no longer used and thus reduces the productivity of the crop. This map will be created in a grid format with a unit cell size of 10 m. Size of the usable zone tends to decrease due to subsidence. Agricultural cultivation can only be done on a drainable zone (i.e gravity-drainable zone), by assuming that there is no mechanical pumping performed gravity-drainability when the limit is reached.

Profit/loss ratio of crops production

This is a simple model that aims to calculate the ratio of profit/loss of a crop scenario. The model takes into account the potential revenue from the sales profits and potential losses due to emission and/or subsidence, and then calculates their ratio. Calculation period is divided into per-life of each plant and per 100 years. In this model, we assumed that 1 ton CO_2 loss costs about USD 5.5 or equivalent to IDR (Indonesian Rupiah) 77,000.

Model resolutions and assumptions

The spatial models run with 10×10 m spatial resolution. *EmSub* model uses 1-year time step for calculation. In profit/loss model, it is assumed that the crop prices and expenses are constant. For each crop scenario, the harvest time is only once a year. The drainage values for combined-plants scenarios are weighted based on the age of the plant. For example, plant A has life time of 3 months with 0.3 m drainage depth, while plant B has life time 5 months with 0.5 m drainage depth. Scenario for combined plant A and B has annual drainage depth of $(0.3 \times 3/8) + (0.5 \times 5/8) = 0.425$ m.

Results and discussion

Data preparation and model evaluation

The main data for the *GCFlow* consists of hydraulic conductivity, storage coefficient, DEM, daily rainfall, channel structure and manning roughness coefficient (see *Aswandi et al*., 2015). We used daily rainfall data for a period of April 1st, 2012 to March 31st, 2013. Note that we assumed the daily rainfall data for that period also applies to other years on the same date. The output is daily water table (WT), which is, then, annually averaged. For *EmSub* models, data and parameters are shown in Table 1. In particular, it uses annual WT from *GCFlow* and peat thickness as the input. Dataset of peat, DEM, and hydraulic conductivity vary spatially. The CO_2 content parameter is based on several findings from similar areas in Indonesia. We use *Couwenberg*'s CO_2 emission coefficient for every 1 meter of drainage depth based on Hooijer *et al*. in [8, 9, 10]. The primary and secondary compression indices are obtained by following previous study [4]. Other soil characteristic data are based on *in-situ* observation. Meanwhile, data for crop prices in the market and crop expenses are obtained through direct observation and interview with the farmers.

Table 1: Data for *EmSub* model

No	Name	Value and unit
1	Annual water table elevation (from *GCFlow* model)	m
2	Peat thickness	m
3	Surface elevation (DEM)	m
4	Soil characteristics (general)	
	• Hydraulic conductivity	$mday^{-1}$
	• Storage coefficient	0.3 m^3 m^{-3}
5	Soil characteristics (CO_2 emission)	
	• CO_2 content	0.58 kg kg^{-1}
	• Couwenberg coefficient	9 kg m^{-2} $year^{-1}$ m^{-1}
6	Soil characteristics (consolidation)	
	• Bulk density	200 kg m^{-3}
	• Particle density	1200 kg m^{-3}
	• Primary compression index	2.2
	• Secondary compression index	0.06
7	Time step output	1 year
8	Drainability limit	
	• Gravity-drainability coefficient	0.00002 km km^{-1}
	• Distance to the river	3 km
	• Elevation of the nearest river	5 m

Source: Aswandi *et al* (2015)

Impact of different drainage scenarios in 100 years simulation

Model output in the 100th year simulation

Depth of water table is proportional to subsidence and thus affects the land cover. Model outputs show that scenario of 0.8 m drainage (current condition) potentially releases about 794,000 ton of CO_2 or equivalent to IDR 61.2 billion (Table 2). In addition, the 0.8 cm drainage scenario causes 52 cm subsidence and leaves 62% of usable land cover. The losses become smaller (bigger) in the shallower (deeper) drainage scenario. For instance, the drainage scenario of 0.1 m has potential CO_2 emission of about 279,500 ton (IDR 21.5 billion), 19.8 cm subsidence, and no damage on the land cover. However, the drainage scenario of 1.5 m can result in 1.4 million ton CO_2 emission (IDR 108 billion), 90.6 cm subsidence, and only 35.9% usable land left.

Table 2: Projection of CO_2 emission and subsidence for different scenarios.

Drainage scenario (m)	Result for 100 years simulation			
	CO2 emission (1000 ton)	CO2 loss (IDR billion)	Subsidence (cm)	Land condition (%)
1.5 (*max*)	1407.1	108.3	90.6	35.9%
1.2	1283.8	98.9	82.8	36.3%
1.0	1093.7	84.2	70.9	48.2%
0.8 (*real*)	794.9	61.2	52.1	62.3%
0.6	595.8	45.9	39.6	76.6%
0.4	450.7	34.7	30.5	89.1%
0.3	412.9	31.8	28.1	95.2%
0.2	364.4	28.1	25.1	99.4%
0.1	279.5	21.5	19.8	100%

Spatial features

One advantage of the *EmSub* model is its capability in spatially simulating the land subsidence, emission, and profit/loss ratio. We reveal spatial distributions of the projected DEM, cumulative CO_2 emissions, peat thickness, and age of usable land in 100 years (Figures not shown). Since the subsidence is large, the emission is very high and the lifetime of usable land is very short. We found that the soils near to canal's boundary will suffer most subsidence and emission. This is probably due to deeper water table in this location than the water table in the center of block (curvature effect of water table surface). DEM data shows that the lowest elevation area resides in the middle block (tertiary block), which is vulnerable to inundation.

Time-series

Figure 2 shows the time-series of simulated peat thickness, cumulative subsidence, DEM, cumulative emissions, and rate of emission per year in several WT scenarios. We can clearly see that peat amount is decreased which results in increasing subsidence, lowering DEM, and increasing CO_2 emission (Fig. 2a-b). Shallow WT table scenarios are seen to have small impact, while deep WT scenarios show large impact (20-60 cm). In the early years, their values increase or decrease rapidly. After long simulation, their impacts are reduced logarithmically, especially for deep WT scenarios (1-1.5 m). Therefore, its rate is reduced and stopped in particular year (Fig. 2d). For 1.5 m and 1.2 m scenarios, the peat is predicted to disappear around 90th year and 120th year (Fig. 2a), respectively. However, the shallower WT simulations show that the peat still exists, at least until 200th year in the future. These results clearly show that deeper WT scenarios release more CO_2 rapidly, which directly contributes to the speed of global warming.

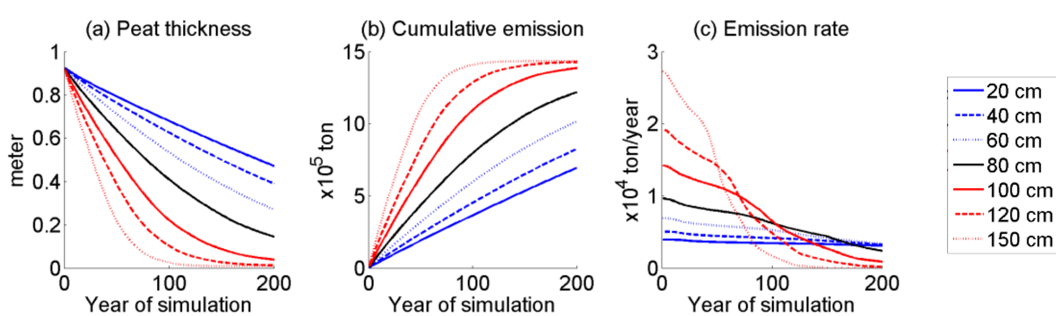

Figure 2: Time-series of model outputs. (a) peat depth, (b) Cumulative emission, and (c) emission rate per year. The model runs are extended to 200 years. Legend is shown in bottom-right of figure.

Profit/loss ratio for several plantations and crops

In order to evaluate the impact of emission and subsidence to the plantations and crops, we run several particular drainage scenarios for each plant, so-called plant scenario. The information of the plants (i.e., typical drainage depth, age, production, price, and expense) is shown in the Table 3. For example, paddy uses drainages of about 0.1 - 0.2 m depth. Then, in the simulation scenario, we run the model twice using both data so that we obtain the approximate impact caused by paddy. The emission released by plant is considered as the losses, which can be converted into money loss. The amount of crop production is affected by land condition (active usable area that can be drainaged).

Table 3: Two group of crop scenarios. It consists of 11 crops and plantation.

No	Plant scenario	Drain Min	Drain Max	Lifetime	Production (kg/ha/year)	Price (IDR/kg)	Expense (IDR)
	Group I						
1	Acacia	80	100	5 year	30000	350	0
3	Oil Palm	60	80	25 year	18000	800	41,000,000.00
2	Rubber	40	60	50 year	2400	5500	3,000,000.00
4	Jelutong	20	40	100 year	3200	5000	3,000,000.00
	Group II						
1	Paddy	10	20	3 month	3000	4500	3,000,000.00
2	Corn	30	40	4 month	5000	3200	2,500,000.00
3	Soybean	30	40	3 month	1500	6000	2,000,000.00
4	Cassava	30	40	5 month	5000	2000	1,000,000.00
5	Red Chilli	20	30	4 month	1000	40000	10,000,000.00
6	Long bean	20	30	2 month	3000	4000	2,500,000.00
7	Peanut	30	40	3 month	1200	10000	3,000,000.00

Figure 3 exhibits model results comparison between plants scenarios. The plants in the first group release high CO_2 emission (Fig. 3a). Among plants in the first group, *acacia* is the highest contributor (795 - 1094 thousand ton), followed by palm oil (596 – 795 thousand ton), rubber (451 – 596 thousand ton), and *jelutong* (364 – 451 thousand ton). The largest subsidence is also caused by *acacia* with averaged subsidence of 52 – 71 cm, while the smallest subsidence is caused by *jelutong* (25 – 31 cm) (Fig. 3b). In case of percentage drainable area due to subsidence, farmers are expected to lose about 50% of area if the *Acacia* would be planted (Fig. 3c). Meanwhile, the *jelutong* scenario could save the drainable area up to 89 – 99%. *Acacia* lives in the deep drained land of about 80 – 100 cm depth. Palm oil and rubber are also considered using deep drainage of about 60 – 80 cm and 40 – 60 cm depth, respectively. We may suggest that the deep drainages are susceptible and inappropriate to the peat swamp because it could affect the peat substantially, release more CO_2 emissions, and trigger strong subsidence. On the other hand, *jelutong* has been shown to contribute be friendly to the environment. *Jelutong* also lives quite long (Table 4, lifetime). In 100 years, farmers need only 1 time planting, compared to *acacia*, palm oil and rubber that need 20 times, 4 times, and 2 times planting in 100 year, respectively. Finally, *jelutong* gives the highest profit/loss ratio among industrial forests, which is very profitable to be applied (Fig. 3d). Otherwise, *acacia*, palm oil and rubber are less appropriate in the study area and should be avoided.

In individual food crops scenarios, corn, soybean, cassava and peanut are the largest contributors of CO_2 emission (413 – 451 thousand ton) (Fig. 3a). The second contributors for CO_2 emission are red chilli and long bean (364 – 413 thousand ton). Corn, soybean, cassava, and peanut cause land subsidence of about 28 – 31 cm (Fig. 3b). The lowest emission is coming from paddy (280 - 364 thousand tons). Land subsidence in paddy is also the smallest (about 20 – 25 cm).

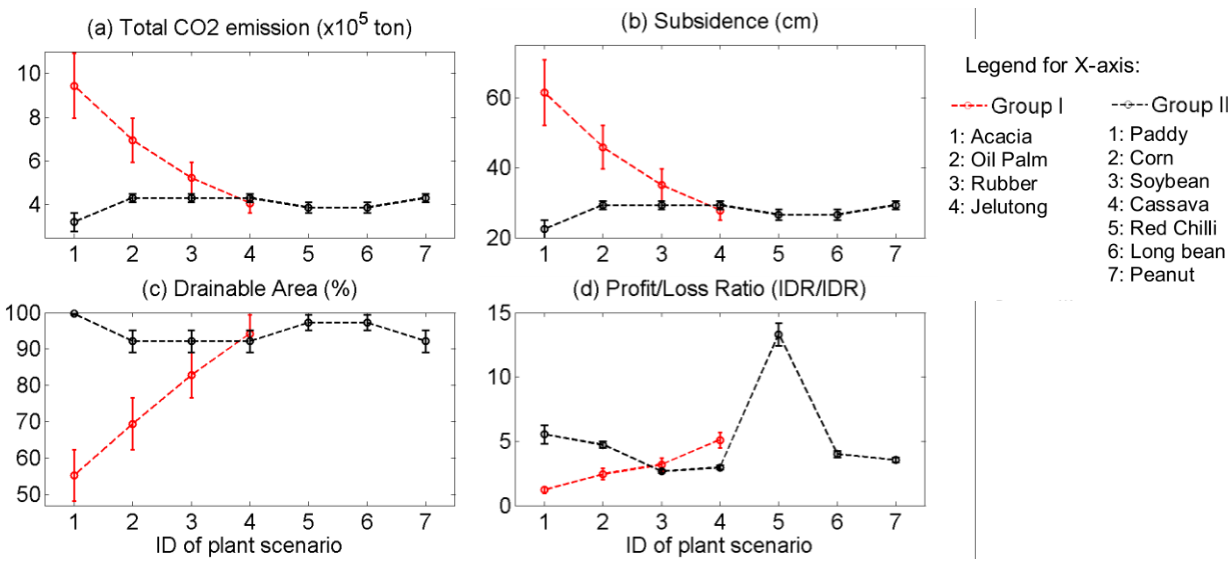

Figure 3: Distribution of impacts on different plantations. (a) and (b) exhibits area average of 100 years CO_2 emission and subsidence, respectively. (c) shows drainable area in the 100th year. (d) shows profit/loss ratio measured by annual selling profit divided with predicted CO_2 loss. Horizontal axis denotes the ID of plant scenario. Legend of scenario ID is shown in the right.

Conclusion

The model shows clearly that the deep water table causes more CO_2 emission and more subsidence than the shallow water table. In addition, the lowered soils may cause wide-inundated area which are not suitable for plantation. The effects can be smaller and higher depending on the depth of drainage. In order to evaluate the impact of emission and subsidence to the plantations and crops, sensitivity experiments using selected and combined plantations are conducted. In general, the model has shown that the industrial plantation group (e.g. *acacia*, palm oil, rubber, *jelutong*) contributes largely to the CO_2 emission and subsidence. This may be related to the depth of drainage. In addition, high CO_2 emission and large subsidence could reduce profit significantly. In particular, the highest rate of the CO_2 emission and subsidence is triggered by *acacia*, which needs very deep water table. The impacts caused by food crops group (paddy, corn, soybean, cassava, red chilli, long bean, peanut) are much smaller. The paddy contributes the smallest CO_2 emission and subsidence. Farmers should consider changing the forest into food crops in order to both save the environment and stabilize the profit.

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SHALLOW SUBSURFACE DRAINAGE IN PADDY FIELDS: ENVIRONMENTAL CONSEQUENCES AND CROP RESPONSES ANALYSIS

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Abstract

Increased population along with decreased productive lands due to urban expansion are major challenges of policy makers emphasizing on better use of limited available profitable land resources. Rice production systems in northern Iran which generally experience single crop per year, could be a suitable target for improving self-sufficiency of the country if their drainage problems were controlled in a sustainable manner. On the other hand, drainage should secure sustainable agriculture in the region with less consequences on the fragile environment. A comprehensive- drainage pilot study was conducted on a 4.5 ha consolidated paddy fields of Sari Agricultural Sciences and Natural Resources University, Mazandaran province, Iran, to explore effects of different drainage strategies on crop yields and salt, phosphorus and nitrate losses for developing a drainage system as a new approach. The pilot consisted of 11 shallow subsurface drain lines with 0.65 and 0.9 m depths and 15 and 30 m spacings resulting in three conventional subsurface drainage systems and a bilevel subsurface drainage system. Moreover, the traditional surface drainage of the consolidated paddy fields was included in this study. Two types of water management including mid-season drainage and alternate irrigation and drainage were experienced during 4- rice growing seasons (2011- 2015). Additionally, free drainage was practiced during 4- canola growing seasons in the study period. Nitrate and phosphorus losses, salt loads and crop yields were monitored in the growing seasons. Salt loads and phosphorus losses were generally higher under shallow drains than deep drains. Under different water management strategies, increase in drainage intensity resulted in more nitrate loss. Subsurface drainage caused gradual improvement in the overall productivity of the study area through increase in rice and canola yield. Based on the results, shallow drainage systems could ensure agricultural sustainability in northern Iran's paddy fields.

KEY WORDS: Annual cropping, Nitrogen, Phosphorous, Salt load, Productivity.

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Introduction

Due to continued population growth until 2050, overall demand for food or agricultural products is expected to increase. At present, more than 1.5 billion hectares of the globe's land surface (about 12 percent) is used for crop production. In spite of the presence of considerable amounts of land potentially suitable for agriculture, much of it is covered by forests, protected for environmental reasons, or employed for urban settlements (FAO, 2012). Rapid industrialization and urbanization will put more pressure on the profitable lands and water resources which consequently limit horizontal development of agriculture. Under such circumstances, increased crop production per capita arable land is mainly possible through land and water management systems in the cultivated area.

Occupying about 30 % of the world's irrigated cropland (Lampayan et al., 2015), rice production systems are suitable targets for investment to improve food security in future. Based on the Iranian ministry of Jihad Agriculture (2015), 4.55 percent of total 11.84 Mha cropped lands of the country is allotted to paddy fields. The major part of the fields is located in Northern provinces (Mazandaran, Gilan and Golestan) of Iran. Most of these fields experience once crop a year and remain fallow during rainy seasons due to ponding and waterlogging. These conditions made paddy cultivation as an unsuitable job from economic viewpoint for farmers who only rely on the income of their paddy fields resulting 1.4 % decrease in the area of Iran's paddy fields during 2000-2011 (FAO, 2014). To prevent change in land use from paddy fields to other uses, the government of Iran has initiated land consolidation projects in the fields several years ago to increase agricultural productivity (Asgari et al., 2012). Improved water management through separate water supply and drainage canals, is another merit of such projects. Due to the inability of land consolidation projects to combat waterlogging and ponding problems in northern Iran's paddy fields (Darzi-Naftchali and Shahnazari, 2014), the feasibility studies for installation of subsurface drainage were done to include the crop diversification and low cost rice farming to the objectives of paddy land consolidation. Subsurface drainage provides suitable condition for intensive agriculture in the paddy fields. However, before adoption of such a new technology at large scale, its environmental effects should be quantified at pilot level. A drainage pilot comprising different drainage systems was implemented at the Sari Agricultural Sciences and Natural Resources University (SANRU) in 2011 to find out various effects of subsurface drainage systems. This paper presents major results of this pilot study.

Materials and methods

Poorly drained- consolidated paddy field of the SANRU (36.3◦N; 53.04◦E; 15 m below sea level) was selected as representative conditions of northern Iran's paddy fields. Minimum, maximum and average daily air temperature of the area are -6, 42.5 and 17.6 ^{o}C. The soil on the field is silty clay and clay to a depth of 3 m with a very low conductive layer approximately at 30-60 cm depth. Through national land consolidation projects, the irregular paddy plots of the study site were shaped as standard plots with 30 m wide and 100 m long. Providing access roads and improving irrigation and drainage facilities were other aspects of the projects. In 2011, different subsurface drainage systems were installed at the study area using two drain depths (0.65 and 0.9 m) and two drain spacing (15 and 30 m). Depth and spacing of subsurface drains were selected based on national recommendations and field conditions. The drainage systems were: D0.9L30, D0.65L30 and D0.65L15 in which, the subscripts of D and L demonstrate depth and spacing of the drainage systems, respectively. Additionally, another subsurface drainage system consisting 4 drain lines with 15 m spacing and 0.65 and 0.9 m depths as alternate (Bilevel) was installed at the study area. All subsurface drain pipes were connected to an open drain with a depth of 1.2 m. A paddy plot which was only under the influence of the open drain was considered as Control plot. Detailed description of the drainage systems can be found in Darzi-Naftchali et al., (2013).

The study is comprised of 8 growing seasons (2011-2016) including 4- rice growing seasons and 4- canola growing seasons. Rice cultivation (Daylamani Tarom cultivar) was done under two water managements including midseason drainage (July 21 to October 10 in 2011 and May 28 to August 11 in 2012) and alternate irrigation and drainage (May 10 to August 5 in 2014 and June 4 to August 28 in 2015). Shallow groundwater was extracted to irrigate the paddy plots during rice growing seasons. Average values of electrical conductivity (EC) of irrigation water during 2011, 2012, 2014 and 2015 rice growing seasons were, respectively, 1.12, 1.29, 1.25 and 1.3 ds m^{-1}. After rice harvest in 2011, 2012, 2014 and 2015, respectively, 6, 7, 7 and 8 kg of canola seeds were cultivated in subsurface- drained area. During canola growing seasons (November 28, 2011- May 8, 2012; October 4, 2012- May 15, 2013; October 10, 2014- May 10, 2015; October 3, 2015- May 3, 2016), the fields were under free drainage unless short periods at the end of the seasons when the outlet of drains were closed to prevent deficit water stress. A summary of water management practices and fertilizations is provided in Table 1.

Measurements of nitrate and total phosphorus (TP) concentration in drainage effluents as well as electrical conductivity (EC) of drainage water were carried out during different growing seasons (at least three successive days during each drainage periods of rice growing seasons and 15- day intervals during 2011-12 and 2014-15 canola growing seasons). Moreover, drainage outflow was measured daily whenever subsurface drains were discharged. Using these measurements, total losses of nitrate, TP and salt were calculated. At harvest, in each growing seasons, crop yield was determined under different drainage systems. Data analysis was performed using statistical software package SAS (SAS Institute, 2004).

Table 1. Water management practices and fertilizations during rice and canola growing seasons

2011- rice	**Activity**
Basal fertilizer	140 kg ha^{-1} triple superphosphate
8 DAP	90 kg ha^{-1} urea
25-31 DAP	Midseason drainage
68-82 DAP	End- of season drainage
2012- rice	
9 DAP	90 kg ha^{-1} urea
25-31 DAP	Midseason drainage
72-86 DAP	End- of season drainage
2014- rice	
Basal fertilizer	100 kg ha^{-1} triple superphosphate, 100 kg ha^{-1} potassium sulfate, and 80 kg ha^{-1} urea
13 DAP	80 kg ha^{-1} urea
31 DAP	30 kg ha^{-1} urea
25-34 DAP	1st drainage period
44- 49 DAP	2nd drainage period
64-88 DAP	End- of season drainage
2015- rice	
Basal fertilizer	50 kg ha^{-1} triple superphosphate, 50 kg ha^{-1} potassium sulfate, and 100 kg ha^{-1} urea
12 DAP	50 kg ha^{-1} urea
28-32 DAP	1st drainage period
39- 43 DAP	2nd drainage period
71-86 DAP	End- of season drainage
2011-12 canola	
100 DAP	35 kg ha^{-1} urea
121 DAP	35 kg ha^{-1} urea
2012-13 canola	
155 DAP	35 kg ha^{-1} urea
2014-15 canola	
21 DAP	70 kg ha^{-1} urea
128 DAP	70 kg ha^{-1} urea
2014-15 canola	
Basal fertilizer	50 kg ha^{-1} triple superphosphate
52 DAP	50 kg ha^{-1} urea

1- Days after planting

Results and discussion

Salinity can occur even using good quality irrigation water in poorly drained soils (Ritzema et al., 2008). Relatively flat- heavy texture soils of the study site as well as the salinity of irrigation water (1.12- 1.3 ds m^{-1} during the study period), necessitate salt load monitoring through different drainage systems. The results of mean comparison of EC of drainage effluents are presented in

Table 2. Total water samples used for EC measurements were 46 and 10 for subsurface drainage systems and Control, respectively. Generally, the salinity of drainage effluents were maximum in the first rice growing season after subsurface drainage installation and then gradually decreased mainly due to removal of accumulated salts in flow paths during earlier growing seasons. After the 2014 rice growing season, the variations of EC were almost negligible depending on EC of irrigation water or precipitation. Moreover, relative increase in EC in 2014 and 2015 rice growing season probably attributed to further improvement in soil structure due to alternate irrigation and drainage practice which provides suitable conditions for appearing cracks on the soil surface (Ye et al., 2013). Comparing EC of different drainage systems having same depth or spacing in rice and canola growing season indicate that shallow drains resulted in more EC in drainage effluents than deep drains. Overall comparison of EC well demonstrate this result unless for the most intensive drainage system (Bilevel). EC of surface runoff was significantly higher than that in subsurface drainage effluents in the 2011 rice season while it was comparable with the corresponding EC in subsurface drain discharge in 2012, 2014 and 2015 rice growing seasons.

Table 2. Mean comparison of electrical conductivity (ds m^{-1}) of drainage water as affected by different drainage systems and growing seasons

Drainage System	Growing season						Overall
	Rice 2011	Canola 2011-12	Rice 2012	Rice 2014	Rice 2015	Canola 2015-16	
D0.90L30	1.62^{b}	1.45^{e}	1.08^{b}	1.06^{d}	1.19^{c}	1.32^{b}	1.25^{d}
Bilevel-D0.65	1.97^{b}	1.66^{c}	1.10^{b}	1.10^{dc}	1.51^{b}	1.38^{b}	1.39^{cd}
Bilevel-D0.90	2.37^{b}	2.22^{a}	1.23^{ab}	1.31^{bcd}	1.79^{a}	1.72^{a}	1.71^{b}
D0.65L30	1.83^{b}	1.55^{d}	1.33^{ab}	1.55^{ab}	1.60^{b}	1.40^{b}	1.50^{c}
D0.65L15	2.04^{b}	1.88^{b}	1.44^{a}	1.61^{a}	1.73^{a}	1.63^{ab}	1.68^{b}
Control	4.24^{a}	-	1.12^{b}	1.32^{bc}	1.51^{b}	-	1.92^{a}

Means followed by the same letter in a column are not significantly different at $P < 0.05$ by LSD test.

Subsurface drainage system may cause losses in various forms of nitrogen through the drainage effluent (Gilliam and Skaggs, 1986). Seasonal variations of nitrate concentrations in drainage effluents and surface runoff is presented in Table 3. Total water samples used for nitrate measurements were 55 and 14, respectively, for subsurface drainage systems and Control. Nitrate concentration in drainage effluents showed various patterns in different growing seasons. In 2011, 2012 and 2014 rice seasons, maximum nitrate concentration was observed in shallow drains while in 2015 rice season and canola growing seasons, its maximum was found in deeper drains. In addition to the depth and spacing of a drainage system, water management practices, hydrological conditions, amounts and types of applied fertilizers, crop characteristics, soil properties and agricultural operations are major factors affecting nitrate losses through drainage systems. Longer drainage period in canola seasons may cause extending preferential flow paths to lower soil profile resulting more nitrate losses through deeper drains. Overall, among subsurface drainage systems, maximum and minimum nitrate concentrations were related to D0.9L30 and D0.65L30, respectively.

Table 3. Mean comparison of nitrate concentration (mg L^{-1}) in drainage water as affected by different drainage systems and growing seasons

Drainage System	Growing season						Overall
	Rice 2011	Canola 2015-16	Rice 2012	Rice 2014	Rice 2015	Canola 2015-16	
D0.9L30	3.89[c]	4.63[a]	11.40[ab]	2.70[a]	4.67[abc]	21.85[a]	9.23[a]
Bilevel-D0.65	4.62[abc]	3.71[ab]	10.92[ab]	3.42[a]	5.57[ab]	12.23[ab]	6.81[a]
Bilevel-D0.9	4.44[bc]	4.67[a]	11.65[ab]	4.00[a]	6.43[a]	9.15[b]	6.58[a]
D0.65L30	5.39[abc]	3.47[b]	9.23[ab]	3.66[a]	4.50[abc]	10.08[b]	6.17[a]
D0.65L15	6.67[ab]	4.50[a]	12.42[a]	4.55[a]	3.57[bc]	10.15[b]	7.05[a]
Control	6.44[a]	-	5.63[b]	4.81[a]	3.33[c]	-	5.19[a]

Means followed by the same letter in a column are not significantly different at $P < 0.05$ by LSD test.

Figure 1 shows the results of mean comparison of nitrate losses among different growing seasons and drainage systems. In canola seasons, nitrate losses were significantly higher than those in rice growing seasons while, no significant differences were found among the losses in 2012, 2014 and 2015 rice seasons. Generally, there were no considerable differences between nitrate losses under two water management practices in rice growing seasons. Short periods of drainage as well as time opportunity between fertilization and drainage initialization provided suitable condition for nitrogen uptake by rice plants (Darzi-Naftchali et al., 2016a). Moreover, transformation of nitrate to other components of nitrogen cycle probably resulted in less nitrate to be available for losses through drainage. In 2015-16 canola season, nitrate loss was 320 % more than that in 2011-12 canola season. Part of this increased losses may related to improved soil structure and formation of flow paths in the soil profile due to the performance of subsurface drainage systems during several years after installation. Nitrate concentration in drainage effluents were much higher in 2015-16 canola season than those in 2011-12 canoal season (Table 3). Additionally, in 2015-16 canola season, total drainage water through D0.9L30, Bilevel, D0.65L30 and D0.65L15 was, respectively, 8.60, 78.98, 13.90 and 20.25 % higher than the corresponding one in 2011-12 canola season (data not shown).

Maximum and minimum nitrate losses were 8.14 and 4.17 kg ha^{-1} per growing season related to Bilevel and D0.65L30, respectively, the most intensive and less intensive subsurface drainage systems. Total nitrate losses through D0.65L30 was also lower than that in Control indicating that suitable subsurface drainage may have less environmental effects from nitrate loss viewpoint than conventional farming in the study area. Moreover, measurement of soil nitrogen at the end of 2011 rice season and the beginning of 2012 rice season in Control (which was fallow during this period) indicated 220.2 kg ha^{-1} nitrogen loss from soil profile (Darzi-Naftchali et al., 2016a) through different processes. On the other hand, canola cropping in the subsurface drained area provided suitable condition for soil nitrogen to be used as plant uptake.

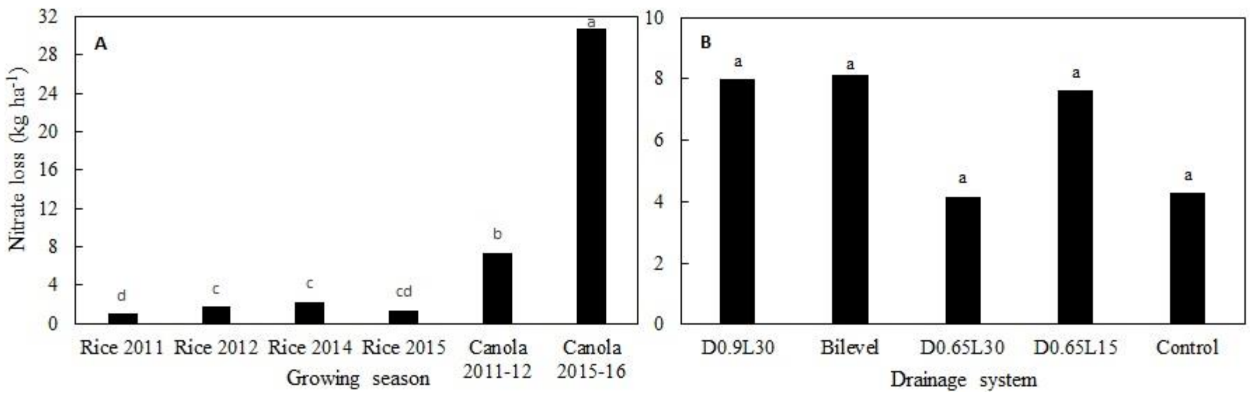

Figure 1. Mean comparison of nitrate loss among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Phosphorus losses were monitored during three first growing seasons after drainage installation. Results of mean comparison of TP losses among growing season as well as drainage systems are displayed in Figure 2. TP loss in 2011-12 canola season was significantly higher than that in 2011 and 2012 rice seasons however, such losses were not considerable in all growing seasons. Among different drainage systems, D0.65L15 resulted in maximum TP loss indicating decrease in drain depth and spacing provides more favorable condition than deeper drains with more spacing for phosphorus loss. This matter was demonstrated in some previous studies such as Poole (2006). Narrow drain spacing or less drain depth decreases the lateral flow path to drain or increases preferential flow to drains both consequently cases increase in P losses through subsurface drainage (Darzi-Naftchali et al., 2016b). Mean comparison analysis indicated that the D0.65L15 drainage system had more negative environmental effects on receiving water bodies than Control which is common condition in the northern Iran's paddy fields. This matter demonstrate that shallow subsurface drainage systems can remove P from heavy textured soils. Significant losses of P through subsurface drained fields were reported in different studies (Gardner et al. 2002; Gentry et al. 2007; Beauchemin et al., 1998).

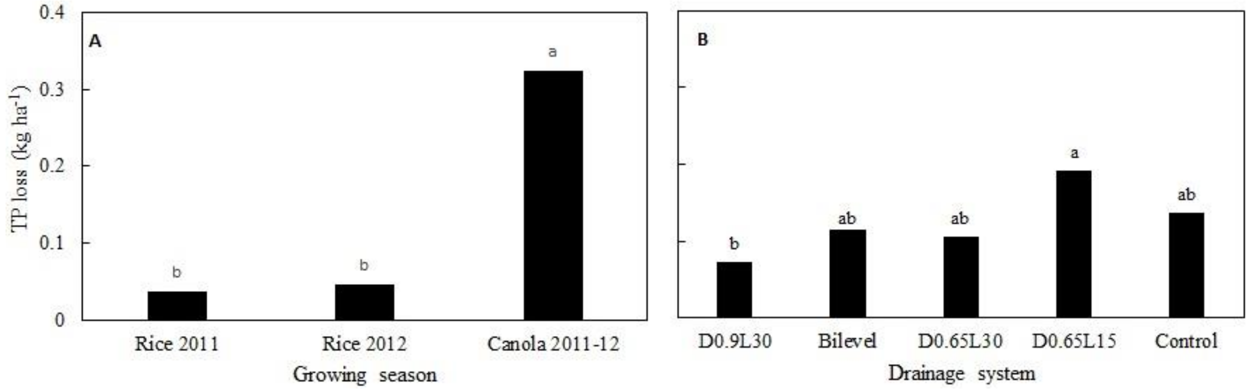

Figure 2. Mean comparison of TP loss among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Figure 3 shows variations in salt load during different cropping seasons and through drainage systems. Salt loads in canola seasons were significantly higher than those in rice seasons due to longer drainage periods and consequently more drainage water. Generally, alternate irrigation and drainage had more negative environmental effects than midseason drainage practice from salt transport point of view. Significantly increase in salt loads through Bilevel and D0.65L15 than D0.9L30 and D0.65L30 emphasizes that more intensive subsurface drainage systems resulted in higher salt load. Salt load in the Control was considerably higher than that in D0.9L30 and D0.65L30 suggesting that these drainage systems are more suitable than conventional mono culture in the study area. Moreover, such drainage systems provide appropriate condition for winter cropping as an additional merit that boosts the overall productivity of the poorly drained paddy fields.

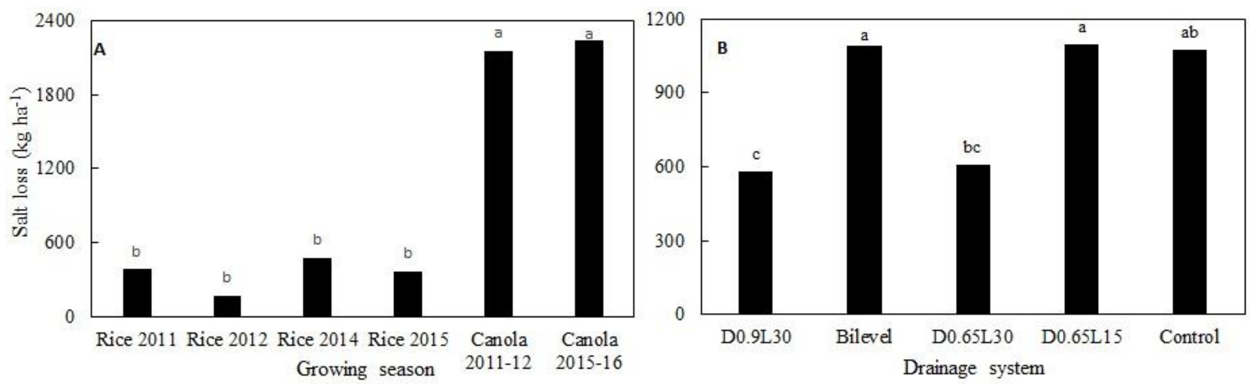

Figure 3. Mean comparison of salt load among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Figures 4 and 5 show, respectively, variations in canola and rice yield during 4 growing seasons. Subsurface drainage resulted in continuous improvement in the productivity of the study area. In 2015- 16 growing season, canola yield was significantly higher than that in 2011-12 and 2012-13 while no differences were found between canola yields in 2014-15 and 2015-16 growing seasons.

In 2015-16, canola yield increased by 1764.2, 407.2 and 133.7 kg ha^{-1} as compared with the yield in 2011-12, 2012-13 and 2014-15, respectively. Based on 4- year data, maximum canola yield is related to D0.90L30. However, no significant difference was observed among canola yields in different drainage systems. Rice yield well responded to differences in the types of water management. Rice yields in 2014 and 2015 were significantly higher than those in 2011 and 2012 suggesting that alternate irrigation and drainage is more suitable strategy than midseason drainage in the study field. Moreover, integrated analysis of rice yields under two water managements indicate that subsurface drainage systems increased rice yield compared with conventional farming in the region. The maximum increase achieved under Bilevel followed by D0.65L30, D0.65L15 and D0.9L30. Various factors such as agricultural inputs and practices, soil characteristics and hydrological conditions influence yield and growth traits of any crop (Darzi- Naftchali and Shahnazari, 2014). Such conditions were generally similar during each growing season and the only difference was the type of drainage system. However, the conditions differed somewhat among growing seasons. Generally, yield data demonstrate that subsurface drainage improved the productivity of the rice fields through providing year- round crop production conditions and increasing rice yield as a major crop in the area. Subsurface drainage has been reported to increase crop yield in some studies (Carter and Camp, 1994; Mathew et al., 2001; Satyanarayana and Boonstra, 2007; Ritzema et al., 2008). Subsurface drainage improves root zone environment from both supplying oxygen to soil and removing toxic substances viewpoints resulting better condition for root development than undrained condition.

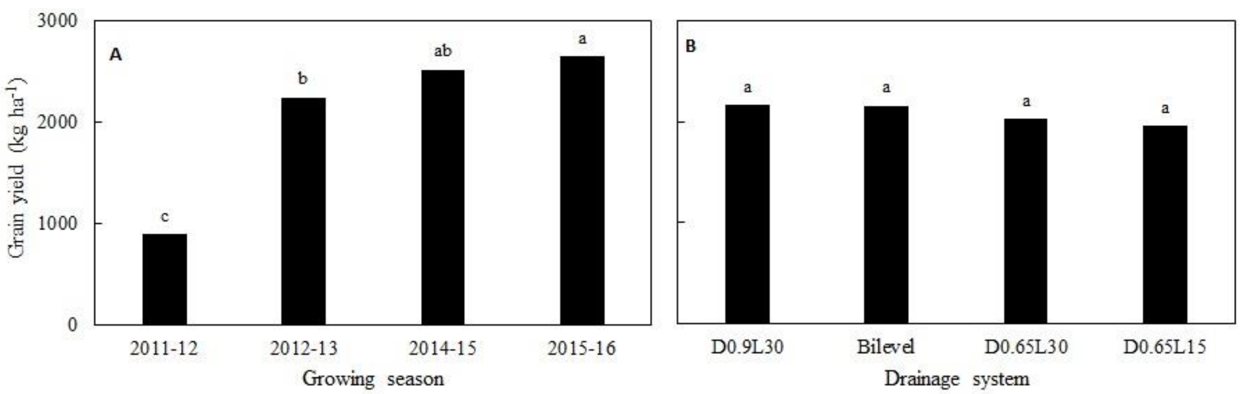

Figure 4. Mean comparison of canola yield among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

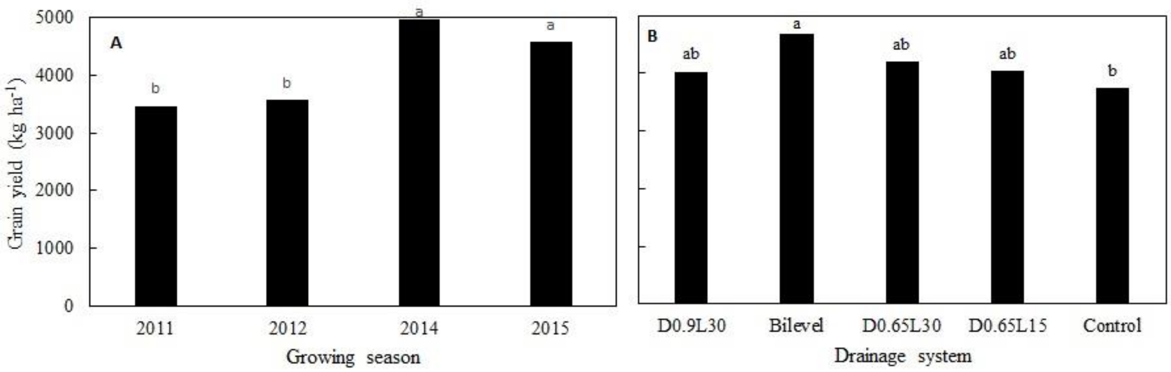

Figure 5. Mean comparison of rice yield among growing seasons (A) and drainage systems (B). Means with the same letter are not significantly different at P<0.05 by LSD test.

Conclusion

This study was conducted to clarify different aspects of providing annual cropping system of rice-canola rotation in northern Iran's paddy fields under different subsurface drainage systems and a conventional surface drainage. Field investigations during 4- rice and 4- canola growing seasons revealed that subsurface drainage could increase the productivity of the poorly drained paddy fields with negative environmental effects that comparable with conventional drainage in the study area. Considering yield increases and environmental aspects related to different drainage systems, it could be concluded that the installation of subsurface drains at 0.65 m depth and 30 m spacing could provide suitable condition for sustainable and economic agriculture in the study area.

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UPSCALING HYDRAULIC CONDUCTIVITY IN SOILS: TECHNIQUES FROM STATISTICAL PHYSICS

Behzad Ghanbarian[1,*]

Abstract

Estimating single- and two-phase hydraulic conductivities in soils, particularly in large scales, is essential for designing irrigation systems and drainage networks. Therefore, upscaling hydraulic conductivity *K* has been a challenge over the years, and rigorous techniques applicable to heterogeneous soils are still required. In the literature, most of the applied methods used for determining an effective and representative value of *K* are based on weighted arithmetic and harmonic means corresponding, respectively to the parallel (layered soils parallel to flow direction) and series (layered soils perpendicular to flow direction) models. In reality, however, soils, exist neither in series nor in parallel form, but are complex multi-scale networks. In this study it is proposed that techniques, such as critical path analysis and effective-medium approximations from statistical physics to upscale hydraulic conductivity in heterogeneous porous media like soils be considered. The former is valid in strongly heterogeneous media, while the latter is applicable to homogeneous and relatively heterogeneous systems. Advantages and disadvantages as well as practical applications of each method are discussed in details.

KEY WORDS: Critical path analysis, Effective-medium approximation, Hydraulic conductivity, Upscaling.

Introduction

Soil hydraulic conductivity *K* is an essential component to design irrigation systems and drainage networks. Therefore, determining an effective value of hydraulic conductivity, representing the porous medium's ability to transit fluid flow, under both fully- and partially-saturated conditions has been of great importance but challenging over years. Although various models were developed to upscale saturated and unsaturated hydraulic conductivities, rigorous techniques applicable to heterogeneous soils are still required. In the literature, mostly applied methods to determine an effective and representative value of *K* are based on weighted arithmetic and harmonic means corresponding, respectively, to the parallel, layered soils parallel to flow direction (Fig. 1), and series, layered soils perpendicular to flow direction (Fig. 2), models.

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In the parallel model, the arithmetic mean hydraulic conductivity K_a in a porous medium equally composed of *n* parallel components each of which has a specific hydraulic conductivity value K_i (see Fig. 1a) is given by

$$K_a = \frac{1}{n}\sum_{i=1}^{n} K_i \qquad (1)$$

However, if the fraction of each component is different (see e.g., Fig. 1b), the weighted arithmetic mean hydraulic conductivity K_{aw} should be determined as follows

$$K_{aw} = \frac{1}{n}\sum_{i=1}^{n} w_i K_i \qquad (2)$$

where w_i represents the corresponding weight associated with each component such that $\sum_{i=1}^{n} w_i = 1$.

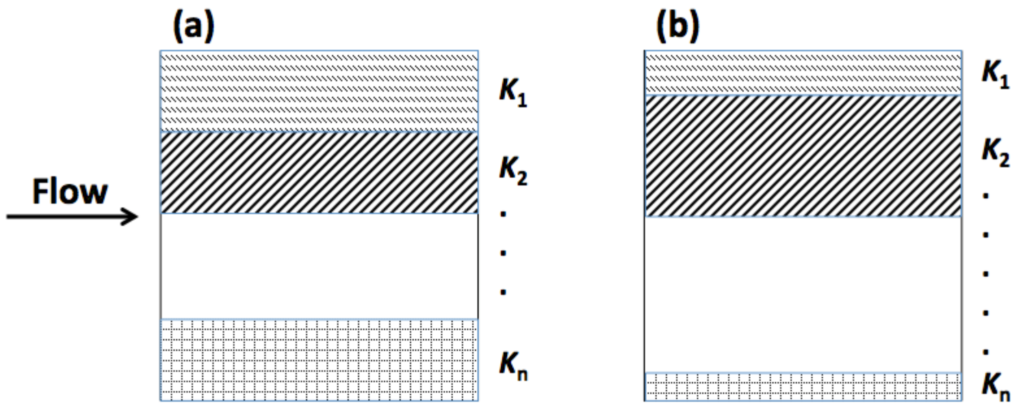

Figure 1. Parallel combination of soil layers of various hydraulic conductivities e.g., K_1, K_2,..,K_n with (a) identical and (b) different thicknesses.

In the series model, the harmonic mean hydraulic conductivity K_h in a porous medium equally composed of *n* components in series (see Fig. 2a) is

$$K_h = \frac{n}{\sum_{i=1}^{n}\frac{1}{K_i}} \qquad (3)$$

If components have different weights (see Fig. 2b), then the weighted harmonic mean hydraulic conductivity K_{hw} should be determined as follows:

$$K_{hw} = \frac{n}{\sum_{i=1}^{n} \frac{w_i}{K_i}} \qquad (4)$$

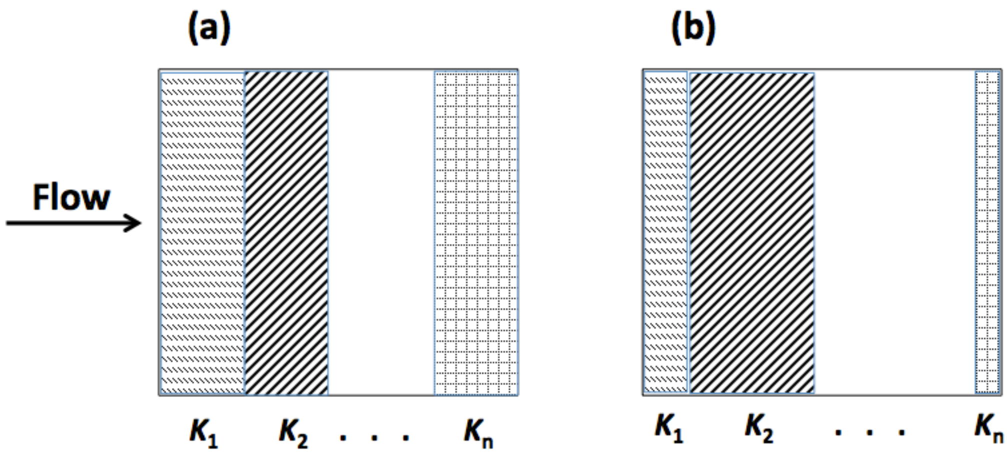

Figure 2. Series combination of soil layers of various hydraulic conductivities e.g., K_1, K_2,…, K_n with (a) identical and (b) different thicknesses.

The series and parallel models define the upper and lower bounds, also known as the Wiener bounds (Wiener, 1912), for the representative hydraulic conductivity of heterogeneous porous media randomly composed of components of various volumes and conductivities. In addition to arithmetic and harmonic means, geometric and weighted geometric means have been also used in the literature (e.g., Gutjahr et al., 1978; Koltermann and Gorelick, 1995; Porter et al., 2013) to determine the representative hydraulic conductivity in soils and rocks

$$K_g = exp\left[\frac{1}{n}\sum_{i=1}^{n} \ln(K_i)\right] \qquad (5)$$

$$K_{gw} = exp[\sum_{i=1}^{n} \mathrm{w_i}\ln(K_i)] \qquad (6)$$

One should note that the (weighted) geometric mean always lies between the (weighted) harmonic and (weighted) arithmetic means ($K_{wh} \leq K_{wg} \leq K_{wa}$; Wiener, 1912). A comprehensive review of harmonic, geometric, and arithmetic means are given by Sanchez-Vila et al. (2006).

The generalized mean hydraulic conductivity K_G of hydraulic conductivities K_1, K_2,…, K_n associated with weights w_1, w_2,…, w_n may be expressed as

$$K_G = \left[\frac{1}{n}\sum_{i=1}^{n} w_i K_i^p\right]^{\frac{1}{p}} \tag{7}$$

where p is a real number. Note that Eq. (7) reduces to the weighted harmonic, geometric, and arithmetic models for p = -1, 0, and 1, respectively. Although the generalized mean hydraulic conductivity (Eq. 7) includes several other models as its special cases, the value of p is priory unknown to determine the representative hydraulic conductivity practically.

For isotropic mixtures of components K_1, K_2, …, K_n, the representative hydraulic conductivity would be independent of the medium structure (Tong et al., 2009). Hashin and Shtrikman (1962) proposed lower and upper bounds for macroscopically homogeneous and isotropic media. For the lower bound, Hashin and Shtrikman (1962) found

$$K_{HS}^l = K_1 + \frac{1-w_1}{\frac{1}{K_2-K_1}+\frac{w_1}{3K_1}} \tag{8}$$

and for the upper bound

$$K_{HS}^u = K_2 + \frac{w_1}{\frac{1}{K_1-K_2}+\frac{1-w_1}{3K_2}} \tag{9}$$

Note that the Hashin-Shtrikman bounds (Eqs. 8 and 9) necessarily duplicate the results of the Maxwell-Eucken model (Maxwell, 1954; Eucken, 1940). For a more comprehensive review of the applications of the effective permeability models to porous media see Renard and de Marsily (1997).

Tong et al. (2009) extended the Hashin-Shtrikman bounds to porous media with n components. For the lower bound, they found

$$K_{EHS}^l = K_1 + nK_1 \frac{\sum_{i=1}^{n}\frac{w_i}{\left(1+C_i^l\right)}}{w_1+\sum_{i=1}^{n}\frac{w_i C_i^l}{\left(1+C_i^l\right)}} \tag{10}$$

and for the upper bound

$$K_{EHS}^u = K_n + nK_n \frac{\sum_{i=1}^{n}\frac{w_i}{\left(1+C_i^u\right)}}{w_n+\sum_{i=1}^{n}\frac{w_i C_i^u}{\left(1+C_i^u\right)}} \tag{11}$$

in which $C_i^l = nK_1/(K_i - K_1)$ and $C_i^u = nK_n/(K_i - K_n)$.

In reality, soils, however, exist neither in series nor in parallel form but are complex multi-scale networks, stochastically heterogeneous mixtures of various components. In what follows, we propose techniques, such as effective-medium approximations and critical path analysis from statistical physics to determine the effective hydraulic conductivity in heterogeneous porous media like soils. The former is valid in strongly heterogeneous media, while the latter is applicable to homogeneous and relatively heterogeneous systems.

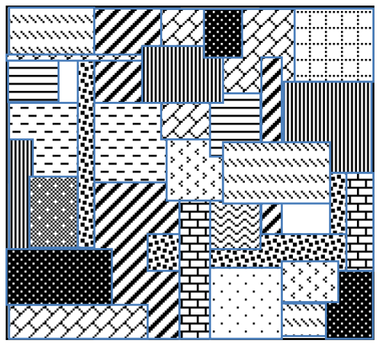

Figure 3. Schematic stochastic combination of soil components of various hydraulic conductivities e.g., K_1, K_2,…, K_n.

Materials and methods

Effective-medium approximation

The effective-medium approximation (EMA) is an upscaling technique from statistical physics in which a heterogeneous porous medium with local hydraulic properties is replaced with a homogeneous medium with the same macroscopic hydraulic properties, such as hydraulic conductivity ($K = K_e$; see Fig. 4). The main idea underlying the EMA is to infer an average hydraulic conductivity for such a heterogeneous medium from local hydraulic conductivities (David et al., 1990; Sahimi, 2011). The macroscopic effective hydraulic conductivity of the homogeneous medium K_e is the same as the macroscopic hydraulic conductivity of the original heterogeneous medium. How is K_e calculated using the EMA and statistics of local conductivities? The spatially dependent permeability in the disordered medium results in local perturbations about the effective permeability of the ordered medium. The effective permeability is then determined by setting the average perturbation to be zero (Kirkpatrick, 1973).

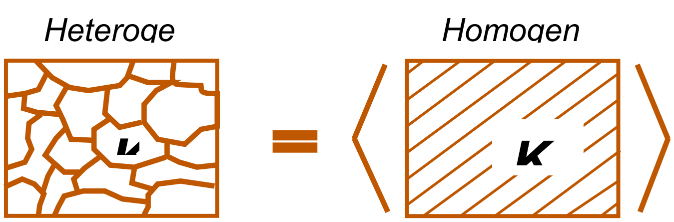

Figure 4. Scheme of a disordered porous medium with an actual permeability *K* replaced by a uniform one with an effective permeability K_e in the effective-medium approximation framework (a modified version from Hori and Yonezawa, 1977).

Two-component porous media

In binary materials built up of two components, the concept of the EMA may be used to determine the effective hydraulic conductivity. To calculate the effective hydraulic conductivity of a binary mixture with various portions of the two components one has (Kirkpatrick, 1973; Ghanbarian and Daigle, 2016)

$$(1-w_1)\frac{K_2-K_e}{K_2+\left(\frac{Z}{2}-1\right)K_e}+w_1\frac{K_1-K_e}{K_1+\left(\frac{Z}{2}-1\right)K_e}=0 \qquad (12)$$

where Z is the average pore coordination number. Note that Eq. (12) reduces to Bruggeman's approximation (Bruggeman, 1935) and Eq. (3) – the well-known weighted harmonic mean discussed above – when Z = 6 and 2, respectively.

We show the effective hydraulic conductivity calculated using Eq. (12) for a medium composed of two components with K_1 = 0.1 and K_2 = 10 (arbitrary units) in Fig. 5. As can be observed, the greater the pore coordination number Z, the more the pore connectivity and thus the greater the effective hydraulic conductivity.

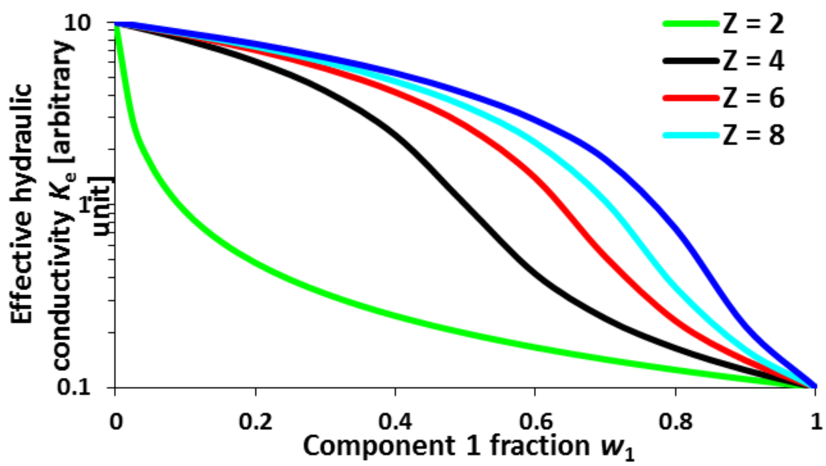

Figure 5. Effective hydraulic conductivity K_e calculated using the effective-medium approximation (Eq. 12) versus the component 1 fraction (w_1) for various values of the coordination number Z, K_1 = 0.1 (arbitrary unit), and K_2 = 10 (arbitrary unit). Note that Eq. (12) with coordination number Z = 2 reduces to Eq. 4, the weighted harmonic mean.

Ghanbarian and Daigle (2016) numerically simulated the saturated hydraulic conductivity in binary mixtures of spheres and ellipsoids (two components) using the lattice-Boltzmann (LB) method and compared that with the effective-medium approximation (EMA) results. They demonstrated that the EMA estimated K_{sat} within a factor of two of the LB simulated values in simple and body-centered cubic packs. Ghanbarian and Daigle (2016) found that the EMA results depend on several factors, such as packing arrangement, grain shape, and porosity.

n-component porous media

Porous media are complex in nature and constructed of more than one or two components. Natural porous media are inherently heterogeneous, typically poorly sorted, and have broad grain- and pore-size distributions. A heterogeneous medium has, therefore, spatially dependent or local hydraulic conductivity K following a distribution. The general EMA formula to determine the effective hydraulic conductivity K_e is

$$\sum_K \frac{K-K_e}{K+\left(\frac{Z}{2}-1\right)K_e} f(K) = 0 \qquad (13)$$

where $f(K)$ is the hydraulic conductivity distribution.

Recently, Ghanbarian et al. (2016a) applied concepts from the EMA to estimate unsaturated hydraulic conductivity in soils from pore throat-size distribution reflected in desaturating capillary pressure curve. For fully saturated conditions, Ghanbarian et al. (2016a) proposed

$$\int_{r_c}^{r_{max}} \frac{g_e(S_w=1) - r^g}{r^g + \left[(1-S_{wc})/S_{wc}\right] g_e(S_w=1)} f(r)\,dr = 0 \qquad (14)$$

where $g_e(S_w = 1)$ is the effective hydraulic conductance under fully saturated conditions, $f(r)$ is the pore throat-size distribution, r is the pore throat radius, r_c is the critical pore throat radius, S_w is the water saturation, and S_{wc} is the critical water saturation at which $K(S_w) = 0$.

For unsaturated conditions one has

$$\int_{r_c}^{r} \frac{g_e(S_w) - r^g}{r^g + \left[(1-S_{wc})/S_{wc}\right] g_e(S_w)} f(r)\,dr = 0 \qquad (15)$$

where $g_e(S_w)$ is the effective hydraulic conductance under partially saturated conditions. Therefore, $K(S_w)$ may be defined as

$$K_r = \frac{K(S_w)}{K_{sat}} = \frac{g_e(S_w)}{g_e(S_w=1)} \qquad (16)$$

Note that Eqs. (14) and (15) are implicit in form, and $g_e(S_w=1)$ and $g_e(S_w)$ should be determined numerically.

The EMA, however, does not produce accurate results near the critical water saturation S_{wc}. Thus, one should use the EMA only at high to intermediate water saturations. A remarkable scaling law from percolation theory is that, above but near the critical water saturation, unsaturated hydraulic conductivity should conform to the following universal power law

$$K_r = K_0(S_w - S_{wc})^2 \qquad (17)$$

Thus, to estimate K_r over the entire range of S_w, one should utilize Eq. (16) in combination with Eqs. (14) and (15) for $S_{wx} \leq S_w \leq 1$, and apply Eq. (17) for $S_{wc} \leq S_w \leq S_{wx}$. S_{wx} is the water saturation at which the scaling law from the EMA switches to that from percolation theory (Eq. 17). Note that the value of S_{wx} and K_0 are determined numerically.

The estimated K_r and the measured values versus water saturation S_w are shown in Fig. 6 for 9 soil samples from the UNSODA database. It is well documented in the literature that the EMA produces precise results as long as the pore throat-size distribution is not too broad (see e.g., Kirkpatrick, 1971). However, the term "broad" has never been satisfactorily quantified. Therefore, a reason for imprecise estimation of K_r for samples 4162 and 4592 shown in Fig. 6 might be due to intrinsic inaccuracy of the EMA for highly disordered porous media with broad pore throat-size distribution. However, there might be other reasons for such underestimations, such as ignoring film and corner flow, which might effectively contribute to fluid flow at low water saturations.

Critical path analysis

Critical path analysis (CPA) is a promising method to understand transport in porous media with no correlation and/or short-range correlation (random systems). According to CPA, hydraulic conductivity in an uncorrelated and disordered medium is mainly controlled by conductances with magnitudes slightly less than the critical conductance g_c, where the critical conductance is the smallest possible value of the conductance for which the set of all larger conductances still forms an infinite connected cluster (Katz and Thompson, 1986).

Katz and Thompson (1986; 1987) were first to apply critical path analysis to relate the saturated hydraulic conductivity, K_{sat}, to electrical conductivity and critical pore radius. Their model is

$$K_{sat} = \frac{f}{56.5}\frac{\sigma_b}{\sigma_w} r_c^2 \qquad (18)$$

where f is the fluidity factor, σ_b is bulk electrical conductivity, σ_w is saturating fluid electrical conductivity, and r_c is the critical pore radius.

Following Katz and Thompson (1987) one may approximate σ_b/σ_w from the optimum pore radius. Ghanbarian-Alavijeh and Hunt (2012) also proposed a method to estimate r_c from capillary pressure data, such as the pore space fractal dimension D. By estimating the critical pore radius r_c and electrical conductivity σ_b/σ_w using the methods proposed respectively by Ghanbarian-Alavijeh and Hunt (2012) and Katz and Thompson (1987), Ghanbarian et al. (2017) proposed the following model to calculate the saturated hydraulic conductivity based on critical path analysis

$$K_{sat} = f\,\frac{A^2 P_a^{-2}}{56.5}\,\frac{\phi}{3}\left[1-\left(\frac{1}{3}\right)^{3-D}\left(1-\frac{\theta_t}{\beta}\right)\right]\left(1-\frac{\theta_t}{\beta}\right)^{\frac{2}{3-D}} \quad (19)$$

where A is the constant coefficient in the Young-Laplace equation, P_a is the entry pressure, θ_t is the critical water content for percolation, and ϕ is the porosity.

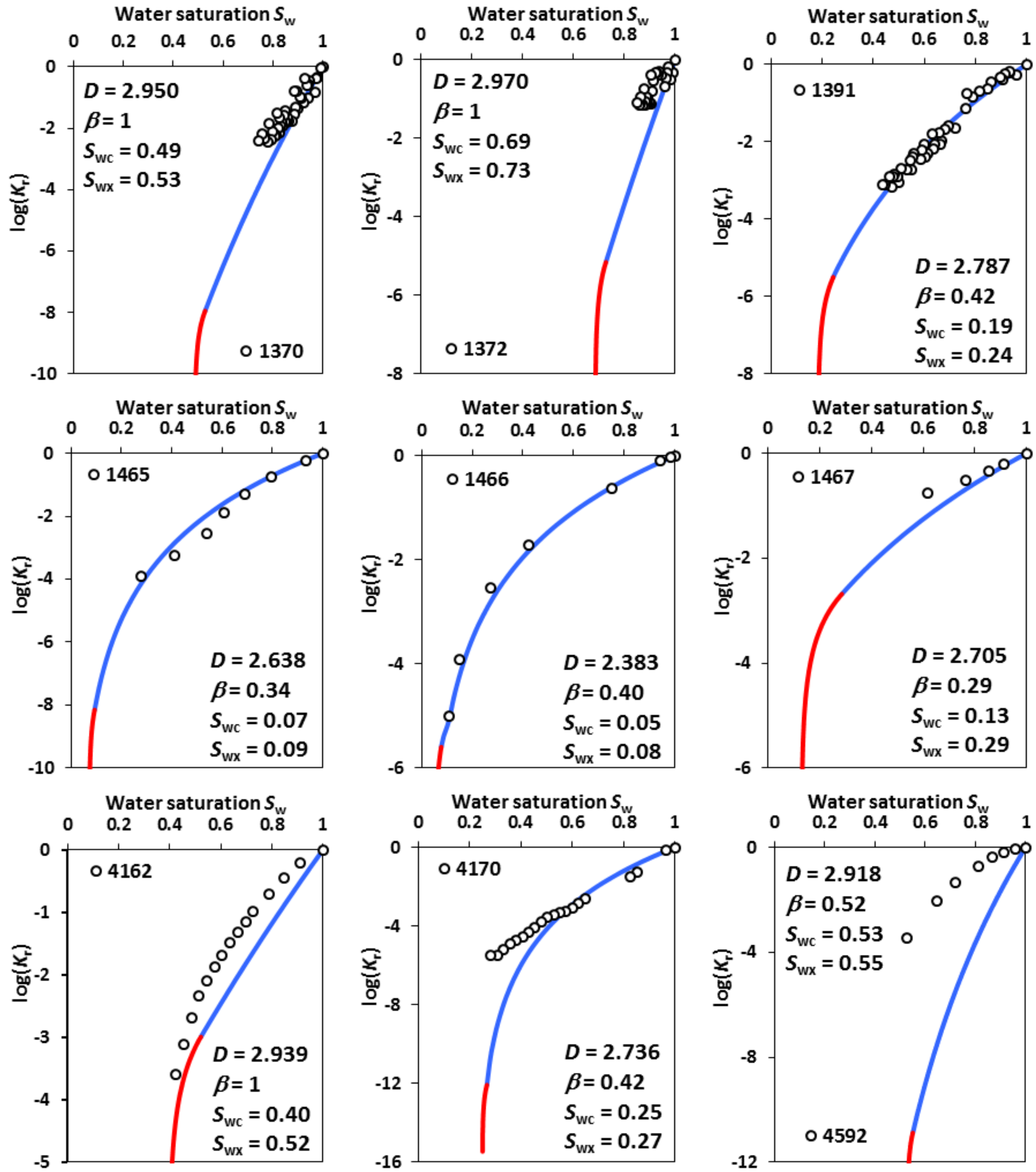

Fig. 6. Comparison of the estimated relative hydraulic conductivity K_r, calculated based on the desaturating capillary pressure curve, and the experimental data, for 9 soil samples from the UNSODA database. The blue and red lines represent the results of effective-medium approximation and percolation theory, respectively (after Ghanbarian et al. 2016a).

The unknown parameters in Eq. (19), such as D, P_a and β are determined by directly fitting the following fractal capillary pressure curve model to measured data

$$S_w = 1 - \frac{\beta}{\phi}\left[1 - \left(\frac{P_c}{p_a}\right)^{D-3}\right], \quad |P_a| \leq |P_c| \leq |P_{cmax}| \tag{20}$$

in which P_c is the capillary pressure, P_a is the entry pressure, and P_{cmax} is the maximum capillary pressure.

Figure 7 presents the saturated hydraulic conductivity estimated using the CPA (Eq. 19) as a function of the average saturated hydraulic conductivity data for 11 soil texture classes from Rawls et al. (1982). As can be observed, critical path analysis estimated K_{sat} within a factor of three of the measured hydraulic conductivity. Interestingly, critical path analysis estimated K_{sat} for fine-textured soils more precisely than that for coarse-textured soils (see Fig. 7), which is consistent with the fact that the CPA produces accurate estimation in heterogeneous soils with broad pore throat-size distribution.

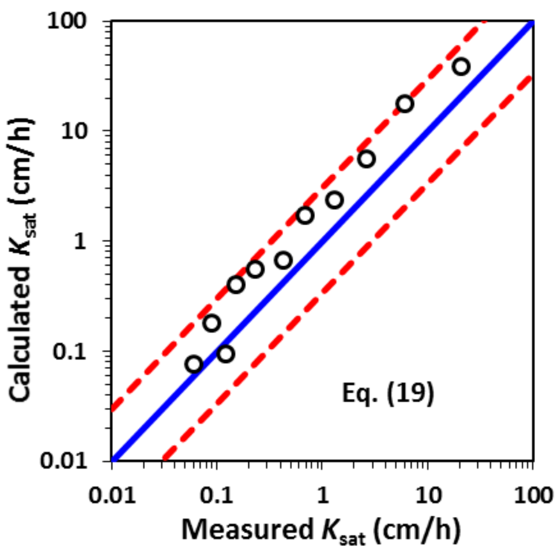

Figure 7. The estimated saturated hydraulic conductivity using the critical path analysis and Eq. (19) versus the average measured value for eleven USDA soil texture classes from Rawls et al. (1982). The blue solid and red dashed lines represent the 1:1 line and the factor of three boundaries, respectively (after Ghanbarian et al., 2017).

Following Hunt (2001), Ghanbarian-Alavijeh and Hunt (2012) proposed a model based upon critical path analysis to estimate the unsaturated hydraulic conductivity of soils. The Ghanbarian-Alavijeh and Hunt (2012) model is

$$\frac{K(S_w)}{K_{sat}} = \begin{cases} \left[\frac{\beta/\phi - 1 + S_w - S_{wc}}{\beta/\phi - S_{wc}}\right]^{\frac{\lambda}{3-D}}, & S_{wx} \le S_w \le 1 \\ \left[\frac{\beta/\phi - 1 + S_{wx} - S_{wc}}{\beta/\phi - S_{wc}}\right]^{\frac{\lambda}{3-D}} \left[\frac{S_w - S_{wc}}{S_{wx} - S_{wc}}\right]^2, & S_{wc} \le S_w \le S_{wx} \end{cases} \tag{21}$$

in which

$$S_{wx} = S_{wc} + \left[\frac{2(\beta - \phi)}{\lambda/(3-D) - 2}\right] \tag{22}$$

where $\lambda = 2(4 - D) - (3 - D)/(2D - 3)$ (Ghanbarian et al., 2016b). For a comprehensive review of various unsaturated hydraulic conductivity models based on the CPA for different conditions, see Ghanbarian et al. (2015).

To evaluate Eq. (21), Ghanbarian and Hunt (2017) selected 104 soil samples from the UNSODA database. The input parameters, such as D and β were determined by fitting Eq. (20) to the drainage capillary pressure curve.

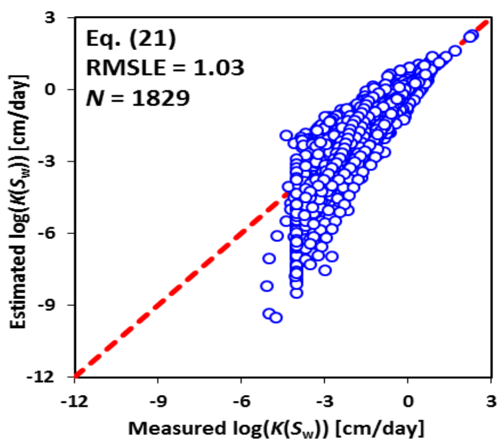

Figure 8. The logarithm of the estimated unsaturated hydraulic conductivity $K(S_w)$ using Eq. (21) with $\lambda = 2(4-D)-(3-D)/(2D-3)$ versus the logarithm of the measured one for 104 soil samples from the UNSODA database. RMSLE is the root mean squared log-transformed error and N is the total number of values. The red dashed line denotes the 1:1 line (after Ghanbarian and Hunt, 2017).

Figure 8 shows the estimated log($K(S_w)$) versus the measured log($K(S_w)$) for 104 soil samples from the UNSODA database. Equation (21) with $\lambda = 2(4 - D) - (3 - D)/(2D - 3)$ estimates $K(S_w)$ suitably scattered around the 1:1 line over the entire range of saturation. However, there still exist tendencies to underestimate $K(S_w)$ at lower water saturations. Errors in the estimation of $K(S_w)$ in particular at lower water saturations might be due to lack of equilibrium conditions in the measurements. Another plausible source of error for $K(S_w)$ underestimation might be due to multimodal pore-size distribution behavior in some soil samples analyzed. In addition, neglecting film and corner flow in the model Eq. (21) development might be another reason for $K(S_w)$ underestimation. One should note that Eq. (21), developed based on concepts from critical path analysis and percolation theory, is neither a function of capillary number – a dimensionless quantity measuring the ratio of viscous to capillary forces (Lake, 1989) – nor a function of flow rate, while both factors may significantly affect hydraulic conductivity measurements and estimations.

Conclusion

In this study, we applied upscaling techniques from statistical physics, such as the effective-medium approximation (EMA) and critical path analysis (CPA) to estimate the saturated and unsaturated hydraulic conductivities (i.e., K_{sat} and $K(S_w)$) in soils from pore-scale characteristics. Theoretically, the EMA upscales properly in homogeneous and relatively heterogeneous porous media, while the CPA works accurately in heterogeneous media with broad pore-size distribution. By comparison with numerical simulations and experiments, we showed that both the EMA and CPA methods estimated K_{sat} and $K(S_w)$ reasonably accurate in porous media. More investigation is required to address the effects of film and corner flow as well as capillary number via critical path analysis and percolation theory and the effective-medium approximation.

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EFFECTS OF CONTROLLED DRAINAGE ON NON-POINT SOURCE DISCHARGE FROM PADDY RICE IN KOREA

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Abstract

The objective of this study was to develop water management practices to reduce pollutant loads and to develop guidelines for paddy rice cultivation. The experimental fields were established at Chunpo-myeon, Iksan-si, in the Saemangeum watershed. The experiment was performed during the growing season to assess water and mass balances of the study field in 2013 and 2015. In this study the two different farming practices were applied: conventional and water treatment. Conventional practices were applied to maintain an average water depth of paddy fields at 7 cm, while the water depth of water treated plots were maintained at 7 cm to midsummer drainage and then raised to 12 cm afterward. Chemical fertilizer was applied in both plots. The water balance analysis indicated that the drainage of water treatment decreases by 24.2% (conventional: 394.5 mm, water treatment: 298.4 mm) as compared to the conventional treatment. Drainage when compared to the inflow of water treatment decreases from 0.9% to 9.6% as compared to the conventional treatment. The mass balance analysis indicated that T-N (Total-Nitrogen) drainage load of water treatment decreases by 27.1% (conventional: 1.25 kg/10a, water treatment: 0.91 kg/10a) and T-P (Total Phosphorus) decreases by 38.0% (conventional: 0.125 kg/10a, water treatment: 0.077 kg/10a) as compared to the conventional treatment. T-N drainage load when compared to the inflow of water treatment decreases from 0.5% to 3.3% and T-P decreases from 0.6% to 3.3% respectively as compared to the conventional treatment. The results of this study confirmed that water treatment in paddy fields reduces pollutant loads and could be used as a guidelines for farmers.

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KEY WORDS: Paddy, Non-point source, Drainage outlet heighten, Water balance, Mass balance

Introduction

Point source pollutant control has been implemented to improve water quality and thus most investment has been poured to this respect. As the result, approximately two thirds of total pollutants to water bodies is attributed to nonpoint source origin and thus has to be managed properly for further enhancement in water quality (Korean Relevant Ministerial Consortium, 2012).

Nutrient runoff from agricultural field is a substantial contributor to the surface water impairment and thus the nutrient loads reduction from paddy field has become an important issue in the Asian monsoon region (Kao et al. 2001; Yoon et al. 2003; Hama 2012). Paddy field accounts for more than 60 % of farm land and uses about 80 % of agricultural water use. Thus, the Korean government has run much efforts to reduce runoff from paddy fields (Choi et al. 2015).

Reducing surface drainage is effective in reducing nutrient loss from paddy field and some water saving methods was proposed including shallow ponding, raising drainage outlet, and minimizing midseason drainage (Yoon et al. 2003; Song et al. 2012). Paddy rice cultivation with outlet dikes and forced drainage alters paddy hydrological characteristics and thus water quality dynamics along with farmer's over-fertilization than the recommended in Korea (Kim et al. 2014)

The objective of this study was to investigate paddy nutrients runoff with some water saving method in comparison of conventional paddy farming practice.

Materials and methods

Experimental site layout

The field study was carried out from 2013 to 2015 on duplicated paddy plots of each 0.3 ha of fine sand loamy soil for the two different water management: one conventional and the other water treatment. Experiment fields were located at Iksan city of Jeonbuk Province in Korea. Overall experimental setup is presented in Figure 1.

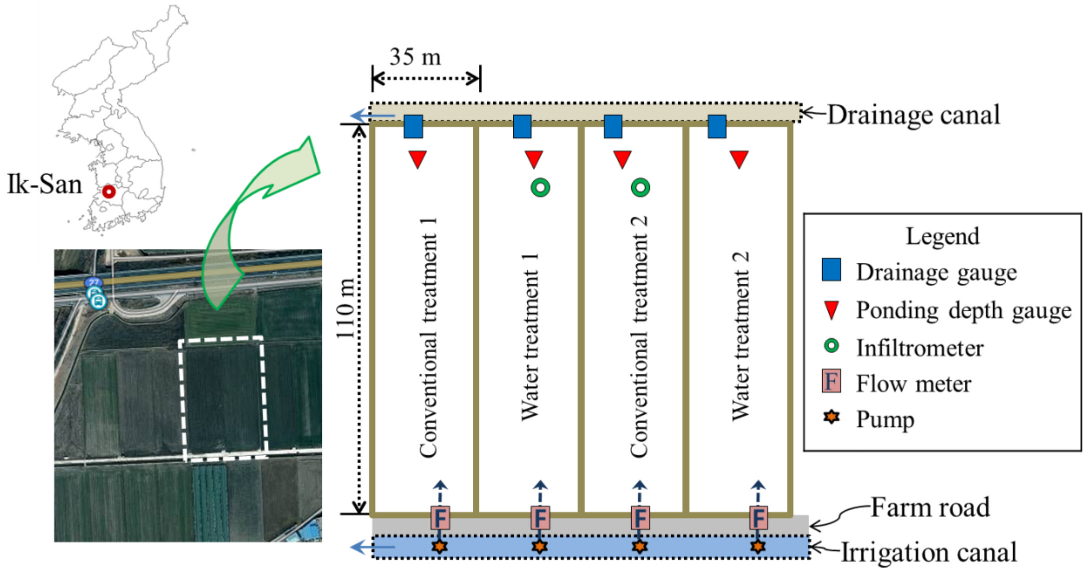

Figure 1. Study location and experimental setup

Experimental treatment and field monitoring

The two different farming (water management) practices were applied: conventional and water treatment. Conventional practices were to maintain an average water depth of paddy fields at 7 cm, while water depth of water treated plots were maintained at 7 cm to midsummer drainage and then raised to 12 cm afterward. Chemical fertilizer was applied in both plots.

In order to investigate hydrology in each paddy field, irrigation and drainage water amount were measured by respective flow meter and drainage weir continuously. Paddy ponding depth was also measured every 30 min with ultrasonic water level, while an infiltrometer was installed in a paddy field of each water treatment methods. Biweekly water samples were collected from paddy water in non-rainy, while continuous waters were sampled from the drainage outlet when rainfall event occurred. Water samples were transported to the lap for the analysis of nutrient contents along with basic water component. Paddy nutrient runoff was then calculated by multiplying drainage flow rate with corresponding water quality.

Results and discussion

The water balance analysis indicated that drainage of water treatment decreases by 24.2% (conventional: 394.5 mm, water treatment: 298.4 mm) compared to the conventional treatment. Drainage compared to inflow of water treatment decreases from 0.9% to 9.6% compared the conventional treatment. As shown in Table 1, there was no statistical significant difference in rice harvest between water treatment methods.

Table 1. Rice harvest comparison between conventional and water treated plots

Year	Treatment	Yield (kg/10a)			
		Rough rice	Brown rice	Milled rice	Head rice
2013	Conventional	718	594	549	503
	Water treatment	671	559	499	460
2014	Conventional	778	666	592	544
	Water treatment	814	715	632	583
2015	Conventional	769	646	588	449
	Water treatment	768	633	571	425

Figure 2 presents the results of nutrient loads from the two different water management schemes. Annual mean total nitrogen loads for the three years of experiment were 1.25 and 0.91 kg/10a for the conventional and water treated paddy plots, respectively. About 27 % of nitrogen loads was reduced with water treatment as compared to the conventional practice. Total phosphorus runoff was even more reduced by up to 38% with water treatment as compared to the conventional farming (T-P loads of 0.125 kg/10a and 0.077 kg/10a, correspondently). Considering phosphorus moving along with suspended solid, more ponding water with water outlet raising may reduce greatly the force of rainfall hit to soil particle and thus reduce soil detachment potentially transportable with drainage and resulted in reduction in TP loads. This confirmed that water treatment in paddy farming can reduces pollutant loads and can be used as a paddy BMP.

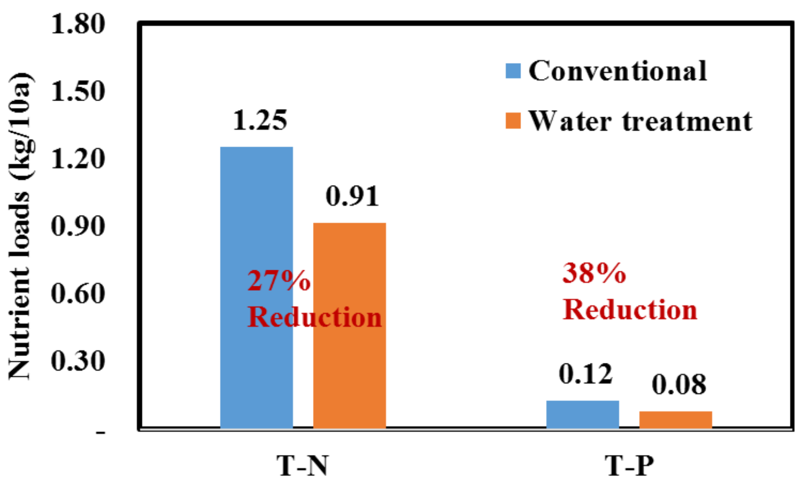

Figure 2. Nutrient loads reduction with water treatment

Conclusion

In this study, the two different farming (water management) practices were investigated in order to evaluate the effect of water treatment in paddy nutrient loads reduction. Annual nutrient loads was substantially reduced with alternative water management of drainage outlet raising as compared to conventional practice. Mean nitrogen loads was 1.25 and 0.91 kg/10a for the conventional and water treated paddy plots and about 27 % reduction was achieved with water treatment. Greater percentage of total phosphorus loads reduction (38%) was attained with water treatment than conventional farming. The study finding confirmed that water treatment in paddy farming can reduces pollutant loads and can be used as a paddy BMP.

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NON-EXCAVATION SUBSURFACE IRRIGATION AND DRAINAGE SYSTEM IN THE RECLAIMED LOWLAND TO BE CULTIVATED WITH UPLAND FIELD CROP

Hyuntai Kim[1,*], Donguk Seo[2], Jeonyong Ryu[3]

Abstract

Although in the past reclaimed land was developed and used mainly as paddy fields in Korea, there is a currently a need to improve the reclaimed land to be cultivated for highland-field crops, due to the necessity for a smooth management of grain supply and demand in order to be able to cope with the changes in the international and domestic agricultural environment, and the earning of a higher revenue from farming highland-field crops instead of rice. However, it is difficult to cultivate highland-field crops in reclaimed land, because it is mostly located in lowland zones containing high salinity soil that is difficult to drain due to the characteristics of fine grained soil which is a major component of reclaimed land. In addition, there is the major problem of re-salinization of root zone soil caused by the capillary rise of saline groundwater during the dry season. In this study, seepage analysis was conducted on each type of subsurface drainage system to draw a high-capacity drainage system, and subsoil breaking and no-excavation subsurface drainage system were proposed to be utilized for the improvement of reclaimed land at low-cost to cultivate highland-field crops. The following results were acquired through pilot construction in the field.

i. Reclaimed soil of Korea, which is mostly impermeable ($k<1\times10^{-4}$ cm/s), requires the introduction of ①subsurface drains and ②subsoil breaking method, to improve the land to be cultivated for highland-field crop.

ii. In order to array the appropriate spacing (3∼10m) by soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation methods.

iii. The introduction of a subsurface irrigation and drainage system is necessary to clean drain systems and to prevent re-salinization.

iv. As a result of the construction of a pilot a cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability improved due to the application of a non-excavation method, whatsmore, construction cost dropped significantly (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5m intervals in parallel with subsoil breaking method than that of the existing method with 10m intervals.

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v. It was proven that subsoil breaking and subsurface irrigation and drain systems were efficient to clean the drain system using underground irrigation water as well as to prevent re-salinization. And it was also confirmed that the system made the desalinization of soil from 10~15ds/m to 2~5ds/m within a year under the condition of natural rainfall possible.

vi. As the result of crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth had a moderately high status without any damage by moisture during the wet season, and it led to the conclusion that the system is highly effective for the development of reclaimed land.

KEY WORDS: Subsoil breaking, subsurface irrigation and drainage, Subsurface horizontal filter system, Non-excavation system.

Introduction

Korea has been utilizing the reclaimed low land for paddy field to produce mainly rice as staple food, but nowadays it is required to develop the reclaimed land to cultivate upland crops for income improvement, control of cereal supply and demand.

Generally the reclaimed land is located at a lowland area with high salinity and fine-grained soil. Fine-grained soil causes a difficulty in subsurface drainage that leads to the poor cultivation of upland crops. In order to cultivate the upland crops in the reclaimed farmland, subsurface drain facilities have been installed, but it could not be actively implemented due to the high construction cost and low desalination effects. In addition, there is another challange that reclaimed low land, even if upland crop could be cultivated after desalination, may be re-salinized due to capillary rise of saline water under the ground during dry season.

The purpose of this study is to develop subsoil breaking method and low cost non-excavation subsurface drainage system to improve subsurface drainage and desalination in the reclaimed land. The efficiency of the low cost non-excavation subsurface irrigation and drainage system has been confirmed through the test construction.

Materials and methods

The Necessity for Development of Subsoil Breaking and Drain Construction Method

According to the calculation using Van Schilfgaarde and Hooghoudt equations in the basic design, optimum spacing of culvert is highly correlated with the permeability coefficient of the soil, which is shown in Fig. 1.

If the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10 m, and if k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5 m. If the coefficient of permeability is equal or less than $1*10^{-4}$ cm/s, it may be efficient to improve the permeability of the soil by breaking subsoil.

Low and wet paddy field in Korea usually has a coefficient of permeability less than $1*10^{-4}$ cm/s, but the culverts have been constructed with the spacing more than 10 m due to economic issues for which the culverts could not to be functioned properly.

In order to solve these problems, it is required to develop subsoil breaking and the low cost & high efficient non-excavation subsurface drainage construction methods suitable for the reclaimed soil in Korea.

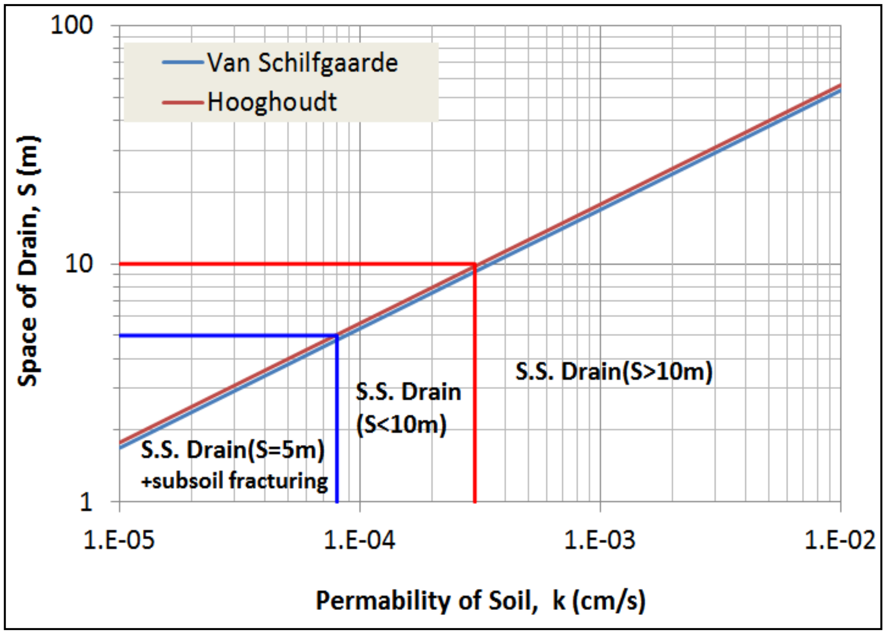


Figure 1. Permeability Coefficient and Spacing of Culvert (Formal Theoretical Model)

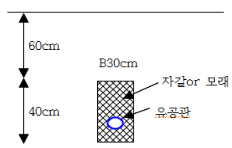
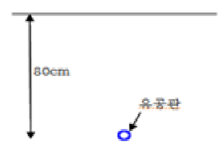
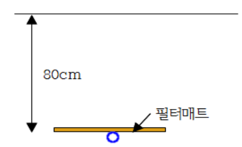
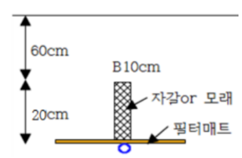
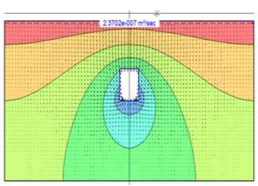
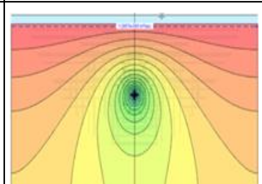
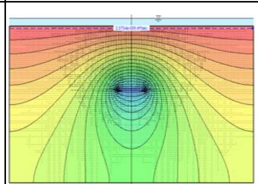
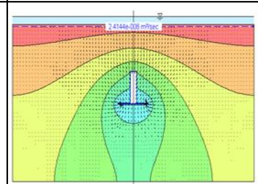
Introduction of Low Cost & Highly Efficient Subsurface Drainage System

Evaluation on the Performance of Subsurface Drainage System by Culvert Types

As shown in Table 1, numerical seepage analysis were conducted to check the performance of subsurface drainage system by four(4) types of culverts, such as ① the existing trench perforated drain pipe + gravel improved culvert ② non-excavation perforated drain (50mm) ③ perforated drain (50mm) + 50cm non-excavation horizontal drain mat ④ perforated drain (50mm) + 50cm wide horizontal mat + non-excavation gravel improved culvert. As a result, subsurface drainage discharge from soil to culvert per meter was in order of ④>①>③>②.

However, ②, ③ and ④ are 1/3 times cheaper than ①. If ① is installed at 10m interval, and ②, ③, ④ are installed at 5m interval, the subsurface drainage per unit area is ④> ③> ②> ①, but the construction cost is ①> ④> ③> ②. In other words, ③ and ④ have higher performances (1.75 times) and lower construction cost (67%) than ①, which means that these culvert construction methods are low in cost and highly efficient.

Table 1. Drainage effects of Subsurface Drainage Culvert by Types

Type of Culvert	①**Excavated Culvert** (gravel B30*H40cm)	②**Non-excavation Culvert** (50mm perforated pipe)	③**Non-excavation Culvert 2** (50mm perforated pipe + filter mat B50cm)	④**Non-excavation Culvert 3** (perforated pipe + filter mat + sand B10cm)
				
Shape of Subsurface Drain				
Discharge of drainage water (m^3/s/m)	**$2.37*10^{-6}$**	**$1.29*10^{-6}$**	**$2.17*10^{-6}$**	**$2.41*10^{-6}$**
Remark(%)	**100**	**54**	**92**	**102**
Installation space (m)	**10**	**5**	**5**	**5**
Discharge of subsurface drainage water per unit area (mm/d)	**20.5 (100%)**	**22.3 (109%)**	**35.8 (175%)**	**41.6 (209%)**
Construction cost (million Won)	**45 (100%)**	**20 (44%)**	**25 (56%)**	**30 (67%)**

The Necessity for Optimization and Test Constructions of Subsurface Culvert

When the permeability coefficient (k) of the soil is less than $3*10^{-4}$ cm/s, the spacing of culvert should be less than 10m and when the k = $1*10^{-4}$ cm/s, the spacing of culvert should be less than 5m. However, due to economic problems, it was forced to be over 10m.

Number ③ (50mm perforated pipe + 50cm horizontal mat) and ④ (wrinkle perforated pipe + 50cm horizontal mat + rice husks improved non-excavation culvert) construction methods can be used to resolve the problems in association with their lower construction cost (67%) and higher drainage performances (175%).

However, the calculation of drainage performance obtained through theoretical numerical analysis needs to be verified in the field. Therefore, test construction of number ① and ② for verifying their drainage performance were carried out.

In addition, since the permeability coefficient of the simulation site was less than $1*10^{-4}$ cm/s, the subsoil breaking was also carried out.

Subsurface Irrigation and Drainage System to Prevent Re-Salinization

Re-Salinization Characteristics in Dry Season

As shown in Fig. 2, the soil salinity repeatedly changed after the installation of the subsurface culverts. Soil salinity decreased in the wet season and rose again in the dry season. This phenomenon was caused by capillary rise of brine water. Hence, capillary rise during dry season should be prevented.

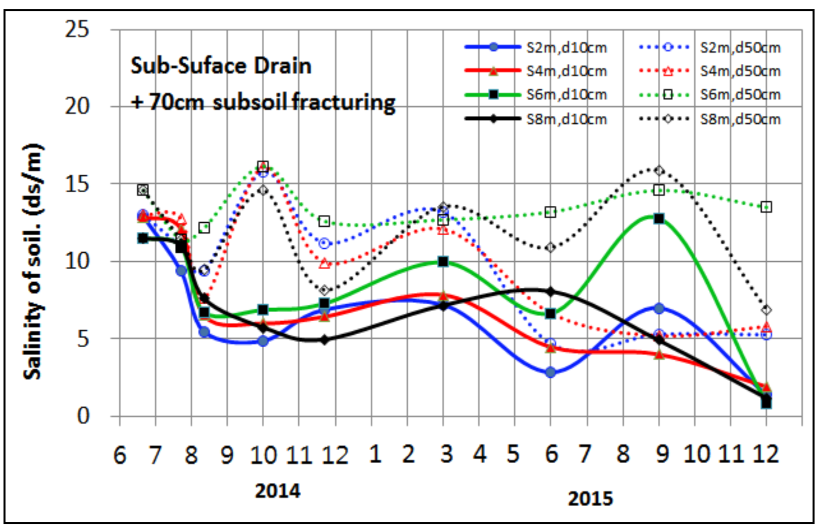


Figure 2. Changes in Soil Salinity of Reclaimed Land during Wet and Dry Seasons

Subsurface Irrigation System for Preventing Re-salinization in Dry Season

As shown in Fig. 3, capillary rise in dry season can be blocked by artificially forming freshwater layer above the saline water. To confirm this method, test construction was carried out.

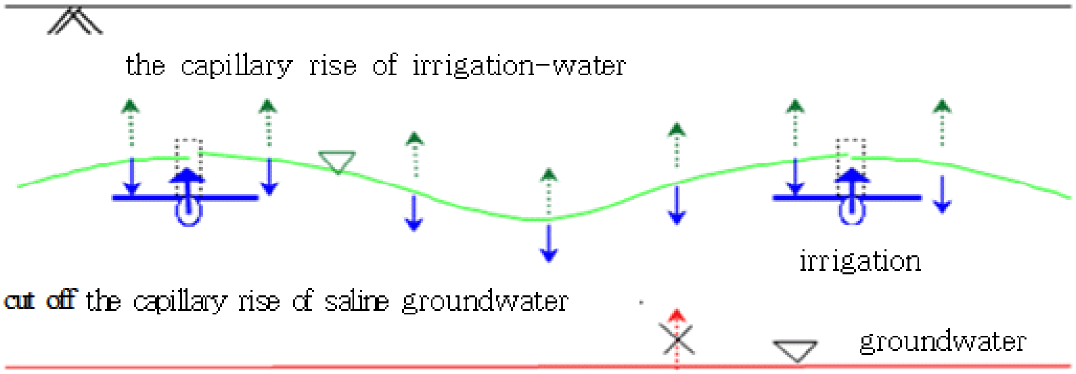


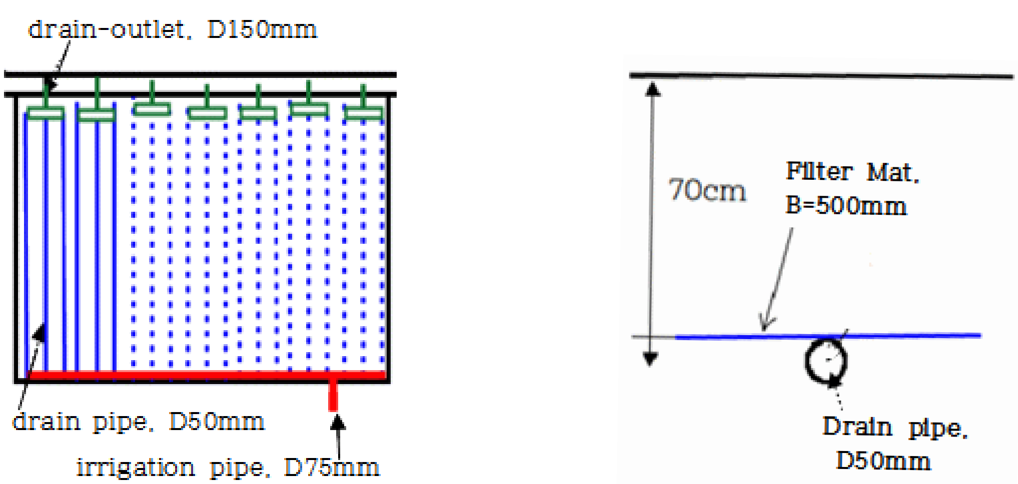
Figure 3. Schematic Diagram of Re-salinization Prevention through Subsurface Irrigation System in dry seask

Layout of Test Site

Test Construction of Non-Excavation Subsurface Irrigation and Drainage System

Plan and Cross Section of Test Construction

As shown in Fig. 4, test construction of subsurface irrigation and drainage system was carried out by using non-excavation single pipe method (0.3 ha). The culvert was constructed by ϕ50mm perforated pipe and 500mm horizontal mat with 5m spacing.

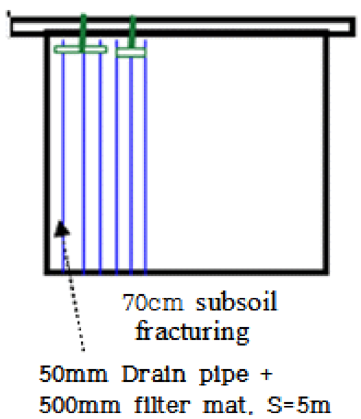


a) Plan of Subsurface Irrigation & Drainage Culvert b) Cross Section of Non-Excavation Culvert

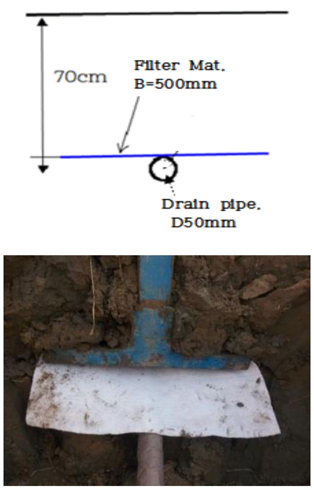
Figure 4. Plan and Cross Section of Non-Excavation Subsurface Irrigation and Drainage System

Test Construction of No-Excavation Single Pipe Subsurface Culvert

Figure 5 shows the test construction of subsurface irrigation and drainage culvert using non-excavation single pipe in 0.3 ha area.



a) Plan of Culvert



b) Cross Section of Culvert

c) Construction of Non-Excavation Culvert

Figure 5. Test Construction of Subsurface Irrigation and Drainage Using Non-Excavation Single Pipe Method

Subsoil Breaking

After the installation of the subsurface culvert as shown in Image 1, subsoil with the depth of 0.7m was crushed by using a backhoe breaker. After subsoil breaking, the soil was completely crushed and the water penetrated evenly into the ground. Almost all the water penetrated into the ground immediately after the rainfall.

Image 1. Subsoil Breaking Using A Backhoe

Results and discussion

Effects of Rainfall Penetration and Subsurface Drainage

As shown in Image 2, the surface water in the no ss block has not been discharged for more than 20 days after rainfall, but a block with culvert and crushed subsoil in the ss drain block has been dried immediately within a day by infiltration after rainfall.

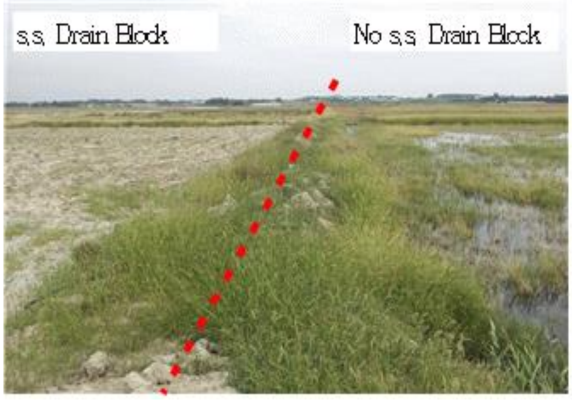


Image 2. Effects of Subsurface Culvert and Subsoil Breaking

Continuity of Subsurface Drainage in Three Years after Construction of Subsurface Culvert and Subsoil Breaking

As shown in Image 3, in three years after construction of subsurface culvert and subsoil breaking, it can be seen that subsurface drainage can effectively drain the water even without surface water drainage after rainfall of 100mm/day. Subsoil breaking improves the soil structure and soil permeability.

a) Vegetation and Subsurface Drainage Status in the Non-excavation Culvert Block	b) Drainage Status of Culvert Drain

Image 3. Condition of Subsurface Drainage After 100mm/day Rain (3 years after construction)

The effects of expediting Desalination and preventing Re-salinization by Subsurface Irrigation and Drainage System

As shown in Fig. 6, the untreated block showed almost no desalination for 2 years. However, the salinity in block with drainage culvert (No I+D System) decreased from the initial salinity of 12 ds/m to 4.2 ds/m in 2 years. The salinity of soil tends to decrease in wet season and increase in dry season.

Non-excavation subsurface irrigation and drainage system (+backhoe breaking) was desalinated up to 2~5ds/m in the first year and the salinity continuously decreased until the end of experiment period without re-salinization.

Through this experiment, it was confirmed that the subsurface irrigation and drainage system has a great effect of preventing re-salinization.

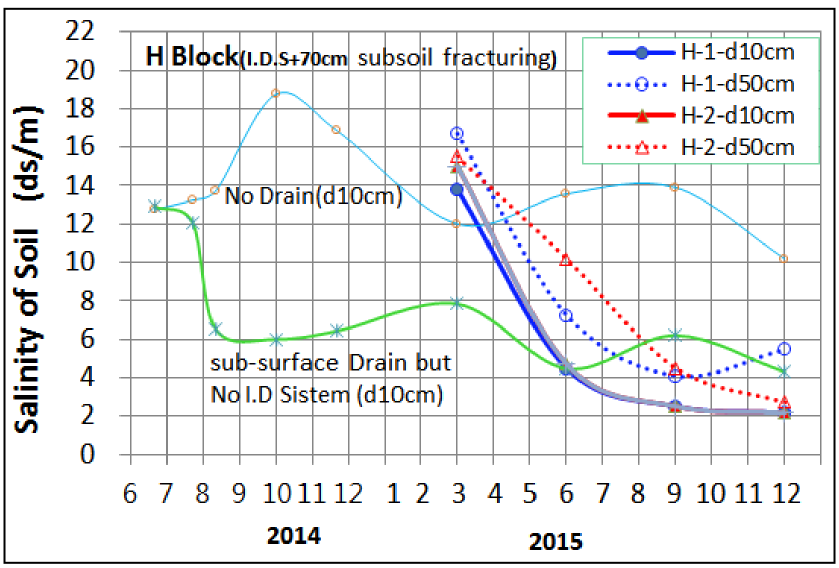


Figure 6. Effects of expediting Desalination and preventing Re-salinization by Subsurface Irrigation & Drainage System and Subsoil Breaking

Vegetation Changes after Desalination

Vegetation changes after desalination for 1 to 2 years is shown in Image 4. It shows that the untreated block was overgrown by halophytes vegetation, while the block with non-excavation culvert (+backhoe breaking) was overgrown by common vegetation.

It is confirmed that the area with subsurface irrigation and drainage culvert is well drained and the soil moisture is suitable for cultivation of upland crops.

	
a) Untreated Block (Halophytes)	b) Block with Subsurface Culvert + Subsoil Breaking (common vegetation)

Image 4. Vegetation Status after 100mm/day Rainfall

Crops Cultivation in 2 Years after Culvert Construction and Subsoil Breaking

The block over 2 years after construction of subsurface irrigation and drainage system and subsoil breaking had a salinity of 1~4 ds/m and was overgrown by crops as shown in Image 4.

It was confirmed that the construction of subsurface culverts in appropriate intervals with subsoil breaking can improve the soil structure even in impermeable reclaimed land and subsurface drainage which expidite desalination and prevent re-salinization to cultivate upland crops possible.

	
a) Growing Status of Kidney Beans	b) Growing Status of Corns
	
c) Growing Status of Sorghum	d) Growing Status of Green Onion

Image 5. Growing Status of Upland Crops in 3 Years after Test Construction

Conclusion

In order to convert the reclaimed land to highland crop field, the disadvantages of subsurface culvert were re-analyzed, and construction of non-excavation irrigation & drainage system with subsoil breaking were proposed. The study resulted in conclusions as follows:

i. Reclaimed land in Korea, in which soil is mostly impermeable ($k<1*10^{-4}$ cm/s), requires the introduction of ①appropriate interval(less then 10m) of subsurface drainage system and ②subsoil breaking method, to improve the land to be cultivated for upland crops.

ii. In order to array the appropriate spacing (3~10m) by the soil type, it is necessary to develop and introduce cost-effective non-excavation subsurface drainage system installation method.

iii. The introduction of subsurface irrigation and drainage system is necessary to clean drain system and to prevent re-salinization.

iv. As a result of the pilot construction of cost-effective non-excavation subsurface irrigation and drainage system, it was confirmed that workability was improved due to the construction of non-excavation method, and construction cost was lower (75%) and subsurface drain and desalinization performance was far superior (over 150%) with 5m intervals in parallel with subsoil breaking method than that of existing method with 10m intervals.

v. It was proved that subsoil breaking and subsurface irrigation and drain system were efficient to clean the drain system using underground irrigation water as well as prevent re-salinization. And also it was confirmed that the system made the desalinization of soil from 10~15ds/m to 2~5ds/m within a year under the condition of natural rainfall possible.

vi. As the result of the crop cultivation on the pilot reclaimed land desalinized by subsoil breaking and subsurface irrigation and drain system, it was found that crop growth without any damage by moisture during wet season was shown in good status, and it led to conclusion that the system is highly effective for the development of reclaimed land.

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POTENTIAL OF SUPER ABSORBING MATERIAL IN A SUBSTRATE MIX FOR EXTENSIVE GREEN ROOFS

Farhad Misaghi[1,*], Zeinab Bigdeli[2], Masoud Saeedi[3]

Abstract

The application of green roofs is increasingly recognized in many countries as a solution to improve environmental quality and reduce runoff quantity. This study investigates the viability of super absorbing materials in a substrate mix for extensive green roofs, where plants are supported by lightweight growing media (substrate) overlying a drainage layer. In addition, the role of super absorbing materials as a growth medium, drainage properties of the substrate mix containing recycled materials, as well as its susceptibility to erosion and resistance to sliding when placed on a slope were investigated. Therefore, the main aim of this study is to investigate the impact of natural zeolite on rainfall infiltration into the soil, runoff, and soil water storage capacity in green roofs .This study includes the establishment, development, and performance of both grass and sedum model green roofs under simulated rainfall events. It indicates supportive suitability of the substrate mix containing recycled waste materials for plants growth. It is resistant to erosion and slippage and capable of providing good drainage. The results showed that infiltration in zeolite-treated soil is very high and treated soil can reduce drained water volume. In the treatment analysis, the highest rate of drained water was recorded as 20.5 (ml) and it was shown that in untreated soil there is a lacks of water as runoff, thus drainage and preserving water in the soils were too low and the lowest rate of drained water was seen in soil treated with 3% zeolite (5 ml).The results of this laboratory investigation were used to extend green roofs into the wider perspective of sustainability benefits.

KEY WORDS: Green Roof, Super Absorbing Material, Drainage.

Introduction

Urbanization is increasing globally and urban populations are congregating in cities (UNDP, 2008). One of the effects of urbanization in such areas is increasing the percentage of impervious surfaces which in itself causes environmental problems, and such a trend is common in urban cities. Moreover, studies show that global warming causes an increasing in extreme rainfall events (Arnell, 1999; Bates et al., 2008) and one of the solutions to cope with such problems is the

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adopting of new storm-water management strategies such as Low Impact Development policies (Voyde et al., 2010), Sustainable Urban Drainage Systems (SUDS) (Stovin, 2010), Low Impact Urban Design and Development policies (LIUDD) (Van Roon, 2005) and Water Sensitive Urban Design strategies (WSUD) (Beecham and Chowdhury, 2012)., The utilization of Green infrastructure through WSUD is among the possible solutions to reduce the negative impacts of urbanization particularly. As well as providing additional amenities and water quality benefits for communities and environment (Beecham, 2003; Beecham et al., 2012, Sharma et al., 2016). Since, green roofs have become widely used in recent years (Emilsson et al., 2006). A green roof refers to the roof of any building which is partially or completely covered with vegetation, planted over a water proofcurtain. It may also include additional layers such as root barrier and drainage and irrigation systems. Green roofs have several purposes for a building such as rainwater harvesting, supplying insulation, increasing neighborliness and the decreasing of urban stress levels of people living in the vicinity by providing a more aesthetically pleasing view, moderating urban air temperature and mitigating the heat island effect (Vandermeulen et al., 2011). There are two types of green roofs: intensive roofs, composed of brushwood with a minimum depth of 12.8 cm (5.0 in) which can support a wider range of plants,yet which are heavier and require more conservation. The other type are called extensive roofs, which are shoal with a minimum depth ranging from 2 cm (0.79 in) to 12.7 cm (5.0 in), and which are lighter than the former type, requiring minimal conservation (Volder et al., 2014). The ever increasing trend of urban development worldwide including Iran is an unavoidable consequence of the science and technology era. Urbanism has a direct relationship with urban frame development and it tends to move away from nature and violates the interaction between man and the natural environment (MoharramNejad and Bahman Poor, 2009). Oneof the most important objectives in green roof studies is assessing how green roofs can affect storm-water quality and quantity. This in itself requires an knowledge of the hydrological performance of green roofs. Hydrological studies of green roofs, particular studies on their water retention capacity, began in Germany several decades ago (Mentens et al., 2006).

Zeolite is a relative superabundant mineral resource with excellent properties including Cation Exchange Capacity (CEC), free structural water storage and surface adsorption which provides it with a significant potential for application in soil improvement. Some advantages like increasing water retention and a much more cost effective fertilization capability can be gained by using zeolite. Zeolite usages are suitable for water-efficient agricultural purposes (Xiubin and Zhanbin, 2001). In recent years, an increasing interest in using natural super absorbants such as zeolite in agricultural activities has been reported (Ozbahce et al., 2014). Adding zeolite to the soil will increase the infiltration rate and improve its ability to hold nutrients and water content (Brannvall, 2007).

Materials and methods

The study area was a greenhouse site located at the University of Zanjan, Iran, at 36.6751°N latitude and 48.4845°E longitude with an ASL elevation of 1500m. Zanjan receives approximately 200-400 mm precipitation per year and the temperature varies between 9°-17˚C. This study was conducted at the greenhouse site with simulated rainfall events (Fig. 1), using 3 treatments and 3 repeats, and a steady flow rate of 35 mm/hr on a steady slope of 5%.

Figure 1. Rainfall simulator system

In this study, a total of nine 31×25×15 cm plastic boxes were used. At the bottom of the system, several holes were made which acted as drainage outlets to allow for quick drainage of excess water from the system after each rainfall event (Fig. 2). After each draining event, a layer of 3 cm sandy soil was used at the bottom of the box, and of the exterior of the boxes were covered by textile to prevent any flowing on the box's walls. Soil samples were taken from the Agricultural Research Farm of Zanjan University located in Zanjan Province, in the Northwest of Iran. Table 1 shows some physical properties of the soil samples.

Table. 1 Some physical properties of soil samples used in the study

Soil texture	Clay- Loam
Bulk density	1.30 gr/cm^3
Total weight of box	15.12 kg

Figure 2. Experiments setup

The zeolite mineral sample was obtained from the natural zeolite mineral collected in Iran. Before using the zeolite, it was ground and then 1 to 3 percent of zeolite, was added to the top layer of the soil (0–15 cm). The statistical design was based on three criteria. The first criterion was a 5 degree slope. Followed by a consistent rainfall at a rate of 35 mm/hr for the whole experiments. Another criteria was the type of treatments including the using of nine transparent plastic boxes to conduct the tests, three treatments (i.e. barren areas, soil treated with 1% and 3% zeolite) with three replicates. A rainfall simulator was used for a specific period with steady rainfall. To setup these green roof beds, all of the systems were arranged and included a drainage collection point to measure outflow rates. Furthermore nine bottles were placed at the bottom of the boxes to collect outflow water in order to measure volumes and perform the analysis. To measure volumes of drained water nine containers were place under the boxes.After 48 hours when moisture reached the FC point, the drained water volume was measured.
The present study aims to investigate the impact of natural zeolite on rainfall infiltration into the soil, runoff, and soil water storage capacity in green roofs. The experiment started after preparing the boxes and after noting the results (Schematic of the study field plot shown in Fig.3). For the statistical analysis of the results, SAS statistical (Statistical Software) and Excel (Microsoft Office Excel ver. 2010) packages were used.

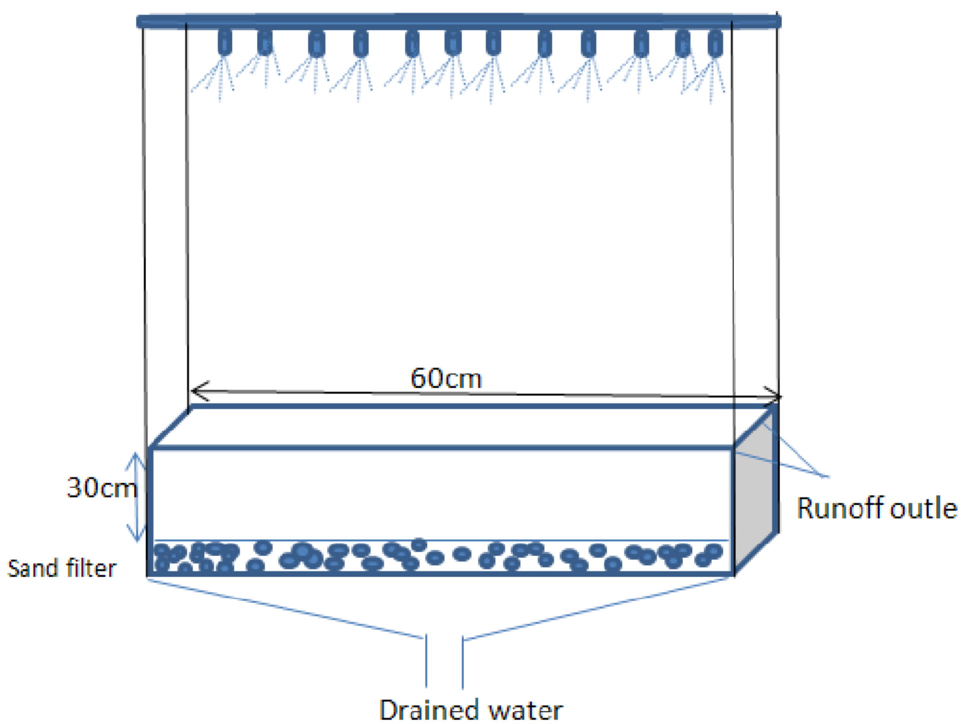

Figure 3. Schematic of the study field plot

Result and discussion

Impact of zeolite application on runoff

According to the results, runoff and drained water were significantly different in the soil samples treated with zeolite (1% and3%) than those with untreated soil samples (Table 2). Table 2 shows that the maximum volume of runoff and drained water was obtained from untreated soil and in the samples containing zeolite, the volume of the runoff and drained water decreased with the least volume obtained for treatment 3. According to the results (Table 2), a significant decrease was observed in the runoff volume, and the drained water volume after the application of zeolite.

Table.2 Impact of zeolite application on runoff

Drained water	**Runoff**	Treatments
3.54[a]	4.51[a]	1
2.95[b]	4.20[b]	2
2.18[c]	3.95[c]	3

Results indicate a significant decrease in runoff volume and drained water through the application of zeolite ($P<0.01$). The volume of surface runoff of zeolite-treated soil samples is significantly decreases, as compared with the untreated soil samples ($P<0.01$). Such a result parallels studies carried out by Ghazavi (2015) that reported an increase of the infiltration rate and soil water content in soil treated with zeolite as compared to the untreated soil. A significant decrease in runoff, drained water and sediment has been observed zeolite is applied ($P<0.01$). Afrous (2015) found that the highest and lowest concentrations of nitrate in outlet drain water was observed in soil samples without zeolite and calcium zeolite with average rates of 83.5 and 6.8 mg/lit, respectively.

Runoff

The comparison of the runoff rate in three main groups of treated and untreated soil samples with 1% and 3% zeolitein (Fig. 4), show that Treatment 3 generally tend towards the highest retention performance. Soil water content, measured in one day, was significantly different in the soil samples treated with zeolite and untreated soil. The high rate of water holding capacity, and high absorption capacity of natural zeolite was reported in many researches (Akbar et al., 1999, Pickering et al., 2002). In controlled treatment, the highest rate of runoff was 3.5 (ml) and the lowest volume of runoff is related to the soil treated with zeolite 3% was 1.8 (ml). The results show that green roofs can significantly reduce runoff, especially the rate of maximum runoff (Fig. 4).

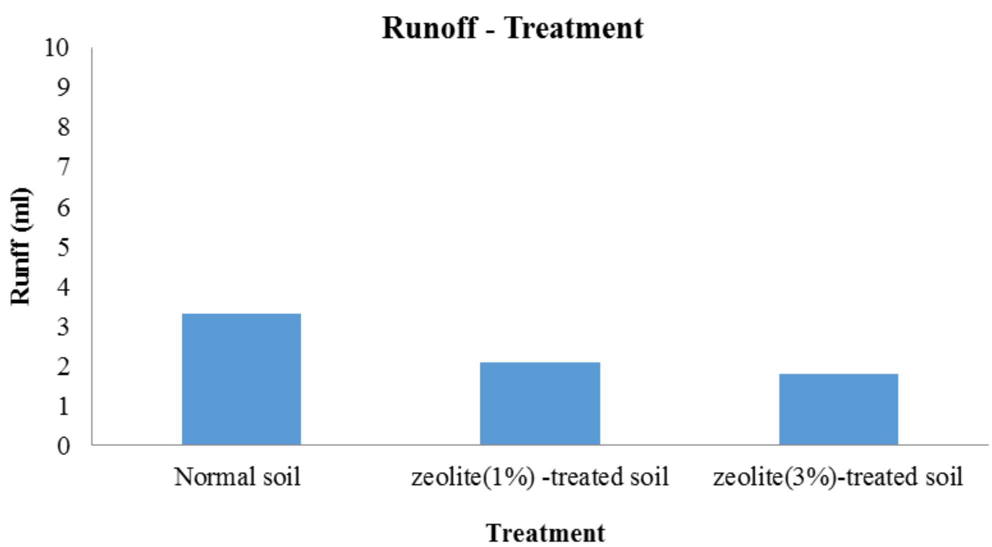

Figure 4. The variations of runoff volume (ml) in normal and zeolite-treated soils

Drained water

Fig.3 illustrates drained water content in three main groups of treatments. Fig. 5 shows that the infiltration of the zeolite-treated soil was very high and treated soil can reduce drained water volume.There was a significant difference between drained water content in normal and treats soil with soil samples treated by 1% and 3% of zeolite. In treatment analysis, the highest rate of drained water was recorded as 20.5 (ml) and it was shown that untreated soil lacks a lot of water as runoff, drains and reserved water volumes in the soils were too low and the lowest rate of drained water was seen in the soil treated with 3% zeolite (5 ml).

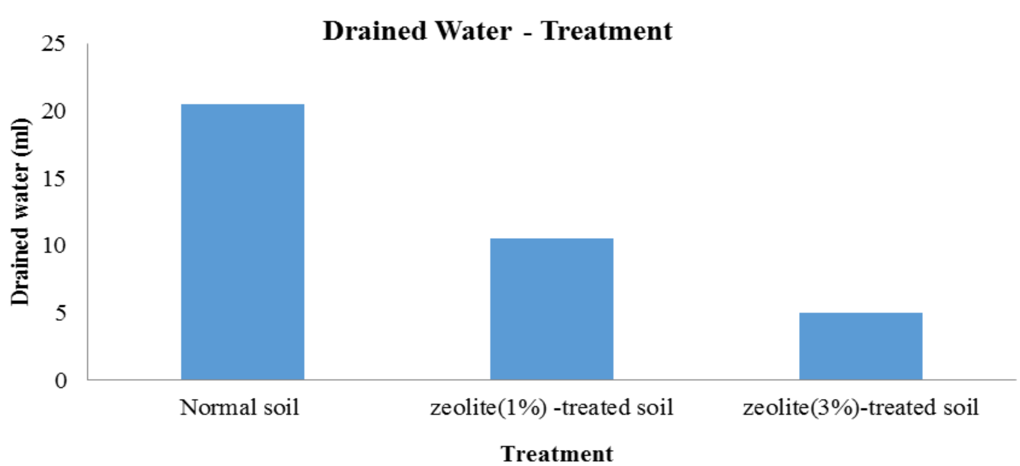

Figure 5. The variations of volume (ml) of drained water in normal and zeolite-treated soils

Conclusion

Green roofs are widely used in many countries as a solution to improve environmental quality and reduce runoff quantity. Green roofs, defined as roofs of buildings that are partially or completely covered with vegetation planted in a growing medium, can provide several advantages in terms of sustainability. This study consistently showed that the high levels of storm-water attenuation can be achieved by using green roofs and concluded that green roofs can significantly reduce the maximum rate runoff and drained water .It can help retaina lot of rainfall content and reduce the height rate of the peak flow. There is a potential opportunity to increase the advantages of green roofs by using super absorbing materials in green roof construction. This study investigated the viability of using super absorbing materials in a substrate mix for extensive green roofs where plants are supported by lightweight growing media (substrate) overlying a drainage layer. The adequacy of super absorbing materials as a growth medium, drainage properties of the substrate mix containing recycled materials as well as its susceptibility to erosion and resistance to sliding when placed on a slope were also investigated. This study included the establishment, development and performance of both grass and sedum model green roofs under simulated rainfall events. It was found that the substrate mix containing recycled construction waste materials was successful in supporting plant growth, resistant to erosion and slippage and was capable of providing good drainage. The results of this laboratory investigation has been recommended to be used to extend green roofs into the wider perspective of sustainability benefits.

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THE EFFECTS OF DIFFERENT DRAIN SPACING AND DEPTHS ON WATER TABLE LEVEL AND SOIL SALINITY IN HARRAN PLAIN OF TURKEY

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Abstract

Harran plain, totally 225000 hectares, is the first big scale irrigated area in South Eastern Anatolia Project (GAP) in Turkey. This Plain has been irrigated since 1995. Approximately, the part of 50.000 ha in this plain has a high water table which was caused by irrigation, geological-hydrogeological structure. The low quality waters infiltrated from irrigation has raised the water table of the perched aquifer which is resulted in a direct hydrological connection between waters of different quality. Thus, high water table and soil salinization increasingly spread. In this study, some drainage criteria were studied. Different drain spacings and different drain depths on the effects of water table, salinization and corn yield are investigated. Three different drain spacings (45 m, 60 m and 75 m)and three different drain depths (1,2 m, 1,5 m and 1,8 m) were used in this study. In addition, a cross drain pipe was placed between two parallel drains spaced 120 m. In the first year, corn was planted between parallel drains and the same agricultural process has been applied for the whole fields. There were no significantly effects between different drain spaces on the crop yields. The depths of water table were ranged from 120 cm to 140 cm during the irrigation season for both of the areas of crosswise drains and different drain spacings and drain depths. The effects of different drain spacings on the salt variation of root zone will be evaluated at the end of the first year and the third year of the study.

KEY WORDS: Drainage, Drain depth, Drain space, Salinity.

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Introduction

The successfully irrigated agriculture needs the moisture-oxygen and salt balance in the soil zone of the plant root for crop growth. When a saline water table rises and remains in the root zone longer than about two days or more, resulting in a high saline moisture condition, the crops grown and agricultural production is usually seriously affected.

Waterlogging may be defined as excessive moisture and anaerobic conditions occurred in the plant root zone. There could be some reasons for the waterlogging such as flood and excessive irrigation, seepage and infiltration of the water from the canals or rivers. However, subsoil conditions and soil texture, inadequate drainage, topography and climate could also stimulate the waterlogging. Overtime, water table could rise. Thus, a good drainage facility is very essential. The waterlogged area may be reclaimed by underground drainage schemes.

Southeastern Anatolia Project, known as the “GAP” in Turkish acronym, in Turkey aims to develop water and land resources in the region and planned as a package that comprised of 13 individual projects on irrigation and energy production on the Euphrates-Tigris basins (GAP, 2016). Harran Plain, totally 225 000 ha, is one of the lands firstly irrigated by GAP in 1995. Currently, 150 000 ha of the plain is irrigated. However, salinity and raising water table have been expanded since excess irrigation and inadequate drainage systems. Approximately 10 years later irrigation, water table levels were 0-1.0 m and 1.0-2.0 m for the area of 16 500 and 34 000 ha, respectively in Harran Plain. For this, the instructions of drainage systems are need to prevent and/or to remove waterlogging (DSI, 2004).

An appropriate drainage is a function of total irrigation water applied to the lands, water quality, crop pattern, soil salinity and soil aeration. All these factors have highly variation for the different lands. For this, the data pertaining to the lands constructed drainage systems should be considered. Otherwise, excessive drainage can cause expensive cost; inadequate drainage might cause environmental problems. An appropriate drainage for the waterlogging lands needs to be known and provided real data related these lands such as drain spacing, water table height level and different envelope materials.

Depth, spacing, and dimensions of ditches or pipe drains for agricultural drainage are the most important engineering factors. The relationship between engineering factors and crop production should be considered together with each other. Some works on drainage in Harran Plain were started by DSI and it was determined the drain depth (1.50 m) and drain spaces (48-125 m) using Donnan equation (DSI, 1978).

In this study, it is aimed to determine drainage criteria based on the instruction of the drainage systems for the lands having salinity problems and high water table in Harran Plain of Turkey.

Materials and Methods

This study was carried out in Harran Plain of Southeastern Anatolia Region in Turkey. The study area is located in (37° 9.7′ and 36° 42′ N lat., 38° 49.6′ and 39° 7.9′ E long; Fig. 1). The plain was developed for irrigated agriculture (150 000 ha) by GAP. The climate of the study area is semiarid with mean temperature, precipitation and evaporation of 17.2°C, 365 mm and 1848 mm, respectively. The precipitation is almost received during the fall season. Elevation of the study area ranges from 345 m in the south to 550 m in the north. The soils have been formed on calcareous materials and are classified as Vertisols, Fluvisols, Calcisols, Cambisols, and Leptosols. A total of 25 soil series have been described in the study area. Soils are mostly finely textured (clay loam to clay) and contain very low to low amounts of organic matter (0.5 to 1.5 %) and high amounts of $CaCO_3$ (on average 250 to 350 g/kg). Dominant clay minerals within salinized area are smectite, polygorskite, chlorite, illite, and kaolonite, in decreasing order of abundance (Dinc et al., 1988; Bilgili, 2013).

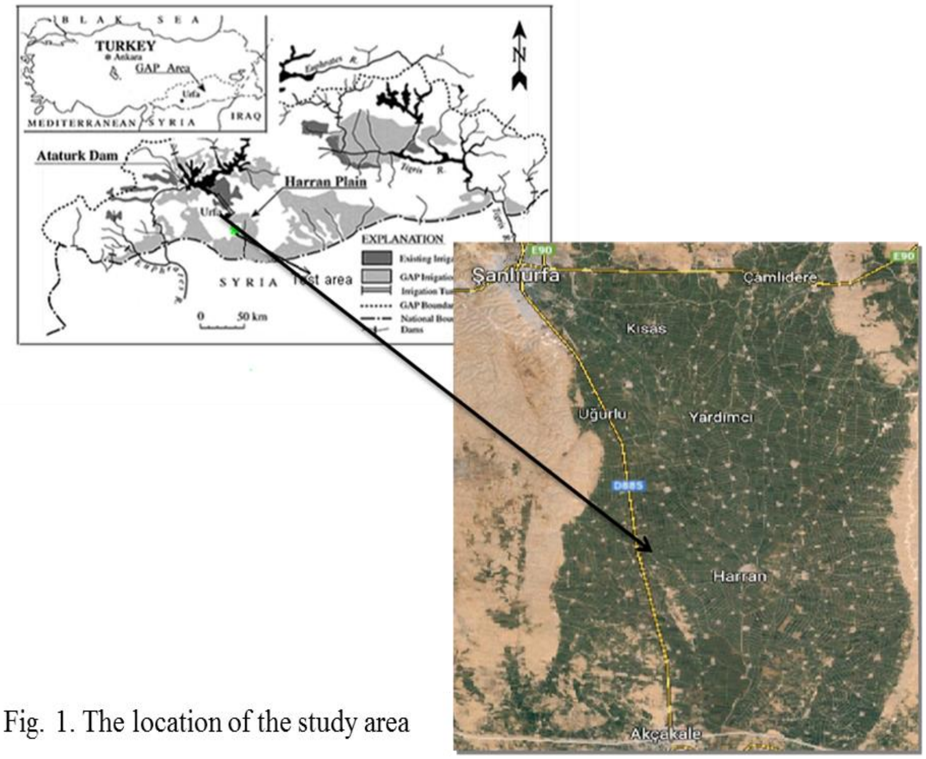

Fig. 1. The location of the study area

Experimental site layout

The study was included 2 different components of the drainage criteria.

Treatment

The effects of different drain spacings on crop yield and soil salinity

A cross drain pipe were placed between two parallel drains spaced 120 m. Thus, different drain spaces were obtained (Fig. 2). In the first year, corn was planted between parallel drains and the same agricultural process has been applied for the whole fields. The effects of different drain spacing on the salt variation of root zone will be evaluated at the end of the first year and the third year of the study.

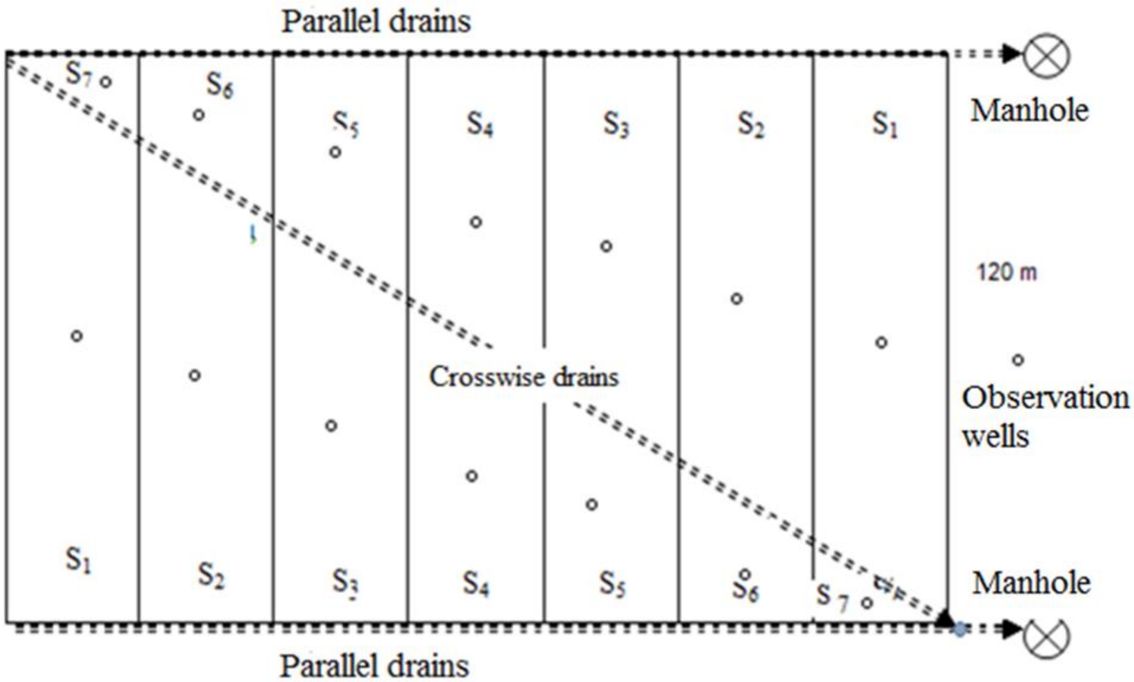

Fig. 2 The shematic layout of the different drain spacings

Treatment

Drain spacing according to the constant water table

Drain spacings and drain depths, and the layout of drains are given in Fig 3.

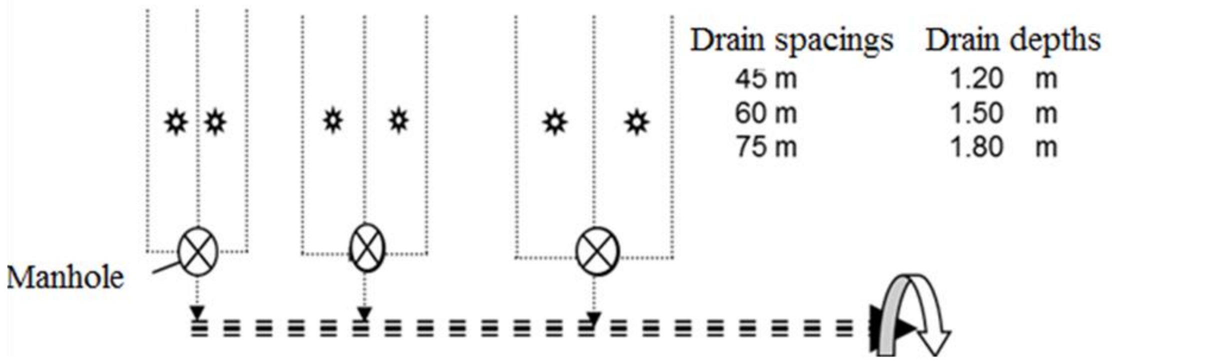

Fig. 3. The layout of the different spacing and depths of the drains for the experiment 2 (D-2)

Results and discussion

Basic properties of soil and water table

The values of hydraulic conductivity for the experimental site are given in Table 1. According to the Auger-hole method for 4 different sites of the study area, the hydraulic conductivity for the experimental site was "medium" level. Considering the texture class of the experimental soils were heavy clay, the hydraulic condructivity was more appropriate.
In addition, infiltration rate was determined using double ring infiltrometer. The parameters of Kostiakov's equation were computed using the test data. This equation $Z = 0{,}198\ (t)^{0{,}875}$ and basic intake rate is 4,2 cm/h. Thus, infiltration rate is very high at the topsoil.

Table 1. The values of hydraulic conductivity for the experimental site

	D1	D2		
	(Crosswise drain)	(75 m)	(60 m)	(45 m)
hydraulic conductivity (m/day)	1.51	1.1	1.98	1.98

The disturbed soil samples were taken from the soils of each experimental site considering the soil profile of 0-210 cm depth. The saturation capacity of the all experimental soils for all depths varied from 65 to 101%. The percentage of clay for the soils were 38-62%. Thus, soil texture were almost clay for the all soil depths. The pH of the soils were 7.28-7.85 and electrical conductivity (ECe) varied from 0.56 to 1.91 dS/m. The lime content fof the soils were high and it was varied from 29.2 to 50.8 %.

Water table measurements

The measurements of water table were started together with irrigation. The obtained data were given in Table 2 and 3.

Table 2. The measurement of water table for crosswise drain (D1)

Observation well no	D1													
	Replication 1							Replication 2						
Days	1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	145	133	125	126	110	112	119	116	108	126	131	139	120	145
2	143	133	124	125	114	110	119	114	108	127	131	137	120	144
3	143	130	124	123	110	108	118	115	106	125	128	135	118	143
4	144	133	123	120	113	121	75	116	101	127	90	137	120	144
5	144	137	127	126	112	110	114	113	103	124	131	138	121	145
6	149	139	131	130	117	116	124	120	112	131	136	142	125	150
7	146	135	128	128	113	115	120	116	110	130	134	140	125	147
8	145	136	129	130	116	114	121	118	110	129	132	139	123	146
9	143	135	128	115	114	110	118	115	106	127	137	137	119	143
10	143	133	125	124	112	111	116	116	106	126	129	136	118	143
11	149	137	130	130	116	115	123	119	112	131	135	142	124	145
12	147	137	130	129	117	115	122	119	106	129	135	141	125	148
13	146	136	130	126	114	113	117	118	87	128	139	140	121	148
14	148	137	129	129	116	115	121	120	111	130	135	141	123	149
15	153	139	132	131	119	117	123	121	113	133	137	143	127	153
16	149	131	131	131	119	117	123	121	113	114	136	142	125	150
17	150	139	132	131	119	117	123	121	113	116	136	143	125	150
18	147	136	129	127	113	112	114	118	103	128	132	139	121	147
19	147	135	128	126	115	114	118	119	107	129	134	140	123	148
20	152	141	134	132	121	121	126	125	116	135	140	146	128	153
21	153	142	135	134	123	122	126	126	117	136	140	147	129	154

The effects of the different drain spacings on water table are given in Table 3. As seen in Fig. 2, the depths of the water table for the boreholes numbered as S3 and S7 were approximately 140-145 cm while those were 100-110 cm for the S13 (Table 2).

Table 3. The water table measurements for the different drain spacings determined according to costant water table

Observation well no	D2-2 (60 m)				D3-3 (60 m)				D2-3 (45 m)			
Days	1	2	3	4	1	2	3	4	1	2	3	4
1	118	134	141	120	120	115	125	111	126	131	134	129
2	113	131	141	117	119	118	127	116	122	128	131	130
3	129	129	140	113	126	118	125	130	111	129	133	115
4	121	134	140	124	124	118	123	117	129	133	134	131
5	120	134	141	123	122	116	125	120	128	133	134	130
6	117	132	140	120	114	118	125	116	125	130	132	123
7	113	131	142	116	116	118	126	114	112	125	131	117
8	110	130	141	111	113	119	126	114	123	123	130	124
9	119	134	142	122	124	119	125	116	125	130	134	126
10	121	134	142	124	125	118	127	116	130	131	134	132
11	116	133	143	121	110	110	119	117	121	128	133	121
12	119	135	142	124	115	112	122	119	126	133	135	126
13	122	135	143	127	121	125	132	114	128	133	135	130
14	137	138	141	138	134	121	127	129	134	137	138	138
15	130	137	141	137	128	122	130	119	133	136	137	135
16	129	137	143	139	131	123	129	124	134	136	137	137
17	130	139	143	137	130	122	128	122	134	137	139	137
18	150	142	143	141	133	131	136	126	135	140	142	138

As seen in Fig. 4, The water table depths were measured as 130-140 cm for drain spacing of 75 m and drain depth of 180 cm while the water table depths were measured almost the same for the drain spacing of 45 m and drain depth of 120 cm. All the different drain depths (120 cm, 150 cm and 180 cm) give the same results. However, taking into account more drain spacings and drain depths could be more economical if the downstream conditions are appropriate.

Bahceci and Nacar (2007) were simulated the effects of varying drain depth (the original average drain depth was 1.5 m) on the ground watertable and root zone salinity. To do so, the simulation model was run for a drain depth from Dd = 1.0 to 1.8 m, with an interval of 0.2 m for 10 years. When drain depth was set to 1.0 m, the root zone salinity became 3.83 dS/m in the summer and 3.53 dS/m in the winter. When the drain depth increased from 1.0 to 1.2 m, the root zone salinity decreased from 3.83 to 2.63 and from 3.53 to 2.44 dSm-1 in the summer and the winter season, respectively. Simulations indicated that as drain depth increased from 1.2 to 1.4 m, the root zone salinity decreased from 2.63 to 2.19 and from 2.44 to 2.0 3dSm-1 in the summer and winter seasons, respectively. When the drain depth increased from 1.4 to 1.6 or1.8 m, it would result in no change in root zone salinity.

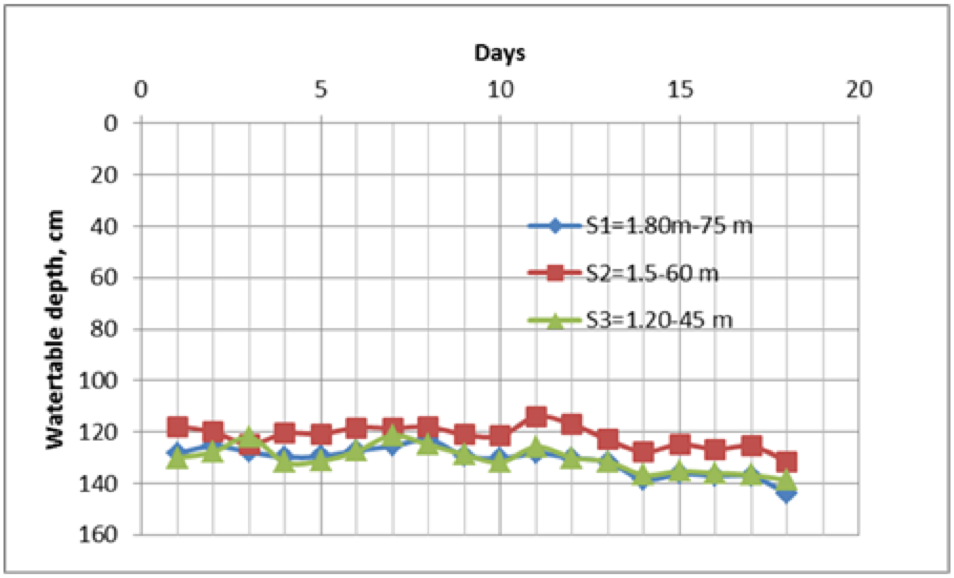

Fig. 4. Watertable depths for different drain spacing and drain depths

Safwat and Ritzema (1990) and Oosterbaan and Abu Senna (1990) have shown that, for Egypt's Nile Delta, average seasonal depths of the water table in the range of 1.0 to 1.2 m are amply sufficient for effective salinity control, whereas maintaining deeper water tables may even negatively affect the irrigation efficiency.

There were no significantly relationships between corn yield and the depths of water table. Average corn yield was 75 tonnes/ha. Considering some studies using different crops, the relative yields of potatoes, onions, maize, and carrots in dependence of the depth of the water table in a muck soil, A depth of 0.6 m is safe for all four crops, although potatoes and carrots perform slightly better when the depth is 0.8 m or more. The yield of onions even decreases at depths of more than 0.8 m. This effect is probably related to the quality of the muck soil (Oosterban, 1994).

Drain Performances

The drain performances were evluated using the measurements of the water table and the results were given considiering Criteria of Ritzema (1994) in Table 4. The piozemetric measurements in the study area are shown as a shematic layout in Fig. 5.

Accoroding the results obtained, the calculated entarnce resistances were 0,28, 0,26 and 0,12 for the drain spacings of 75 m, 60 m and 45 m, respectively. The entrance resistance for all the three drain spacings was normal, the drain performance was good.

Considering silt content of drainge water, the amount of silt in the drainage water were claculated as 63.3, 31.8 and 69.0 g/m3 for the drain spacings of 75, 60 and 45 m, respectively. On the other hand, there were no significantly differences the values of pH and EC in the drainage water (Table 5).

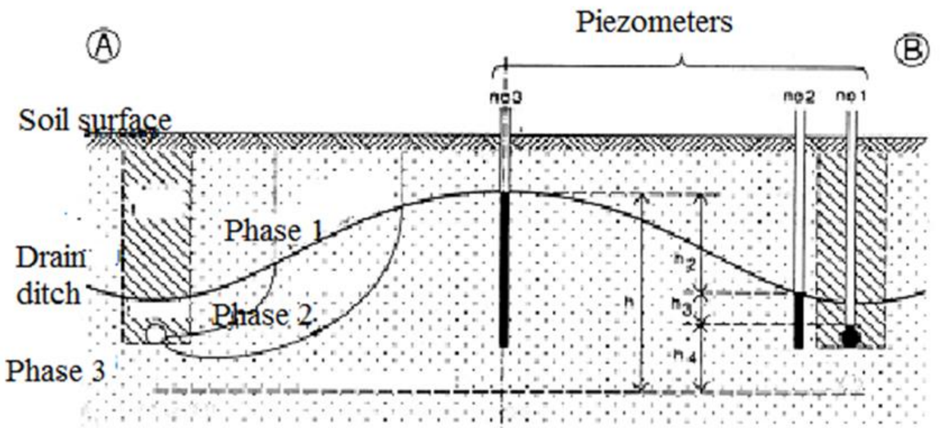

Fig. 5 The piezometers and head losses

Table 4. The evalutaion criteria of water entrance resistance (Ritzema, 1994).

Evaluation criteria $h_3/(h_2+h_3)$	Entrance resistance	Drain performance
<0.2-0.3	Normaly	Good
0.3-0.6	High	Medium-weak
>0.6	Very high	Very weak

Table 5. The analysis results of the water samples collected from the drains

	pH	EC	Cations (me/L)					Anions (me/L)				
		dS/m	Na	K	Ca	Mg	Total	CO_3^-	HCO_3^-	Cl	Total	Silt (g/m^3)
D1(1)	7,33	0,702	1,85	0,05	4,43	1,82	8,15	0,94	3,57	3,64	8,15	19,1
D1(2)	7,25	0,872	1,85	0,05	4,26	2,43	8,59	1,6	3,3	3,69	8,59	30,5
D2-1(75 m)	7,10	0,895	2,09	0,04	4,66	2,59	9,38	1,22	4,05	4,11	9,38	63,3
D2-1(60 m)	7,97	0,788	1,65	0,04	3,91	2,09	7,69	1,16	3,15	3,38	7,69	31,8
D2-1(45 m)	7,76	0,696	1,61	0,04	4,54	1,89	8,08	1,52	3,28	3,28	8,08	69,0

Conclusion

The depths of the water table were ranged from 120 cm to 140 cm during the irrigation season for both of the areas of crosswise drains and different drain spacings and drain depths. In addition, there were no difference in terms of soil salinity. In this study, the gravel was used as the envelop and the entrance resistance was "normal" and the drain line performance was "good". In addition, there were no considerably sediment risk considering the content of silt in the drainage water. Thus, it might be stated that the envelope material, gravel, performed appropriately.

As a result, the currently application of the drain depths and drain spacings for Harran Plain performed an appropriate the depth of water table. The variation of the soil salinity will be able to evaluate at the end of this study.

Acknowledgement

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ASSESSMENT OF DIFFERENT LEVELS OF NITROGEN AND CONTROLLED DRAINAGE ON YIELD AND WATER PRODUCTIVITY

Masoud Noshadi[1,*], Samaneh Karimi[2]

Abstract

The growth of world population and demand for agricultural products is a majora global issues. Controlled drainage (CD) is a management technique to control water level for increasing the yield. This research was conducted to evaluate the effect of controlled drainage and nitrogen fertilizer on wheat yield and water productivity as a factorial randomized complete block design. The treatments were consisted at three fertilizer levels; 0, 200 and 300 kgN/ha and three water table depths including control water tables at 60cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. The results showed that the wheat yield in CD60 was 10% lower than CD120 and in CD90 was 18% more than CD120. The water productivity in CD60 and CD90 was 52.6 and 57.9% more than CD120, respectively. By increasing the values of nitrogen fertilizer the wheat yield and water productivity were also increased.

KEY WORDS: Controlled drainage, Fertilizer, Wheat, Water productivity.

Introduction

Irrigation and drainage have sensitive roles in providing stability in worldfood prodiction.. In agriculture, drainage is important for the regulating of soil salinity, water logging and improving the plant environment (Jia et al., 2006). Controlled drainage is an appropriate management method for the improving of the use of water resources (Ayars et al., 2006). Nitrogen is one of the essential nutrients for plant growth.;therefore, soil fertility and soil nitrogen are synonymous with each other. Wheat in different stages of growth needs different values of nitrogen. Therefore, the use of nitrogen is important to a certain level and for a specific time (Lotfelahi et al., 2012). Water

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resources play a key role in the economic development of any country. Water productivity (WP) is indicator of crop production (Kg) or crop revenue per unit (m^3) of applied irrigation water. The improvement of WP could be an effective method for food production in limited water resources (Heidare, 2012). An increase in water productivity might aid in the farmer being able tto cope with water scarcity in agriculture and it could serve as an indicator for sustainable agricultural intensification (FAO, 2012; WWAP, 2012). The interaction of controlled drainage (management of the water table and retaining it at an acceptable depth) and the application of a suitable nitrogen fertilizer could increase the water productivity and yield of a crop.

Wesstrom et al. (2001) investigated the effect of controlled drainage on wheat yield and losses of nitrogen and phosphorus fertilizers in sandy loam soils. The results showed that the volume of drainage water in water table depths of 60 and 70 cm decreased by 65% to 95% in respect to free drainage respectively. The yield in controlled drainage was 2% to 18% and nitrogen uptake by plants was 3 to 13 kg/ha more than free drainage.

Fisher et al. (1999) compared controlled drainage in a 40 cm water table with free drainage for corn and soybean crop in a silt loam soil. The mean yield in corn and soybean was 19% and 64%, respectively which was more than that of the free drainage crop. The nitrogen uptake in controlled drainage for corn and soybean was 13% and 62% higher than that of free drainage.

In this research the effects of controlled drainage on crop yield and water productivity has been investigated.

Materials and methods

This research was conducted in the form of a factorial randomized complete block design with three replications. The treatments consisted of three fertilizer levels; 0, 200 and 300 kg N/ha and three water table depths including control water tables at 60cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. The fertilizer treatments consisted of three fertilizer levels including 0, 200 and 300 (kg N/ha) and three water table depths including 60 cm (CD60), 90 cm (CD90) and 120 cm (CD120) depths. In this research 27 lysimeters were used in the College of Agriculture research field, Shiraz University, Shiraz, Iran, with latitude of 29° 36' and longitude of with 1810 meters above mean sea level.

The lysimeters were made of GRP pipes with an inner diameter of 2.1 m and laid at a depth of 3.1 m with an 8% Floor slope. The lysimeters were installed on agricultural land. 10 cm gravel were placed at the bottom of the lysimeters, and then the lysimeters were filled with field soil. The four exit pipes were installed at depths of 30, 60, 90 and 130 cm on top of the lysimeters for drainage sampling. To establish the level of the water table at depths of 60 and 90 cm of soil, water was slowly passed throughand a slight discharge from the bottom of the lysimeters was observed (pipes which were installed at 130cm depth).

Irrigation requirements were calculated using a Penman-Monteith Reference crop equation and coefficients recommended by FAO 56. Irrigation intervals were considered at 10 days. After each irrigation, irrigation water depths were observed to be 30% more than the net irrigation water depth. In lysimeters with controlled drainage, the water table dropped because wheat uses sub-irrigation water,;therefore, the sub-irrigation water entered the lysimeters as underground water in the control water table depths. The irrigation method applied was in the form of surface irrigation and irrigation water was measured using a volumetric flow meters. The values of the irrigation water and groundwater are portrayed in Table 3.

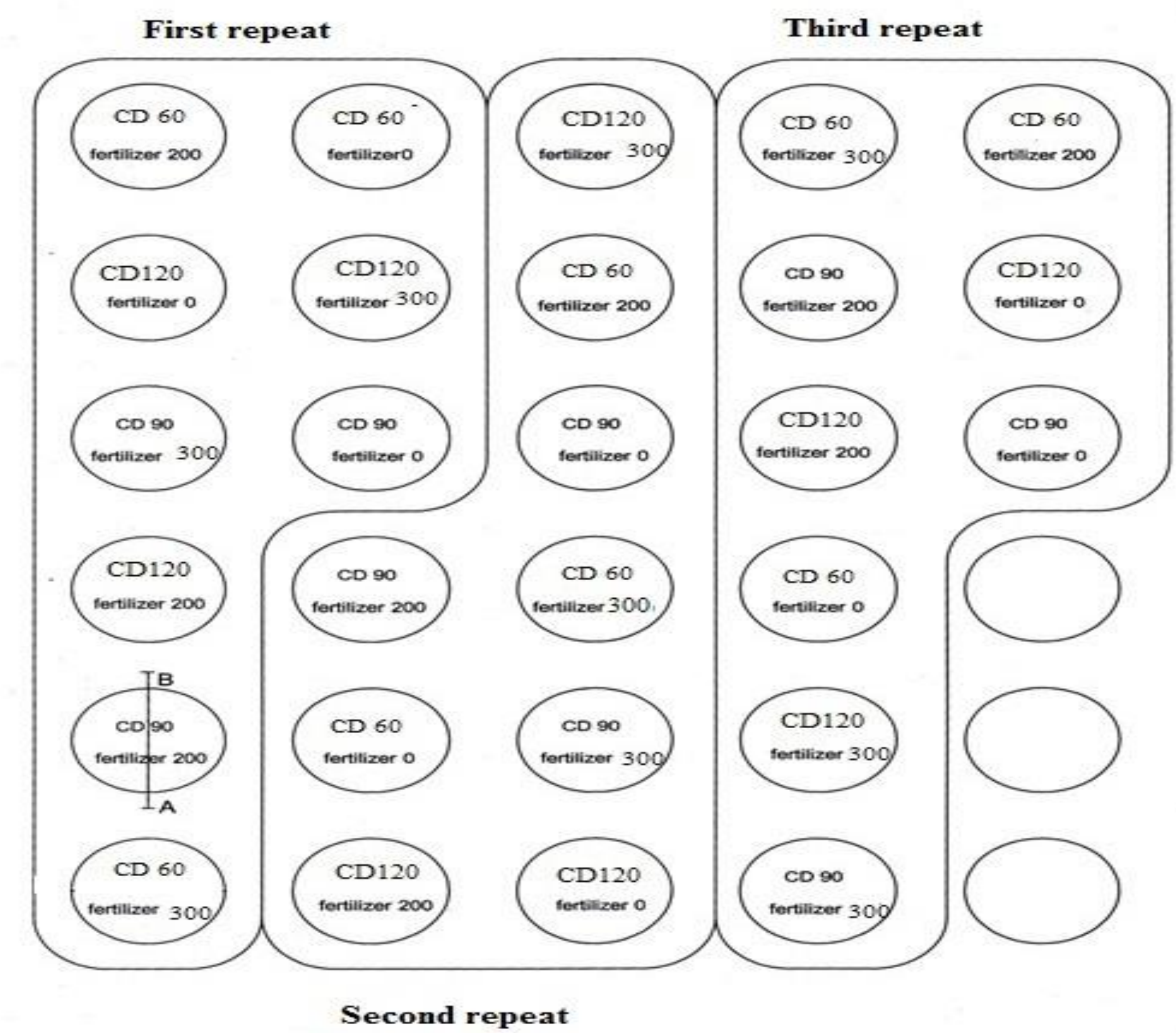

Figure 1. A schematic design on Treatments

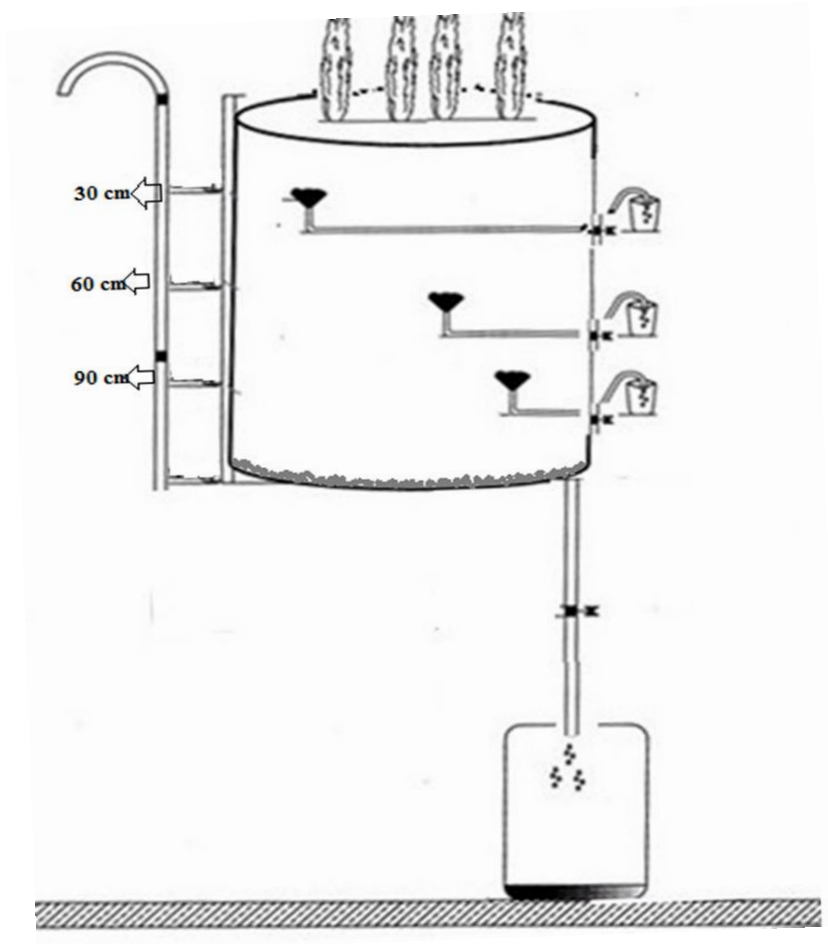

Figure 2: Cross section of the lysimeter used (section AB)

Results and discussion

Irrigation water

Based on the results obtained, the irrigation water depths in CD60 and CD90 were 40.1 and 24.4% lower than CD120, respectively. The irrigation water depths in CD60 decreased by 20.9% as compared to CD90. The effect of nitrogen fertilizer on the reducing of irrigation water was significant at 5% level probability, thus by increasing the values of fertilizer, the values of the irrigation water depth decreased. The mean irrigation water depths in 200 and 300 kg N/ha were 2.1 and 4.1% lower than 0 kg N/ ha, respectively (Table 1). The maximum and minimum irrigation water depths were in CD120 and CD60 treatments with 300 kg N/ha, respectively. This difference was significant at 5% level of probability. According to Table (2), the interaction effect of controlled drainage and nitrogen levels on irrigation water depths was significant.

Table 1. The total irrigation water depths in different treatments (mm)

	Nitrogen(kg/ha)			
Drainage treatment	0	200	300	Mean
CD60**	480.78 *e**	451.73 f	437.37 g	456.63 C
CD90	590.80 b	580.45 c	559.76 d	577.01 B
CD120	763 a	763 a	763 a	763 A
Mean	611.53 A	598.39 B	586.71 B	

*According to Duncan's test data with the same letters are not significantly different at the 5% level.

** CD60: controlled drainage at depth of 60 cm, CD90: controlled drainage at a depth of 90 cm, CD120: controlled drainage at a depth of 120 cm

Table 2. Analysis of variance of wheat grain yield in different treatments

Source	DF	Type III SS	Mean Square	F Value	Pr > F
C	2	428843.86	214421.928	11126.9	<.0001
F	2	2773.5431	1386.7716	71.96	<.0001
c*f	4	1658.2807	414.5702	21.51	<.0001
Error	16	308.3307	19.2707		
Corrected Total	26	433609.75			

Table 3. The irrigation water depth indifferent treatments (L)

Treatment	Sub irrigation	Surface Irrigation	Total irrigation water depth
CD(60)-F1	319.03	543.47	862.5
CD(60)-F2	351.86	510.64	862.5
CD(60)-F3	368.1	494.4	862.5
CD(90)-F1	194.66	667.84	862.5
CD(90)-F2	206.36	656.14	862.5
CD(90)-F3	229.75	632.75	862.5
CD(120)-F1	0	862.5	862.5
CD(120)-F2	0	862.5	862.5
CD(120)-F3	0	862.5	862.5

Yield

The results showed that the maximum and minimum grain yields were 7.12 Mg/ ha (with 300kg N/ha) in CD90 and 3.29 Mg/ha (with 0 kg N/ha) in CD60 treatments, respectively. The total grain yield in CD60 and CD90 treatments decreased 10% and increased 18% relative to CD120, respectively. This difference was significant at 5% level of probability. Statistical analysis show that the interactions of controlled drainage and nitrogen levels on the grain yield was significant (Table 4).

According to Figure 3, the grain yield increased by increasing the amount of fertilizer. The mean grain yield in 200 and 300 kg N/ha fertilizer treatments were 43 and 65% more than 0 kg N/ha, respectively. The results showed that the grain yield in 300 kg N/ha fertilizer increased 15% as compared to 200 kg N/ha fertilizer.

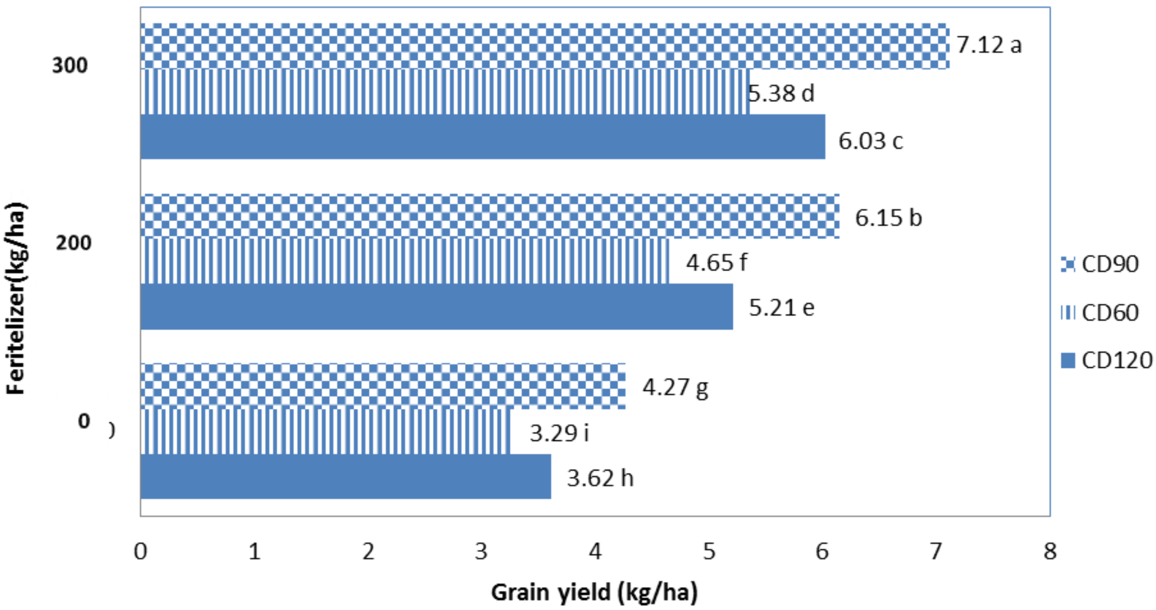

Figure 3. The mean grain yield in different fertilizers levels

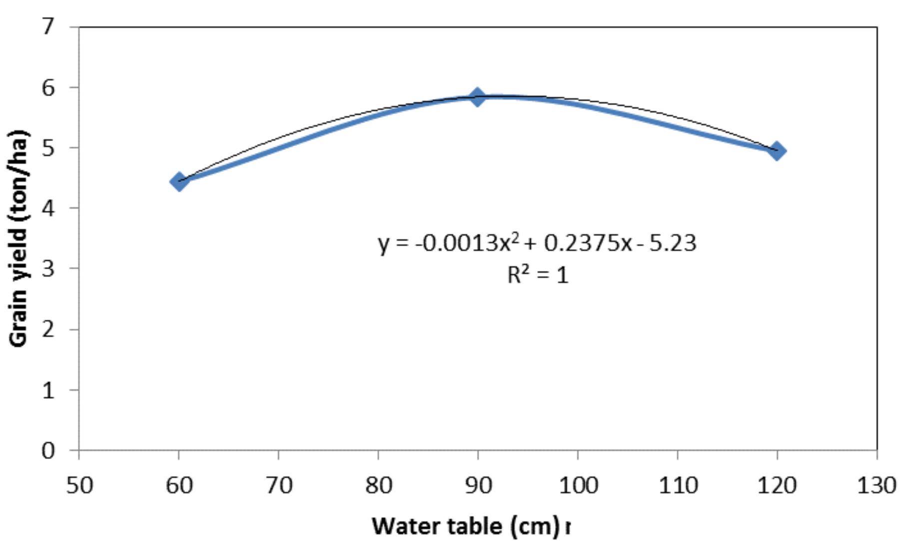

Figure 4. The relationship between yield and water table depth

According to Figure 4, water table depth of more than or lower than 90 cm could reduce the yield. One of the reasons for the reducing of the yield in water tables lower than 90 cm is the lack of ventilation in the root zone and in water tables of more than 90 cm the capillary rise (sub-irrigation) is too low. The results showed that the lack of ventilation (water logging) in the root zone has a greater effect in decreasing the yield.

The total yield in CD60 and CD90 treatments decreased by 6.1% and increased by 14.4% relative to the CD120 treatment, respectively.

Water productivity

According to Table (4) the water productivity in CD60 and CD90 treatments were 52.6 and 57.9% more than the CD120 treatment, respectively. This difference was significant at 5% level of probability. The water productivity in the CD60 treatment decreased 3.3% as compared to the CD90 treatment. Statistical analysis show that the interaction of controlled drainage and nitrogen levels on water productivity was significant. The mean WP in 200 and 300 kg N/ha fertilizer was 49 and 76.3% more than 0 kgN/ ha, respectively. Water productivity in 300 kg N/ha fertilizer increased by 18.2% as compared to 200 kg N/ha fertilizer. This difference was significant at 5% level of probability.

Table 4. The mean water productivity in different treatments (kg/m^3)

Drainage treatment	Nitrogen(kg/ha)			Mean
	0	200	300	
CD60**	0.61 g^*	0.91 d	1.09 b	0.87 B
CD90	0.64 f	0.94 c	1.13 a	0.9 A
CD120	0.42 h	0.6 g	0.7 e	0.57 C
Mean	0.55 C	0.82 B	0.97 A	

*According to Duncan's test data with the same letters are not significantly different at the 5% level.

** CD60: controlled drainage at depth of 60 cm, CD90: controlled drainage at a depth of 90 cm, CD120: controlled drainage at a depth of 120 cm

Conclusions

The results show that with the increasing of the water table depth, the irrigation water depth increases and sub-irrigation decreases. Moreover; by controlling the water table depth more or lower than 90 cm (CD90), the total yield and grain yield decreased. The water table at depths lower than 90 cm causes a lack of aeration in the root zone and in water table depths more than 90 cm the sub-irrigation is not sufficient.

In can be concluded that, in terms of both yield and water productivity, the optimum water table depth is 80 cm (CD80) with 200kg N/ha fertilizer (Fig. 5).

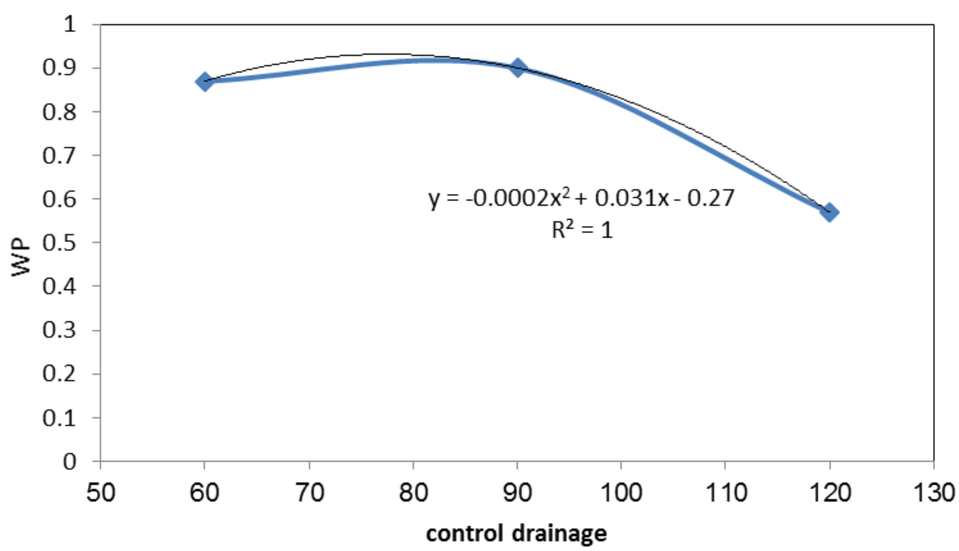

Figure 5. The relationship between water table depth and water productivity

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RAINFALL FREQUENCY ANALYSIS FOR LAND DRAINAGE CRITERIA IN BIHAR - A CASE STUDY

Lal Bahadur Roy[1,*], Ashutosh Upadhyaya[2]

Abstract

Irrigation and drainage are complimentary to each other. Normally land drainage is a problem in very flat or level land. Drainage congestion leads to waterlogging. The problem of waterlogging is a world-wide phenomenon which occurs mainly due to the rise of the groundwater table beyond permissible limits. Land subjected to waterlogging has already affected about 3 to 6 M ha of cultivable land in India.

Bihar is an agriculture based state of India and is facing the two problems of floods and droughts. Among the adverse effects of floods is waterlogging in agriculture fields, since there is no adequate land drainage system in the state. In this study, the determining of the effects of one to seven consecutive days of maximum rainfall corresponding to a return period varying from 2 to 20 years and a crop tolerance period, which helps in the determination of a drainage coefficient for agricultural fields, utilizing the daily rainfall data of Patna for the period 1980-2009 has been considered. A positions plotting method and other probability distributions have been applied to estimate one day to seven consecutive days of maximum rainfall over various return periods.

The comparison of these methods, show that Gamma distribution gives the best coefficient for the determination and predicts values closer to the values obtained by the plotting position method. Results also show that for a return period of 2 to 20 years, the plotting position method gives the lowest values of one day maximum rainfall. Drainage coefficient with a bund height as 100 mm and 150 mm have also been determined from depth duration frequency curves.

KEY WORDS: Land drainage, Waterlogging, Rainfall frequency analysis, Drainage coefficient, Gamma distribution

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Introduction

Rainfall causes flow on land, some water Infiltrates into the soil .This water must be removed from agriculture lands so that it does not create problem of waterlogging. Excess water removed from the surface of land is called drainage. The draining of water from a catchment after precipitation is known as runoff. When all the losses are abstracted from the precipitation it is reduced to runoff. Waterlogging is defined as the retention of area under water for a considerable period, causing severe damage or complete loss of crop. An area is waterlogged when water table rises to an extent so that it interferes with effective root zone of a crop.

Drainage coefficient (DC) is the amount of water to be removed from a crop land in one day so that plants do not destroy due to excess water. A commonly used unit of DC is mm/day. DC represents a flow rate lower than the peak of the hydrograph. Drainage coefficient is the key parameter in hydraulic design of any drainage system.

Gupta et al (1971) gave the values of DC for agricultural lands for different parts of India which can be readily used by the planners and designs in the field of irrigated agriculture.

As per IS: 8835 (1978) criteria drains should be designed for 3 days rainfall of 5 year occurrence interval. However, in exact cases, requiring higher degree of protection, the frequency of 10 to 15 years can be justified in terms of economy. This code has recommended that cross-drainage structures should be designed for 3-day rainfall of 50 years frequency for different periods of disposal depending upon the tolerance period of crops.

Bhattacharya and Sarkar (1982) analysed 40 years (1931-70) rainfall data of Hoshangabad in M.P. for four heavy rainy months of June, July, August and September to conclude 1 day to 5 consecutive days rainfall of 5 years recurrence interval. They found that 15-30 years data will be sufficient to give a sensible self-belief on the predicted 5- year return period rainfall values.

A design DC is obtained by considering runoff from design rainfall. For determination drainage coefficient, one day to seven consecutive days rainfall from 30 year data from 1980 to 2009 of Patna district have been used. The location map and the soil map of the study area are as given in Figure 1, 2 respectively. In the present study, DC has been calculating by plotting position method, normal distribution, log normal distribution, Pearson method, log Pearson method, Extreme distribution, log extreme distribution and Gamma distribution method (Thom, 1958). Also an effort has been made to determine best fit Probability distribution for this. The objective of this is

- To determine drainage coefficient / design discharge of drain from 1 day to 7 days consecutive maximum annual rainfall series by using depth – duration - frequency curves
- To determine the best fit probability distribution for 1 to 7 days consecutive maximum annual rainfall series

Location of the study area

Patna has latitude $\mathbf{25^{\circ}60'}$N, longitude of $\mathbf{85^{\circ}11'}$E and altitude of 54.0 m. It is the capital of Bihar, an easterly state of India. It comes under eastern part of India and has seasons of south - west monsoon from June to September, north - east monsoon from October to December, winter season from January to Feb with single rainfall peak .This case study area experiences mono-model type rainfall characterized by single rainfall peak during a year. Mean annual rainfall of Patna is 1054 mm. Normal rainfall in SW monsoon (June-sep) is 906 mm, in NE monsoon (Oct-Dec) is 71mm, in winter (Jan-Feb) is 28 mm and in summer (Mar-May) is 49 mm. Rice is the major field crop and for which productivity is 3171 kg/ha. Planning commission of India has kept in the area middle genetic plain region. Also the geographical location and soil group map for Patna district of Bihar are as given in Figure 1 and 2 respectively. There are mainly three types of major soils present in Patna district as given below.

Major Soils	**Area (‘000 ha)**	**Percent of total**
Clay to clay loam soils	67.1	31.3
Sandy loam soils	70.5	32.9
Medium to heavy soils	76.2	35.6

Figure1. Location the Study area

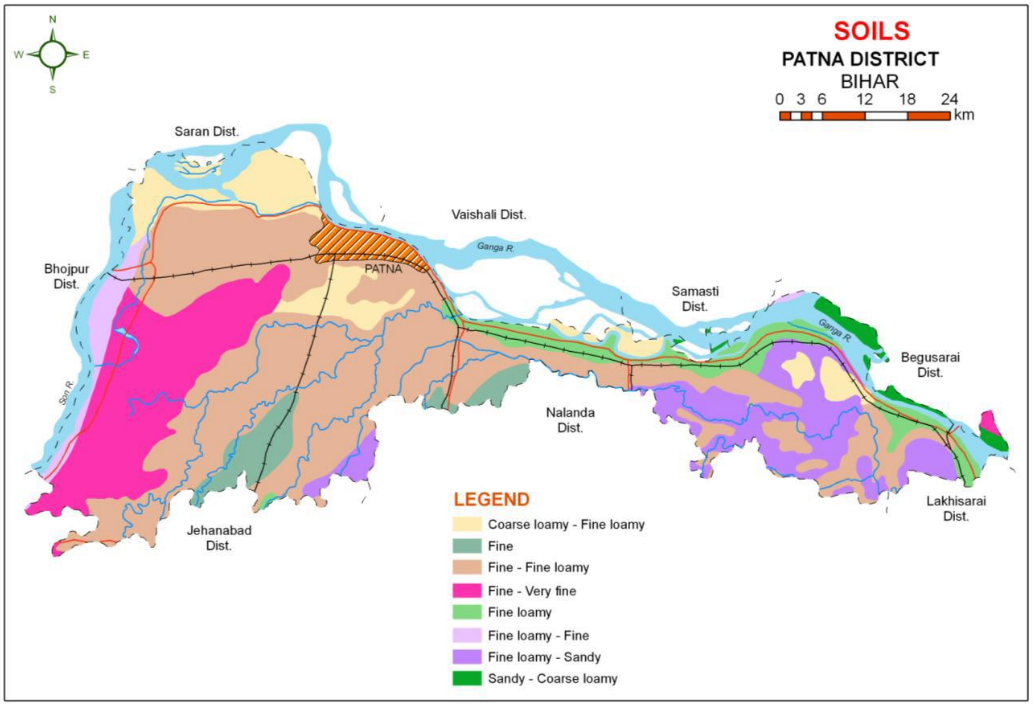

Figure2. Map for Soil groups in Patna district (Source: www.krishi.bih.nic.in)

Materials and methods

In general, 24 hrs rainfall of 5-10 years return period is taken for design of drainage system. In agriculture 5 year return period value is commonly used. Therefore, it is necessary to have information on maximum amount of rainfall of various durations.

The values of the annual maximum rainfall for a given catchment area for large numbers of successive years constitute a hydrologic data series and it is called annual series. The data are then arranged in decreasing order of magnitude and the probability of exceedence of each event is calculating by the Weibull's formula in plotting position method. Further other probability distributions like normal distribution, log normal distribution, log normal distribution, Pearson type III distribution, log Pearson type III distribution, extreme value type distribution, log extreme value type distribution and Gamma distribution have also been used.

From above frequency analysis, rainfall values and probability corresponding to these values are generated in the form of tables. By applying the linear interpolation one can compute rainfall corresponding to different probability levels and thus corresponding to different return periods. A graph is plotted between return period and maximum consecutive days rainfall as per Upadhayaya and Singh (1998). The best fit curve is plotted and tangent is drawn from 100 mm bund height and

150 mm bund height to each of the curves. The length of the ordinate gives allowable safe storage of water in the cropped field. The slope of the tangent lines indicates the design discharge or drainage coefficient.

In general, 24 hrs rainfall of 5-10 years return period is taken for design of a disposal drainage system. In agriculture 5 year return period value is more commonly used (WAPCOS, 1988). If the tangent line is shifted parallel to pass through the zero point of the co-ordinate axes, design discharge is commuted.

Drainage coefficient which is determined by plotting position method has been compared to frame different distribution functions and frame which the highest and lowest drainage coefficients are determined. All distributions, as mentioned above, have used for determination of consecutive days maximum rainfall with desired return period but it has been found that normal, log normal, Pearson, log Pearson type III, Extreme, log extreme distributions are not fit in calculating the maximum rainfall and only Gamma distribution is fit in calculating the consecutive days maximum rainfall with desired return period**.**

As submergence depth of 10 to 15 % for rice crop is safely allowed in crop field, assuming the tall rice variety of 1 m depth, 100 mm and 150 mm depth of rainfall is assumed to be the allowable storage. Thus tangent lines are drawn for all the four curves of 2, 5, 10 and 20 year return periods joining the ordinate at 100 mm and 150 mm.

Results and discussion

Using a computer program in FORTRAN 77, first of all rainfall, maximum one day rainfall to seven consecutive days rainfall were calculated as given in Table 1. These maximum rainfalls are analysed by plotting position method. By this method probability and return period are calculated. Maximum rainfalls are calculated with 2 years, 5 years, 10 years,15 years and 20 years return period by normal distribution, log normal distribution, Pearson type III distribution, log Pearson type III distribution, Extreme type I distribution, log Extreme type I distribution and Gamma distribution method with desired return periods. Some of the results are as given in Table 2 and 3.

Graphs are plotted between consecutive days maximum rainfalls for return period varying from 2 to 20 years as given in Figure -3. Rainfall values are computed by different theoretical probability distributions and plotting position method. Some of the theoretical probability distributions need standard deviation, mean and coefficient of skewness of the original data series for computation of rainfall corresponding to desired return period.

These Consecutive days rainfalls should be compared with rainfall values which are computed by plotting position method. On comparison it was found that normal distribution, log normal distribution, Pearson method, Log Pearson method, extreme value type I distribution, Log extreme value type I distribution are not best fit in all consecutive day maximum rainfall but Gamma distribution is the best fit among all probability distributions because computed **chi square** value is lower than tabulated **chi square** value as given in Table 4. However, in some cases log normal distribution is best fit. In some other cases extreme and log extreme distribution are best fit.

Gamma distribution is best fit but in all consecutive days maximum rainfall as shown in Table 5. For illustration the comparison of 1 day, 2 days, 3 days and 7 days of maximum rainfall computed from different distributions are as given from 6 to 9.

From comparison of 1 day maximum rainfall from plotting position method and that from Gamma distribution method it was found that the percentage difference varies from 3.95 % to 11.53 %. Similarly for two days maximum rainfall, the difference varies from 0.76 % to 8.4 % and that for 3days maximum rainfall varies from 2.42 % to 10.25 %.and that for 7 days maximum rainfall varies from 0.2 % to 9.41 %.

For Drainage coefficients derived from depth – duration – frequency analysis for the study area assuming bund height as 150 mm and 100 mm are given in Table 10 and 11 respectively. Also the drainage coefficients derived from plotting position method and Gamma distribution method assuming rainfall losses as 50% are given in Table 12 and 13 respectively.

From depth duration frequency curves, the design discharge for 2 years, 5 years, 10 years,15 years and 20 years return period were found as 10 mm/day, 30 mm/day, 40 mm/day, 50 mm/day and 60 mm/day respectively with the bund height as 150 mm and 20 mm/day 50 mm/day, 60 mm/day, 80 mm/day and 90 mm/day respectively, when the bund height is kept as 100 mm for the agricultural land in Patna district.

Table 1 Maximum Consecutive Days Rainfall for Patna for 30 Year (1980-2009)

S. No.	Year	1 Day Max	2 Day Max	3 Day Max	4 Day Max	5 Day Max	6 Day Max	7 Day Max
1	1980	135.3	181.4	188.2	221.6	257.1	268.8	268.8
2	1981	200	200	200	206.6	218.55	230.95	238.35
3	1982	51.3	67.2	87.1	104.7	104.7	107.1	116.5
4	1983	58.1	93.3	113.7	122.5	125.5	125.7	128.9
5	1984	97.2	152.4	179.5	183.4	188.2	207.6	215.1
6	1985	102.6	192.8	209	250.1	311.7	315.1	315.1
7	1986	90.4	161.2	202.7	246.2	265.1	284.1	288.6
8	1987	79	128.5	139.3	158.5	172.3	212.6	233.4
9	1988	166	219.8	240.6	243.5	313.9	367.7	394.6
10	1989	111.3	114.7	134.3	155.6	159.6	161.5	178.2
11	1990	129.8	245.3	292.2	293.4	295.8	309.1	309.1
12	1991	93.4	185.3	189.6	197.1	201.4	202.7	207
13	1992	71.2	119.1	169.7	180.5	185.4	185.4	185.4
14	1993	131.8	137.1	141.5	157.3	236.6	237	237
15	1994	96.8	105.6	116.9	147.6	179.6	196.05	204.85
16	1995	98.7	103	180.2	180.2	180.2	181.5	181.9
17	1996	98.7	103	180.2	180.2	180.2	181.5	181.9
18	1997	205.4	307.2	380.8	467.4	496.1	521.7	524.8

S. No.	Year	1 Day Max	2 Day Max	3 Day Max	4 Day Max	5 Day Max	6 Day Max	7 Day Max
19	1998	74.5	93.1	123.7	139.5	157.3	165.5	179.9
20	1999	94.8	152	163.6	171.6	172.3	180.3	181.1
21	2000	117.5	121.7	127	147	159.4	168.6	181.8
22	2001	102.9	161.8	202.7	278.9	288.8	291.6	292.6
23	2002	158.4	164	166.1	171.5	174.1	176	181.2
24	2003	99.1	127.2	177.3	250.8	268.7	280.3	287.3
25	2004	75.4	96.4	99.2	115.5	146.3	164	165.6
26	2005	71	119.4	126.6	141.8	187.7	194.2	198.5
27	2006	157	220.9	232	310.6	318.6	326.2	331.7
28	2007	166.7	212.3	251.1	296.7	332.5	333.3	368
29	2008	81.6	100.8	138.4	177	209.1	217.4	223
30	2009	94.1	102.2	105.6	105.9	125.8	129.2	150

Table 2 One day to seven consecutive days maximum rainfall by plotting position method for Patna district for 30 years (1980-2009)

Consecutive days Rainfall	2 Year Return Period (mm)	5 Year Return Period (mm)	10 Year Return Period (mm)	15 Year Return Period (mm)	20 Year Return Period (mm)
1 Day Max	98.7	152.3	166.61	196.78	201.57
2 Days Max	132.46	198.4	220.77	242.95	263.97
3 Days Max	173.5	207.6	249.86	288.22	317.92
4 Days Max	180.2	250.6	296.27	309.25	356.12
5 Days Max	187.95	294.6	317.99	331.15	379.99
6 Days Max	205.15	305.3	332.39	364.37	412.4
7 Days Max	211.05	305.5	363.36	392.02	432.4

Table 3 One day to seven consecutive days maximum rainfall from Gamma distribution for Patna district for 30 years (1980-2009)

Consecutive Days	Computed Chi Square values	Tabulated Chi Square values
1 Day Max	39.32	42.56
2 Days Max	29.39	42.56
3 Days Max	30.58	42.56
4 Days Max	32.02	42.56
5 Days Max	31.09	42.56
6 Days Max	31.03	42.56
7 Days Max	31.42	42.56

Table 4 Chi Square Values For Gamma Distribution for Patna District

Consecutive Rainfall	2 Year Return Period (mm)	5 Year Return Period (mm)	10 Year Return Period (mm)	15 Year Return Period (mm)	20 Year Return Period (mm)
1 Day Max	105.78	141.35	162.75	174.08	181.85
2 Days Max	143.59	192.64	222.38	234.38	249.12
3 Days Max	168.49	223.22	255.93	273.45	285.32
4 Days Max	191.45	257.77	297.68	319.04	333.45
5 Days Max	211.17	283.18	326.43	349.44	365.18
6 Days Max	220.88	296.98	342.75	367.21	383.81
7 Days Max	228.62	304.88	350.80	375.08	391.70

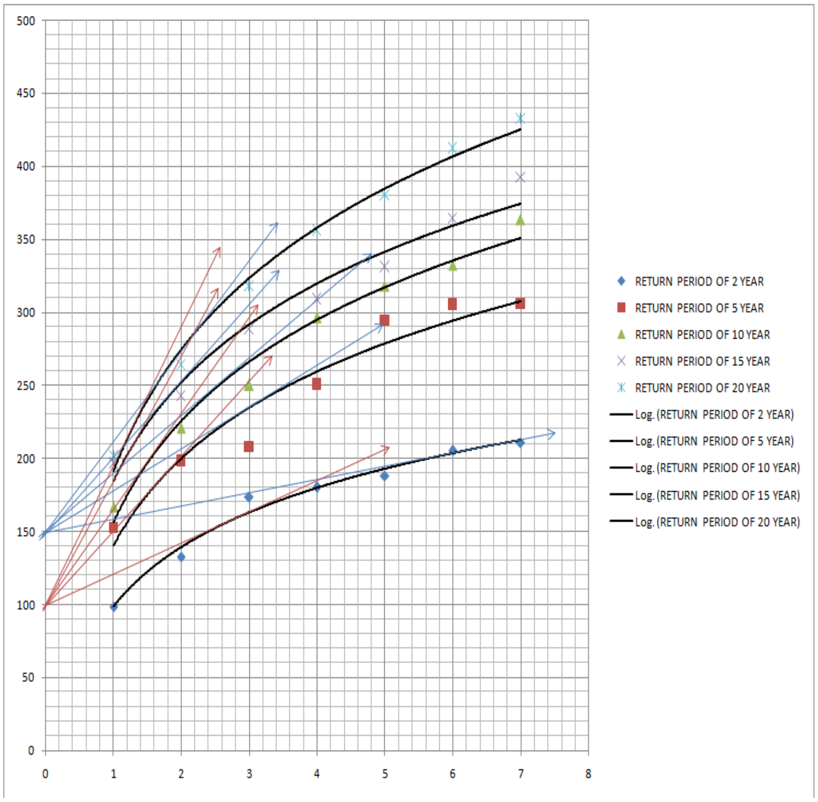

Figure 3 Consecutive Days Maximum Rainfall and Return Period for Patna District.(***x-axis: Days & y-axis: Maximum Rainfall in mm)***

Table 5 Best Fit Distributions for the Study Area, Patna

Consecutive Rainfall	**Normal**	**Log Normal**	**Pearson**	**Log Pearson**	**Extreme**	**Log Extreme**	**Gamma**
1 Day Max	Not Fit	Not Fit	Not Fit	Not Fit	Not Fit	Best Fit	Best Fit
2 Days Max	Best Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
3 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Not Fit	Best Fit
4 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
5 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
6 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit
7 Days Max	Not Fit	Best Fit	Not Fit	Not Fit	Best Fit	Best Fit	Best Fit

Table 6 Comparison of 1 Day Maximum Rainfall Computed from Plotting Position Method and that Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position Method (mm)	Two Parameter Gamma Distribution (mm)	Difference (mm)	Percentage %
2	98.7	105.78	- 7.08	7.17
5	153.3	141.35	11.95	7.79
10	166.61	162.75	3.86	3.95
15	196.78	174.O8	22.70	11.53
20	201.57	181.85	19.72	9.78

Table 7 Comparisons of 2 Days Maximum Rainfall Computed from Plotting Position Method and that Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position Method (mm)	Gamma Distribution (mm)	Difference	%
2	132.46	143.59	- 11.13	8.40
5	198.40	192.64	5.76	2.90
10	220.70	222.38	-1.68	0.76
15	242.95	234.38	8.57	3.52
20	263.97	249.12	14.85	5.62

Table 8 Comparisons of 3 Days Maximum Rainfall Computed from Plotting Position Method and Rainfall Computed from Gamma Distribution for Patna

Return Period (Year)	Plotting Position (mm)	Gamma Distribution (mm)	Difference (mm)	%
2	173.50	168.49	5.01	2.88
5	207.6	223.22	- 15.63	7.52
10	249.86	255.93	-6.07	2.42
15	288.22	273.45	14.77	5.12
20	317.92	285.32	32.6	10.25

Table 9 Comparisons of 7 Days Maximum Rainfall Computed from Plotting Position Method and Rainfall from Gamma Distribution Method for Patna

Return Period (Year)	Plotting Position (mm)	Gamma Distribution (mm)	Difference (mm)	%
2	211.05	228.62	-17.57	8.32
5	305.5	304.88	0.62	0.20
10	363.36	350.8	12.56	3.45
15	392.02	375.08	16.74	4.32
20	432.4	391.7	40.70	9.41

Table 10 DC for Patna District Assuming Bund Height as 150 mm

Return Period (Year)	Slope	Drainage Coefficient (DC)
2	$\frac{200-150}{5.5-0}$	9 ≈ 10 mm/day
5	$\frac{235-150}{3-0}$	28.33 ≈ 30 mm/day
10	$\frac{255-150}{2.7-0}$	38 ≈ 40 mm/day
15	$\frac{260-150}{2.2-0}$	50 mm/day
20	$\frac{300-150}{2.5-0}$	60 mm/day

Table 11 Drainage Coefficients for Patna District with Bund Height as 100 mm

Return Period (Year)	Slope	Drainage Coefficient
2	$\frac{150-100}{2.4-0}$	20.83 ≈ 20 mm/day
5	$\frac{180-100}{1.6-0}$	50 mm/day
10	$\frac{200-100}{1.6-0}$	62.5 ≈ 60 mm/day
15	$\frac{218-100}{1.4-0}$	84.28 ≈ 80 mm/day
20	$\frac{230-100}{1.4-0}$	92.85 ≈ 90 mm/day

Table 12 Drainage Coefficient by plotting position method for Patna Assuming Rainfall Losses as 50 %

Consecutive Days	5 Year Return Period (mm/day)	10 Year Return Period (mm/day)	20 Year Return Period (mm/day)
1 Day Max	76.15	83.30	100.78
2 Days Max	49.60	55.19	65.99
3 Days Max	34.60	41.64	52.98
4 Days Max	31.32	37.03	44.51
5 Days Max	29.43	31.79	37.99
6 Days Max	25.44	27.69	34.36
7 Days Max	21.82	25.95	30.88

Table 13 Drainage Coefficient by Gamma Distribution method for Patna Assuming Rainfall Losses as 50 %

Consecutive Days	5 Year Return Period	10 Year Return Period	20 Year Return Period
1 Day Max	70.67	81.38	90.92
2 Days Max	48.16	55.59	62.28
3 Days Max	37.20	42.65	47.55
4 Days Max	32.22	37.21	41.68
5 Days Max	28.32	32.64	36.51
6 Days Max	24.75	28.56	31.98
7 Day Max	21.77	25.05	27.98

Conclusions

Plotting position method and various other probability distribution methods like normal, log normal, Pearson, log Pearson extreme, log extreme and Gamma distributions were tested with 1 to 7 days consecutive maximum rainfall series corresponding to various return periods for Patna district. These distributions take different parameters into account likes mean, standard deviation, coefficient of skewness and 7 days consecutive rainfall. None of probability distributions except Gamma probability distribution was found fitting in the rainfall series for Patna district, because computed chi square values were always less than the tabulated chi square values only in the case of two parameters Gamma distribution.

Thus Analysis of above consecutive days maximum rainfall data series applying above distributions showed that to get best estimate of 1 day, 2 days, 3 days, 4 days, 5 days, 6 days and 7 consecutive days maximum rainfall, Gamma distribution should be applied for the area under study.

For secured disposal of drainage water, design discharge of 2 year, 5 year, 10 year, 15 year and 20 year return periods are 10 mm/day, 30 mm/day, 40 mm/day, 50 mm/day and 60 mm/day respectively for bund height as 150 mm and 20 mm/day 50 mm/day, 60 mm/day, 80 mm/day and 90 mm/day for bund height as 100 mm respectively for the area under study.

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POLDER DRAINAGE SYSTEM TO MITIGATE VULNERABLE ECOSYSTEM OF COASTAL BANGLADESH

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Abstract

People of the coastal belt of Bangladesh are fully dependent for their comprehensive livelihood on the coastal embankment. Bangladesh Water Development Board (BWDB) constructed an embankment in the 14 coastal districts of Bangladesh. They have made 139 polders since 1960s to grow more food by protecting coastal land from saline intrusion caused by tidal flooding and to ensure the preservation of sweet water in canals for agricultural production in dry seasons. Embankments built to prevent flooding or coastal tidal surge of low-lying land are also called a levees or dykes which are constructed along a riverbank and at some distance from the river to retain floodwater or tidal effect. These embankments provide a protected environment for people's resources. The coastal region of Bangladesh portrays acute socio-ecological complexities, where people are gradually becoming powerless, socio-economically marginalized and vulnerable. The complexity arise through vulnerable coastal and mangrove ecosystem and fluctuating socio-economic life patterns that are caused by a number of ecologically inconsistent developmental intervention and land use practices. There are many natural and man-made hazards like cyclones, embankment erosion, tidal surges, salinity, water logging, floods during heavy rain fall, drought, pests in crops etc. that increase the risk of disaster among the vulnerable community. Under the programme of flood control and drainage improvement, about 7,555 km of embankment (including coastal embankments of about 4,000 km), 7,907 hydraulic structures including sluices, and around one thousand river regulators, 1,082 river closures and 3,204 km of drainage channels have been built at the cost of a thousand core taka. Under the scheme a total of 332 projects, aimed at protecting 3.5 million ha of land from flood inundation, have been implemented. Thus, about 24% of the total land area and 39% of the net cultivated area have been protected. However, the success of embankment construction depends technically on the natural detention basin, channel improvements, flow diversions and bank stabilization and anti-erosive measures. The CEP comprises a complex network of dikes and drainage sluices and was the first comprehensive plan for providing protection against flood and saline water intrusion in the coastal area. The function of the embankment depends on many coastal factors of which the most prominent issues were the management of sluice gates, managing canals downstream the sluice gate, operation & maintenance of sluice gate, regular monitoring of the embankment, illegal cutting of the embankment to set pipes for shrimp farming, etc. Here the greatest concern was people's involvement or a community based approach to manage the polder system for embankment &

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canals in the context of sustainability. The Embankment and Drainage Act 1952 ensures the protection of lands from floods, erosion or other damage by water through the constructing and repairing of the embankment, but it has developed gaps over the years. Sluice gates were also constructed at certain places to control water channeling from the sea /channel to inland canals. But since, 1980s people with money and access to power started taking lease of the water bodies inside Polders to cultivate saline water shrimp farms; and as a result thousands of unplanned cannels were made in the embankment causing it to become thin and weak. Whatsmore, it also excluded poor farmers from accessing and controlling water bodies, causing them to cultivate their land with a single crop. The local government officials now properly understand community demands and feel more accountable to construct and maintain a sustainable embankment.

KEY WORDS: Polder, Ecosystem, Mitigation, BWDB, Zaminder, CRA.

Introduction

Embankment a ridge built with earth or rock to contain flood water or to construct a road, railway, and canal. Embankments vary in nature and function under a variety of situations. Designed to control or prevent flooding, flood control embankment is one of several types of embankments on the floodplains. An embankment built to prevent flooding of low-lying land is also called a levee or dyke constructed along a riverbank and at some distance from the river to retain floodwater. (Baseline, 2012) The earliest recorded embankment in this subcontinent was built during the Sultani period (1213-1519 AD). In Bangladesh coastal embankments were constructed as early as the 17th century on private initiative under the patronage of zaminders. Systematic development of large-scale embankments for flood control started in the 1960s. Since then hundreds of kilometers of embankments have been built along rivers and in the coastal areas of Bangladesh. These embankments provide a protected environment for agricultural and other economic activities. Food security challenges were major consideration under the programme of flood control and drainage improvement, about 7,555 km of embankment (including coastal embankments of about 4,000 km), 7,907 hydraulic structures including sluices, and around one thousand river regulators, 1,082 river closures and 3,204 km of drainage channels have been built spending a hundred million taka. Under the scheme a total of 332 projects, aimed at freeing 3.5 million ha of land from flood water, have been implemented. Thus, about 24% of the total land area and 39% of the net cultivated area have been protected. However, in this programme some form of natural detention basin, channel improvements, flow diversions and bank stabilization and anti-erosive measures have been tried. Other than the flood control embankments on the floodplains, the railway and national road embankments constructed during the colonial period played a major role in flood mitigation. A brief account of major embankments in Bangladesh is given here. Brahmaputra Right Bank Embankment One of the first planed embankments constructed in 1960s to provide flood protection to about 230,000 ha lying on the western side of the Brahmaputra-Jamuna and Tista rivers. It is 217 km long and extends from Kaunia in Rangpur at the northern end up to Beraupazila in Sirajganj district at the southern end. Construction of the embankment started in 1963 and was completed in 1968 at a cost of about BDT 80 million. The average height is 4.5m, crest width 6m and side slope 1:3 on both sides. The embankment has been under constant threat of erosion by the Jamuna River and needs relocation further away from the river bank till now. The Coastal Embankment Project (CEP) covers the coastal districts of Bangladesh and includes Cox's Bazar, Chittagong, Feni, Noakhali, Lakshmipur, Bhola, Barisal, Patuakhali, Jhalokati, Barguna, Pirojpur, Khulna, Satkhira and Bagerhat districts. The CEP comprises a complex network of dikes and drainage sluices and was the first comprehensive plan for providing protection against flood and saline water intrusion in the coastal area. The project was implemented between 1961 and 1978 by the BWDB (Bangladesh Water Development Board) in two phases. Phase I comprises some 92 polders providing protection to one million ha of land. Phase II consists of 16 polders covering another 0.40 million ha. 'Polder' is a Dutch word meaning an area enclosed by dikes. Within the CEP more than 4,000 km of embankment and 1,039 drainage sluices have been constructed. But since, 1980s people start to enter from the outsider with money and access to power through taking lease of the water bodies inside Polders to farming saline tolerance shrimps and crab fattening; as a result thousands of unplanned cannels were constructed into embankment thus it is causing weak and thin. And, it also excluded poor farmers accessing and control over water bodies. Moreover their cropping land turns into single crop. According to the geological physical characteristics coastal zone is defined by three hydrological indicators tidal influence, salinity intrusion and influence of cyclones and storm surges. It covers an areas of 47150 sq. km with a population of 38.5 million (BBS 2011), of 817 persons per sq.km.

Materials and Methods

This study based on the secondary materials and long time working experience with coastal rural people. Here the empirical and descriptive research as well as. It is very close observation in different projects, IGA, Early Response project, Cash for Work, CRA (Community Risk Assessment) and community mobilization orientation reports. Those voices are included in here they are always vulnerable in their life time. FGD and KII with different stakeholders of polder surrounded population. Polder construction was the mega project for coastal area. This polder become changed due to natural and manmade calamity. Once mismanagement and malpractice creates vulnerable ecosystem.

Limitation of Study

This study based on the empirical research and descriptive research which is massive challenges of sustainable output. Community voice have some biasness and intention to hide core message from the truth. Most of the people tried to defenses him/herself and try to establish own opinion. Lack of resource and time it is very much critical to identify the principal of the vulnerable ecosystem. There have the opportunity to further study and action plan to mitigation of ecosystem.

Experimental site analysis

The Bay of Bengal is very much rich in coastal and marine ecosystem such as fisheries, crabs, shrimps etc. On the other hand this area cyclone risk zone during the monsoon period in every year. Moreover world largest mangrove forest are exists in here. This area is very much important for diversified ecosystem. The wetland is main feature in coastal zone, including mudflats and mangroves. The world largest uninterrupted stretch of mangrove ecosystems, the Sunderbans, has been declared World Heritage Site in 1997.

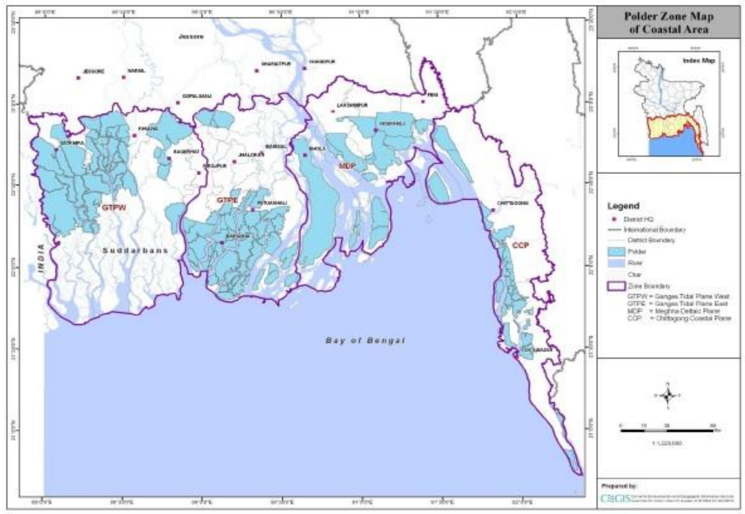

Figure 1 .Source: CEGIS, 2013

Current Maintenance System

The polders are organized into Water Management Groups (WMGs) at village level and Water Management Associations (WMAs) at polder level, with an aim to create effective cooperatives that are in a position to formulate community priorities. Effective operational government agencies

Figure 2

are BWDB, DAE, DoC and LGED. The WMG/WMA's are involved in quality checking of the construction works. The earthworks are carried out by LCS's (Landless Contracting Societies), including women participation. There is different management practice in different level. Union parishad plays a vital role for embankment management. Near about community people and BWDB plays their own management practice. So the management practice of the embankment is a social and organizational both. According to the water management act 1953 embankment is a public property. So, the public authority is strong to protect the any kind of illegal activity on embankment surface. For the good governance the local community and local authority both will be work together for the betterment of the embankment.

Ecosystem of Polder Area

Low dyke construction temporarily for eight months around a year until mid-sixties. On that time grass, weeds and mat-making leaves grew abundantly. Cattle and buffaloes grazed and fish grew naturally. Due to reduction of sweet water flow from upper side like the river Padma, Kopotakho, Tista and Brahmaputra become silted. As a result the saline water getting access easily into the upper stream of Bangladesh. After a long time the ecosystem of these areas are not same as previous century. Due to salinity the ecosystem and livelihood pattern is going to changing gradually. (Bakuluzzaman, 2012) Local paddy of Amon, open fishing and vegetable grow out before the polder system. Local leaseholder constructed dyke to protect flash flood during the monsoon period. Near 1970-1980's the ecosystem were sweet water dependent, too. During the 1972-96 the shrimp started after the polder construction. After 1996 shrimp is the major crop for this area. Huge amount of saline water into the polder for shrimp culture. As a result saline destroy the vegetation into the polder. Slowly domestic animal become reduce from this area. Paddy no longer sustain against shrimp culture due to less profitable sector. Environmentally this area become degraded for saline water.

Figure 3

Problems and Challenges

According to previous discussion the coastal area of Bangladesh are becoming vulnerable through climate changing issues of globalization. Here some visual problems found through different study.

Waterlogging

Waterlogging is problem large parts of coastal, especially in the southwest (Satkhira, Jessore, Khulna and Bagerhat district) and southeast (Noakhali, Feni) coastal zones. This region is characterized by numerous morphologically active tidal river, this is the main drainage network for coastal polder and low lying beels. Since 1960 those areas are restricted for tidal continuation. (Baseline, 2012) Continuous siltation process over the years resulted rise of the river bed level and thereby reduction of conveyance capacity of Peripheral River of the coastal polder significantly leading to large scale of water logging problems inside the polders particularly in the Satkhira, Jessore, Khulna and Bagerhat district. Ecosystem becomes changed due to water logging condition.

Cyclonic storm surges

Bangladesh is the global hotspot for the cyclone storm. Due to global climate change cyclone exposure become causes monsoon period of Bangladesh. During concentration of low pressure amplify the surge in the north part of Bay of Bengal. This is very much challenging for coastal peripheral population.

Salinity intrusion

River water in coastal zone of Bangladesh depends on upper stream fresh water discharge from India which is depending on international water policy. Unethical behavior is influencing salinity intrusion. This is why ecosystem not likes previous century.

Ground water salinity

The shallow groundwater is generally too saline for domestic or irrigation use due either to connate salts or estuarine flooding. However, sufficient flushing of saline water has taken place in isolated pockets to enable a limited domestic use of fresh water in the shallow aquifer. In the deep aquifer the pattern of salinity distribution is more uniform on a regional basis, as is the continuity of the aquifer. The change from potable water to very saline water is sharp and occurs over a relatively short distance (IWM, 2014).

Coastal erosion

This is the natural significance of river characteristics that the delta of the Ganges- Brahmaputra Rivers has not grown significantly toward the sea over last two periods. Changes can be noticed in Sandwip and adjacent islands, in Hatiya Island, in Bhola Island and in the coastline of the Noakhali mainland. Sandwip Island reduced in size in about 200 years. Sandwip channel was nearly isolated from the main distributary network of the rivers in 1764-1793. The Hatiya island elongated and migrated considerably southward during this period. Bhola Island is also elongated north-south (Nuruzzaman, 2015). Due to biggest mangrove forest at Bagerhat, Khulna and Satkhira district comparatively low erosion than South-east part of Bangladesh. Geographically river is changing its nature constantly. Thus the river adjacent embankment become destroy natural changes. On the other hand human behavior responsible for coastal erosion. Unethical cutting and illegal saline water entrance is influencing erosion and ecosystem of that polder.

Gap analysis

There are two types of context work in here. They are external context and internal context. In the global context there are external factor influence through global climate change and its impact. Due to carbon footprint it is less vulnerable for recent time. But in the long run it may turn into vulnerable area. In recent disaster pattern is warning for future vulnerability. On the other hand internal context community people are not aware about impact of destruction of polder. There are clear illustration of coordination gap between external and internal factor. This is the high time to mitigate the vulnerable ecosystem with the conflict management and considering other issues like alternative livelihoods.

Results and Discussion

According to previous discussion and observation it is very much clear about polder history, management system, structure and policy. But there is no doubt that polder enhance the community socio-economic perspective. It is very much essential to mobilize the existing resources to keep it sustainable.

Mitigate Vulnerable Ecosystem

Due to natural siltation rivers are going to sediment through mud, but polder is surrounded by the embankment. As a result mean sea level of river higher than polder surrounded area in some context. In this case TRM (Tidal River Management) in small scale can keep the polder stable. Newly sediment into the polder will enhance fertility in agriculture and vegetation. Moreover people now know about disaster management, embankment and responsibilities of government authorities. This conciseness has been created by the NGOs, who has mobilized community through forming groups and eco-friendly action plan. The local government officials now understand properly about the community demands and feel more accountable to have a sustainable embankment. The Embankment and Drainage Act 1952 ensures the protection of lands from floods, erosion or other damage by water constructing and repairing embankment, but it has developed gaps over the years and decreasing the ecosystem slowly.

Debate through polder

Indigenous flexible water system occurred during the pre-1960s. Structural engineering and mega projects implemented without participation at 1960s. Next steps were small scale projects and pro-poor targeting at 1970s-80s. Without participation the polder management is not maintaining properly. This is why participation as a tool to tackle deferred maintenance. After 40 years later, formalization and standardization of participatory water management for the better practice. But yet the polder became turn into terrifying for the local community. Muscle man take empower to maintain the polder fluently. Unethical water consumption enhance the conflict and life risk. On the other hand polder change the cropping patterns to 1 to 2/3 crops. It increased productivity, more food security and protect population migration. But the tidal surge, inland siltation, water logging and reduction of water flow are the worry about polder.

Major Highlighted Issues

- Proper management of water resources including river flow & implementation of National Water Management Plan
- Enhancing coastal defense system
- Community-based disaster risk reduction
- Increased risks to human health and nutrition
- Safeguarding infrastructure
- Ensuring livelihoods
- Addressing climate induced displacements
- Paradigm shift to wet period crop has been prioritised
- Two dimensional problem for dry season:
- Salinity intrusion
- Lack of efficacy
- Lack of equity
- Lack of sustainability
- Rural inequalities and conflict

Lessen learn

Disaster is the common phenomena for this coastal area and people achieved the copping capacity to survive through alternative livelihood. Different types of NGOs, INGOs and government implementing hundreds of project in this area. There are three things come up to mitigate the vulnerable ecosystem.

1. Ensure participation without biasness and ensure contribution of local people by finance and kind.
2. Empower local government to establish social safety.

3. Fund for polder ecosystem

Thus the polder may effective than the previous period. To make sustainable polder need to maintain some recommendation in here.

- Revise the water policy and master plan with the consideration of ecofriendly.
- Clear understanding of institutional governance system
- Clear roles and responsibility of each actor and factor
- Prioritize environmental issues

Conclusion

The livelihood of the coastal community actually depends on the function of embankment sustainability. Proper management of the coastal polder drainage system is essential to make sustainable development. Different bodies and organizations are working for maintaining the coastal embankment & canals or relative regulators. Due to old drainage design of BWDB, no full repairing works and frequent cyclonic effects are always damaging the coastal embankment which affect the community make them vulnerable in day by day. Various players were involved and united around solutions and finding common demands that include; (i) Construction and repair of sustainable embankment to protect and diversified agricultural production systems and livelihoods (ii) Participation of community people and civil society actors in construction, maintenance, management, removal and control of embankments. Finally, it has to ensure their rights through community participation and build their ownership in the context of polder comprehensive management and ecological health of environment.

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ESTIMATING SOIL HYDRAULIC AND SOLUTE TRANSPORT PARAMETERS IN SUBSURFACE DRAINAGE SYSTEMS USING INVERSE MODELING APPROACH

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Abstract

Due to the time and spatial limitations of subsurface drainage pilots, simulation models have been extensively applied for evaluating such systems. Simulation models are powerful tools which are used for the describing of the interactions between subsurface drainage systems, crop yield and environmental issues. Since the accuracy of simulation models depends extensively on the accuracy of the model inputs, the aim of this study is to present an inverse modeling approach with a genetic algorithm in estimating soil hydraulic and solute transport parameters in subsurface drainage systems and compares it with in-situ determination of soil properties. Inverse modeling is defined as the process of estimating model inputs by matching a forward model to measured data within an optimization algorithm. In this method, sensitivity analysis has a vital role in allowing a possible reduction in the number of parameters that must be estimated, thereby reducing the computational time required for inverse modeling. In this study, measured data was obtained from Amirkabir and Shaeibie sugarcane plantations which have subsurface drainage systems. Both studied areas are semi-arid regions with fine-texture soils. The available measured data for Amirkabir site was drainage discharge and salinity while water table depth was also available for Shaeibie site. SWAP model was used for simulating the outputs of subsurface drainage systems. This model simulates transient water flow using Richards' equation including the extraction rate by drain discharge in the saturated zone as sink terms. The accuracy of different objective functions which were based on the discrepancies between measured and simulated values of drainage discharge, water table depth and drainage salinity was evaluated in the inverse modeling approach. Sensitivity analysis of the SWAP model in both studied areas showed that *n* shape parameter, lateral hydraulic conductivity (K_h), depth to impermeable layer (D), saturated water content (θ_s), and α shape parameter are the most sensitive parameters in simulating subsurface drainage outputs. Thus, these parameters were selected in order to be determined by the inverse modeling approach. In the Amirkabir study area, minimizing the objective function which is based on drainage

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discharge and salinity is the most appropriate approach which can determine soil hydraulic parameters. By applying an inverse modeling approach, Nash–Sutcliffe efficiency (*NSE*) value for predicting drainage discharge and salinity were 0.63 and 0.79, respectively. In Shaeibie study area, minimizing the objective function which included salinity of drainage water and water table depth and also the objective function, based on the combination of drainage discharge, watertable depth and drainage salinity are influential in obtaining soil hydraulic properties that could simulate the outputs of the drainage systems accurately. By using this objective function in determining soil properties, *NSE* value for predicting drainage discharge, water table depth drainage salinity were 0.83, 0.95 and 0.89, respectively.

KEY WORDS: Indirect methods, Soil properties, Simulation, Drainage, Optimization

Introduction

Subsurface drainage systems are an important water management practice tool for farming throughout the world (Ebrahimian et al., 2011; Negm et al., 2014). Although these systems can improve crop production by removing excess water and controlling soil salinity, they have been considered as one of the major sources of pollution that release agrochemicals from agricultural fields to both surface water and groundwater (Negm et al., 2014). Over the past decades, field experiments have contributed substantially to our knowledge and understanding of drainage design and water management for different soils and climates; however, limitations in predicting long-term effects in addition to the impact on areas beyond the field level and the cost effectiveness of these experiments are their major drawbacks (Haan and Skaggs, 2003). Simulation models are useful tools applied for the overcoming of these limitations, as compared to different strategies, suggest solutions, and predict consequences in the medium to long term with much less cost (van Dam et al., 2008; Skaggs et al., 2012). One such drainage simulation model is SWAP (Kroes et al., 2008). The SWAP model has already been applied and tested for various agricultural water management studies throughout the world and has been proven to produce reliable and accurate results (Xu et al, 2016; van Lier et al., 2015; Droogers et al., 2010; van Dam et al., 2008). It has been observed that the SWAP model can be successfully applied to subsurface drainage studies (Qureshi et al., 2013; Noory et al., 2011; El-Sadeq et al., 2001; Sarwar et al., 2000). Sarwar and Feddes (2000) and Sarwar et al (2000) successfully applied the SWAP model to evaluate drainage design parameters for the Fourth Drainage Project in Pakistan. However, they discovered that laboratory determined soil hydraulic parameters could not adequately represent the field conditions for simulation purposes. Sue et al (2005) reported that the performance of SWAP was satisfactory in the simulation of hydrological processes at field scale, including the responses of the watertable and drainage volume and salinity to irrigation and rainfall inputs in a semi-arid region. Verma et al (2010) evaluated the SWAP model for its capability to simulate crop growth and salinity profile for the cyclic irrigation of saline water in an area with a shallow water table that has a a subsurface drainage system. They concluded that the crops could grown very well under such subsurface drainage conditions; but, in dry rainfall years, salinity build-up might occur. The model simulations of Qureshi et al., (2013) suggested that a subsurface drainage system should be installed in arid areas of Iraq to maintain the groundwater table depth at an optimum level.

Although SWAP is now routinely applied for addressing agricultural water management issues, both in research and managerial applications, the problem of obtaining soil hydraulic properties remains a major challenge (Van Dam et al., 2008). A variety of direct measurement methods exists (Dane and Topp, 2002), but since they require strictly defined experimental set-ups and hydrostatic or steady-state conditions with plain boundary conditions, it makes them very time consuming, and thus unsuitable for applications to larger scales (Durner et al., 2008). This necessitates the development of alternative methods to derive the soil hydraulic properties of the application scale of the model (Vrugt et al., 2008; Ritter et al., 2003). An attractive procedure for obtaining model parameters in recent years has been through inverse modeling. This approach involves obtaining easily measured variables (model outputs), and using this information to estimate a set of unknown model parameters using an optimization algorithm (Simunek and Hopmans, 2002). The type of optimization algorithm (Vrugt, et al., 2008; Wöhling, et al., 2008) as well as the sensitivity of unknown parameters to measured variables (Simunek and van Genuchten, 1996) is an issue of great concern in the field application of inverse problems. Ritter et al (2004) evaluated the applying of three different measured data to determine the soil hydraulic properties of volcanic soil. They showed that taking into account all of the measured data gave the best results; however, the monitoring of water content in combination with either pressure head or bottom flux was sufficient. Samani et al. (2007) used the watertable measurmentdata to inversely determine the saturated hydraulic conductivity and the effective porosity in five different unsteady subsurface drainage analytical models of the Boussinesq equation simultaneously. Their findings show that by applying the inverse problem technique, all the analytical models will show good agreement with the measured data. Shin et al. (2012) stated that in an under layered soil profile, when the subsurface flows are dominated by upward fluxes, the solution to the inverse problem appears to be more elusive. However, when the soil profile is predominantly drained, the soil hydraulic parameters can be fairly estimated well across all soil layers. Excellent reviews on inverse modeling of soil hydraulic properties have been presented in Hopmans and Šimůnek (1999), Hopmans et al., (2002), Vrugt et al., (2008) and Mohanty (2013).

Previous researches have shown that optimized values from local optimization algorithms, such as the LevenbergeMarquardt algorithm and Simplex algorithm depend on the location from which these algorithms arise;terefore, they might not be appropriate for calibrating complex and highly nonlinear problems (Wohling et al., 2008). However, the genetic algorithm (GA) method searches the entire population instead of moving from one point to the next and can, therefore, overcome the limitations of traditional methods (Mohanty, 2013, Sedaghatdoost and Ebrahimian, 2015).

Genetic algorithms have been successfully applied in the past decades for optimizing design and management of irrigation systems for different purposes (Ebrahimian et al., 2013). The objective of this study is to apply an inverse modelling approach with the genetic algorithm to estimate the soil hydraulic and solute transport parameters in two subsurface drainage systems using drainage discharge, watertable depths and drainage salinity data.

Materials and Methods

The inverse modeling approach for estimating soil hydraulics and solute transport properties in subsurface drainage systems was implemented by combining a physically based Soil–Water–Atmosphere–Plant model, SWAP with a GA optimization algorithm. The following sections present these items in detail.

Field Experiment

The data collected from Shoeibiyeh and Amir Kabir subsurface drainage experimental sites (31˚52´56″ N, 48˚40´57″ E and 31˚01´24″ N, 16˚52´52″ E, respectively) , in the Khuzestan province of Iran which are located in arid and semi arid regions. In the Shoebiyeh site, the collected data included drainage discharge, drainage salinity and watertable fluctuations collected from April 14 to November 02 , 2011. In the Amir Kabir site, however, watertable data were not available and drainage discharge and salinity data were collected from April 9 to July 24 of 2008. Both sites generally have heavy soils with poor drainage condition and are cropped with sugarcane. Irrigation water was suppliedvia conventional furrow irrigation methods during the study period. Low application efficiency of the irrigation systems resulted in the rise of the saline water table which necessitates the existence of a subsurface drainage system. The subsurface drainage systems in Shoay biyeh and Amir Kabir sites consist of 845 and 500 m long drain tubes installed at 2.1 and 2.0 m below the soil surface, respectively. Horizontal hydraulic conductivity (K_h) was measured using the auger hole method. The position of the impermeable layer (D) was identified via observation in a deep auger hole. A summary of the subsurface drainage design is available in Table 1.

Table 1. A summary of drainage design parameters in Shoeybiyeh and Amir Kabir study areas

Study area	Drain depth (m)	Drain spacing (m)	Depth to impermeable layer (m)	Hydraulic conductivity (m/d)	Initial depth to watertable (m)	Wet perimeter (m)
Shaeibie	2.1	70.0	6.0	1.2	1.8	0.6
Amir Kabir	2.2	40.0	6.0	1.0	1.9	0.6

In-situ measurements indicated that the soil in the study areas consist of two layers containing high amount of silt and clay. A silty clay loam was placed above a silty clay layer in Shaeibie site whereas a silty clay layer covered a silty clay loam in Amir Kabir site. According to Durner et al. (2008), both studied areas consist of weakly heterogeneous soil which can be expressed as a single-layer soil medium to enhance the efficiency of inverse modeling approach. Thus, we assumed a homogeneous soil profile for both study areas to reduce the number of optimized parameters. A summary of soil parameters was presented in Table 2.

Table 2. Summary of soil hydraulic parameters in Shaeibie and Amir Kabir study areas

Study area	texture	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α (-)	n (-)	λ (-)	K_s (cm d^{-1})
Shaeibie	Silty clay loam	0.010	0.520	0.037	1.101	0.5	24.8
Amir Kabir	Silty clay	0.073	0.388	0.120	1.188	0.5	3.37

Piezometers were installed in the sample fields and across the laterals to monitor depth to watertable. Drainage discharge rate from laterals were measured at the manholes with the help of a bucket and a stopwatch.

SWAP model

SWAP is a one-dimensional, physically based model for water, heat and solute transport in variably saturated soils (Kroes et al., 2008). Richards' equation, including root water extraction and the extraction rate by drainage discharge in the saturated zone (as sink terms) is applied to compute the transient soil water flow (Eq. 1) under specified upper- and lower-boundary conditions:

$$\frac{\partial\theta}{\partial t}=\frac{\partial\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]}{\partial z}-S_a(h)-S_d(h) \qquad (1)$$

where θ is volumetric water content (cm^3 cm^{-3}) , t is time (d), $K(h)$ is hydraulic conductivity (cm d^{-1}), h is soil water pressure head (cm), z is the vertical coordinate (cm), $S_a(h)$ is soil water extraction rate by plant roots (cm^3 cm^{-3} d^{-1}), and $S_d(h)$ is the extraction rate by drainage discharge in the saturated zone (d^{-1}). In SWAP model, crop growth was simulated using three different routines: a simple module, a detailed module and a detailed module for grass (re)growth. The simple module is useful when crop growth doesn't need to be simulated or when detailed crop growth input data were not available so, in this study, the simple module was applied during the simulations. The Mualem-Van Genuchten relations, with a modification near saturation, describe the soil hydraulic functions (Eqs. 2 and 3):

$$\theta = \theta_{res} + (\theta_{sat} - \theta_{res})\left(1 + |ah|^{n}\right)^{-m} \tag{2}$$

$$K = K_{sat} S_e^{\lambda}\left[1 - \left(1 - S_E^{\frac{1}{m}}\right)^{m}\right]^2 \tag{3}$$

where θ_{res} is residual water content (cm^3 cm^{-3}), θ_{sat} is the saturated water content (cm^3 cm^{-3}), α (-), n (-) and m (-) are empirical shape factors, K_{sat} is saturated hydraulic conductivity (cm d^{-1}), S_e is relative saturation, and λ is a shape parameter. The drainage discharge rate is computed with the classical steady-state drainage equations of Hooghoudt and Ernst. The difference in hydraulic properties of the layered soil profile determines whether the Hooghoudt or Ernst equation should be used. The drain discharge rate depends on the simulated groundwater level midway between drains. The general equation used for subsurface drainage is:

$$q_{drain} = \frac{h_{gwl} - h_{drain}}{\gamma_{drain}} \tag{4}$$

Where h_{gwl} is the watertable level midway between drains (cm), h_{drain} is the drainage level (cm) and γ_{drain} is the drainage resistance (d). Applying Ritzema's theory (Ritzema, 1994), SWAP assumed five typical drainage situations. For each of these situations the drainage resistance, γ_{drain}, can be defined. In this study, we applied Hooghoudt equation as we assumed the drain is above impervious layer in a homogenous profile.

$$\gamma_{drain} = \frac{L^2}{8K_s d + 4K_s\left(h_{gwl} - h_{rain}\right)} + \gamma_{entr} \tag{5}$$

Where L is the drain spacing (cm), K_h is lateral hydraulic conductivity (cm d^{-1}), d is the equivalent depth (cm) and γ_{entr} is entrance resistance (d). The convection, dispersion and diffusion are the three main processes of solute transport embedded in the SWAP model. The total solute flux is calculated by SWAP model using Eq.(5), given by:

$$J = qc - \theta\left(D_{dif} + D_{dis}\right)\frac{\partial c}{\partial z} \tag{6}$$

Where J is total solute flux (g cm^{-2} d^{-1}), q is Darcy flux (cm d^{-1}), which is averaged over a certain cross section, c is the solute concentration in soil water (g cm^{-3}), D_{dif} is the diffusion coefficient (cm^2 d^{-1}), D_{dis} is the dispersion coefficient (cm^2 d^{-1}). In this study, the molecular diffusion coefficient was assumed to be negligible.

Sensitivity Analysis

Sensitivity analysis is defined as a process which determines how different values of an independent variable (i.e. model inputs) will impact a particular model output under a given set of assumptions. An important aim of the parameter sensitivity analysis is to allow the possible reduction in the number of parameters that must be estimated, thereby reducing the computational time and effort required for model calibration. Sensitivity coefficients were calculated according to Simunek and van Genuchten (1996), as presented in Eq. 7.

$$s\left(z,t,b_j\right)=0.01b_j\frac{\left|\partial h\left(z,t,b_j\right)\right|}{\partial b_j}\approx 0.01b_j\frac{\left|h\left(b+\Delta be_j\right)-h\left(b\right)\right|}{1.01b_j-b_j}=\left|h\left(b+\Delta be_j\right)-h\left(b\right)\right| \quad (7)$$

Where $s(z,t,b_j)$ is change in the auxiliary variable h (drainage discharge, drainage salinity, and watertable depths) corresponding to a 1% change in parameter b_j, e_j is jth unit vector, and Δb is $0.01b$. To compare the sensitivity values among different parameters, time-averaged coefficients were calculated according to the following expression (Inoue et al., 1998):

$$s\left(z,b_j\right)=\frac{1}{t_{end}-t_0}\int_{t_0}^{t_{end}} s(z,t,b_j)dt \quad (8)$$

The range of variables was obtained from existed soil databases (Table 3). By applying Eqs. 7 and 8, the most sensitive parameters were ranked according to their influence on desired model outputs.

Table 3. Minimum and maximum values of decision variable applied in sensitivity analysis

Input parameters	Symbol	Minimum	Maximum
Soil hydraulic parameters			
Residual water content (cm^3 cm^{-3})	θ_r	0.034	0.120
Saturated water content (cm^3 cm^{-3})	θ_s	0.320	0.950
Empirical shape factor (-)	n	1.090	3.180
Inverse of the air-entry value (cm^{-1})	α	0.005	0.145
Empirical shape factor (-)	λ	0.100	5.0
Saturated hydraulic conductivity (cm d^{-1})	K_s	0.500	700.0
Subsurface drainage parameters			
Depth of impermeable layer (m)	D	2.1	17.0
Lateral hydraulic conductivity (cm d^{-1})	K_h	5.0	1000.0
Drain entry resistance (d)	H_e	1.0	60.0
Solute transport parameters			
Dispersion length (cm)	D_l	5.0	100.0
Freundlich adsorption coefficient (cm^3 mg)	K_f	0.0	100.0
Potential decomposition rate (d^{-1})	μ	0.0	10.0
Relative root solute uptake (-)	K_r	0.0	10.0
Freundlich exponent (-)	N_f	0.0	10.0
Reference solute concentration for adsorption (mg cm^3)	c_{ref}	0.0	1000.0
Factor reduction decomposition due to temperature (C^{-1})	γ_T	0.0	0.5
Minimum water content for μ (cm^3 cm^{-3})	θ_{min}	0.0	0.4
Exponent in reduction decomposition due to dryness (-)	f_{dry}	0.0	2.0

Genetic algorithm (GA)

A genetic algorithm was chosen in the purposed inverse modeling procedure to apply the optimization process due to its remarkable ability in a variety optimization problem (Shin et al., 2012; Ebrahimian et al. 2013). GA includes four major operators including selection, crossover, mutation and elitism. First, an initial population of individuals is generated in a gene pool. Then using the fitness of objective function as a selection criteria, some of the created individuals selected to enter the mating pool while others die. Information of each selected individuals (known as parents) are exchanged through crossover with a specified probability (rate). Mutation reproduces individuals to create the next generation. The best individual in each generation survive during using elitism. This operator makes the genetic algorithm converge more rapidly. Using Carrol (1996) guidelines, crossover, mutation rate, number of generations, and population size were set as 0.5, 0.01, 300, and 200, respectively. The ranges of decision variables, which will optimize through optimization algorithm, were presented in Table 3. The SWAP model was linked to the GA to optimize the decision variables by minimizing seven objective functions. Each decision variables set was optimized through seven objective functions (Eqs. 9-15, Table 4) which minimized the differences between observed and simulated values of drainage discharge, drainage salinity, watertable depths, and the combination of them. As watertable depths were not available in Amir Kabir site, equations 1, 3, and 5 were only applied in the inverse modeling approach in this site. We assumed that all observed data obtain with the same accuracy so the optimization was performed with equal weighting on all the observed data which showed that all data have the same accuracy in the objective functions. In objective functions using combination of observed data with different units, the objective function became dimensionless by dividing the differences between measured and simulated of each variable by its corresponding measured data. The flowchart of the inverse modeling approach is presented in Figure 1.

Table 4. Various objective functions applied in this study

Objective functions*	Equation
$OF1=\sum_{i=1}^{N}(D_{obs}(t_i)-D_{sim}(b,t_i))^2$	(9)
$OF2=\sum_{j=1}^{M}(W_{obs}(t_j)-W_{sim}(b,t_j))^2$	(10)
$OF3=\sum_{k=1}^{O}(S_{obs}(t_k)-S_{sim}(b,t_k))^2$	(11)
$OF4=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2$	(12)
$OF5=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(13)
$OF6=\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(14)
$OF7=\sum_{i=1}^{N}\left(\frac{D_{obs}(t_i)-D_{sim}(b,t_i)}{D_{obs}(t_i)}\right)^2+\sum_{j=1}^{M}\left(\frac{W_{obs}(t_j)-W_{sim}(b,t_j)}{W_{obs}(t_j)}\right)^2+\sum_{k=1}^{O}\left(\frac{S_{obs}(t_k)-S_{sim}(b,t_k)}{S_{obs}(t_k)}\right)^2$	(15)

* D_{obs}, W_{obs} and S_{obs} are observed values of drainage discharge, watertable depth and drainage salinity respectively. D_{sim}, W_{sim} and S_{sim} are their corresponding simulated values, respectively.

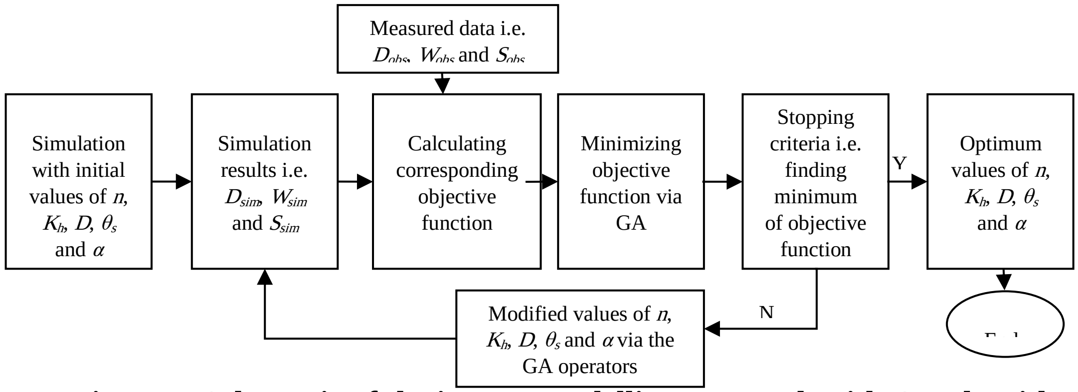

Figure 1. Schematic of the inverse modelling approach with GA algorithm.

Evaluation Criteria

To evaluate the accuracy of the optimized parameters, the performance of the SWAP model was assessed using estimated parameters to simulate drainage discharge, water table depth and drainage salinity. The coefficient of determination (R^2), root of the mean square error (*RMSE*), and Nash–Sutcliffe efficiency (*NSE*) were applied to evaluate the inverse modeling approach. A value of R^2 and *NSE* close to 1 and a small *RMSE* indicate that the simulated values were in a good agreement with the measured values. Skaggs et al. (2012) recommended that NSE>0.40, NSE>0.60 NSE>0.75 could be regarded as acceptable, good, and excellent, respectively, for simulating daily water table depth and drainage discharge.

Results and discussion

Results of time-averaged sensitivity for desired outputs in Shaeibie and Amir Kabir study areas were provided in Table 5. Results showed that van Genuchten shape parameter *n* was, by far, the most influential parameter for all outputs in Shaeibie and Amir Kabir study areas. Parameter *n* is a measure of the pore-size distribution and governs the shape and slope of water retention curve which considered as a sensitive parameter in most vadose zone studies. Lateral hydraulic conductivity (K_h) and depth to impermeable layer (*D*) were second and third sensitive parameters, respectively. K_h governs the ease of water flow from watertable to drain tubes and, previous researches (Skaggs et al., 2012; Wang et al., 2006) indicated that, it was one of the most sensitive parameters in subsurface drainage predictions. The depth of impermeable layer in the soil profile has an important impact on the amount of drainage and the time it takes before the salt accumulation in the drain outflow becomes noticeable; deeper barrier layers result in very long periods before equilibrium is reached (Jury et al., 2003). Moreover, the variability and difficulty of determining field values of depth to the impermeable layer makes calibration desirable when possible and, in some cases, necessary (Skaggs et al., 2012). The parameter θ_s is a capacity parameter that determines the maximum storage of water in a soil, and plays a major role at or near saturation which influences consequently the performance of a drainage system. The soil hydraulic parameter α is the inverse of the air-entry value of a soil, which describes the relationships between water table depth versus volume drained and water table depth versus upward flux. These two parameters ranked fourth and fifth, according to their time-averaged sensitivity values, respectively. Other parameters played a less dominant role and had less sensitivity. It has been noticed that soil hydraulic properties and drainage parameters had much more influence on the drainage salinity in comparison with solute transport parameters. This may arise from the fact that the hydrology part of simulation models, which consists of soil hydraulic properties and drainage parameters, is the main driver of water flow and solute transport (Negm et al. 2014) and consequently had more influence on the outputs models. This result was consistent with the findings of Negm et al. (2014). Based on the results of sensitivity analysis, the five most influential parameters including n, K_h, D, θ_s, and α were chosen to be estimated in both study areas using inverse modeling approach.

Table 5. Time-averaged sensitivity coefficients for soil hydraulic and solute transport parameters in Shaeibie and Amir Kabir study areas*

Outputs	Soil hydraulic and subsurface drainage parameters								
	θ_r	θ_s	α	n	λ	K_s	D	K_h	H_e
Drainage discharge	1.9×10^{-5} 8.9×10^{-5}	1.4×10^{-3} 3.9×10^{-3}	7.5×10^{-4} 4.3×10^{-3}	2.2×10^{-2} 1.6×10^{-2}	6.0×10^{-4} 1.1×10^{-4}	6.4×10^{-4} 8.2×10^{-4}	2.5×10^{-3} 1.9×10^{-4}	2.8×10^{-3} 4.0×10^{-4}	6.4×10^{-4} 4.7×10^{-4}
Watertable depth	5.4×10^{-3} 1.1×10^{-2}	0.31 0.46	0.17 0.55	4.60 1.75	0.10 5.8×10^{-2}	0.13 0.19	0.45 6.5×10^{-2}	0.49 0.11	0.11 6.5×10^{-2}
Drainage salinity	2.5×10^{-3} 1.1×10^{-3}	3.5×10^{-3} 5.7×10^{-2}	2.4×10^{-3} 6.2×10^{-2}	3.8×10^{-2} 0.23	1.6×10^{-3} 3.4×10^{-3}	2.3×10^{-3} 1.3×10^{-2}	4.7×10^{-3} 4.1×10^{-3}	5.2×10^{-3} 7.1×10^{-3}	2.0×10^{-3} 7.8×10^{-3}
	Solute transport parameters								
	D_l	K_f	μ	K_r	N_f	c_{ref}	γ_T	θ_{min}	f_{dry}
Drainage salinity	1.8×10^{-3} 1.5×10^{-5}	1.3×10^{-3} 1.7×10^{-4}	0.0 0.0	0.0 0.0	1.4×10^{-3} 1.8×10^{-5}	2.9×10^{-4} 0.0	0.0 0.0	0.0 0.0	0.0 0.0

* Top and below values are for Shaeibie and Amir Kabir study areas, respectively.

In Shaeibie study area, among all studied objective functions, OF4 and OF7 which are based on two and three different sets of observed data, respectively derived optimum values of parameters that simulated all model outputs precisely. Simunek and van Genuchten (1996), Ritter et al. (2004), Sedaghatdoost and Ebrahimian (2015) were also proved that applying objective function that consists of a combination of datasets determined the unknown parameters suitably. Table 6 showed that parameters obtained by OF4 and OF7 differed substantially with initial values. Generally, in

OF4 and OF7 in the Shaeibie study area, θ_s was estimated lower than initial value while α and n were estimated higher. However, D and K_h parameters were quite similar to the initial values.

Table 6. Soil hydraulic properties estimated by inverse modeling approach using selected objective functions GA in both study areas

Study area	Objective function	θ_s (cm^3 cm^{-3})	α (-)	n (-)	D (cm)	K_h (cm d^{-1})
Shaeibie	OF4	0.363	0.087	1.187	606	156
	OF7	0.377	0.104	1.188	590	174
Amir Kabir	OF5	0.390	0.125	2.417	221	57

Table 7 indicated that *RMSE* values for simulating drainage discharge, watertable depth, and drainage salinity by parameters obtained by optimizing OF4 were 0.16 cm/d, 23.82 cm, and 0.17 mg/cm^2, respectively which proved that the parameters adequately predicted all outputs during study period (Figure 2). Additionally, *NSE* values for outputs were between 0.81 and 0.83 which could be rated as excellent (Skaggs et al. 2012). The results of OF4 demonstrated that the exclusion of drainage salinity in obtaining parameters did not compromise the ability to reproduce model outputs accurately. Since solutes are primarily transported as dissolved components in the water phase (Mishra and Parker, 1989), indeed, the effect of outflow salinity was hidden in the drainage discharge as the majority of salinity is carried with subsurface flow to drainage system.

The unit of RMSE for OF1, OF2, OF6 and OF7 are min, min, l s_1 and mg l_1, respectively.

Table 7. Evaluation criteria of parameters derived by inverse modeling approach using selected objective functions GA in study areas

Study area	Objective function	Drainage discharge			Watertable depth			Drainage salinity		
		R^2	*RMSE* *	*NSE*	R^2	*RMSE*	*NSE*	R^2	*RMSE*	*NSE*
Shaeibie	OF4	0.83	0.16	0.81	0.93	23.82	0.83	0.90	0.17	0.83
	OF7	0.84	0.15	0.83	0.93	12.87	0.95	0.90	0.13	0.89
Amir Kabir	OF5	0.53	0.55	0.63	-	-	-	0.78	14.25	0.79

*The unit of *RMSE* for Drainage discharge, watertable depth, and drainage salinity are cm d^{-1}, cm, and mg cm^2, respectively.

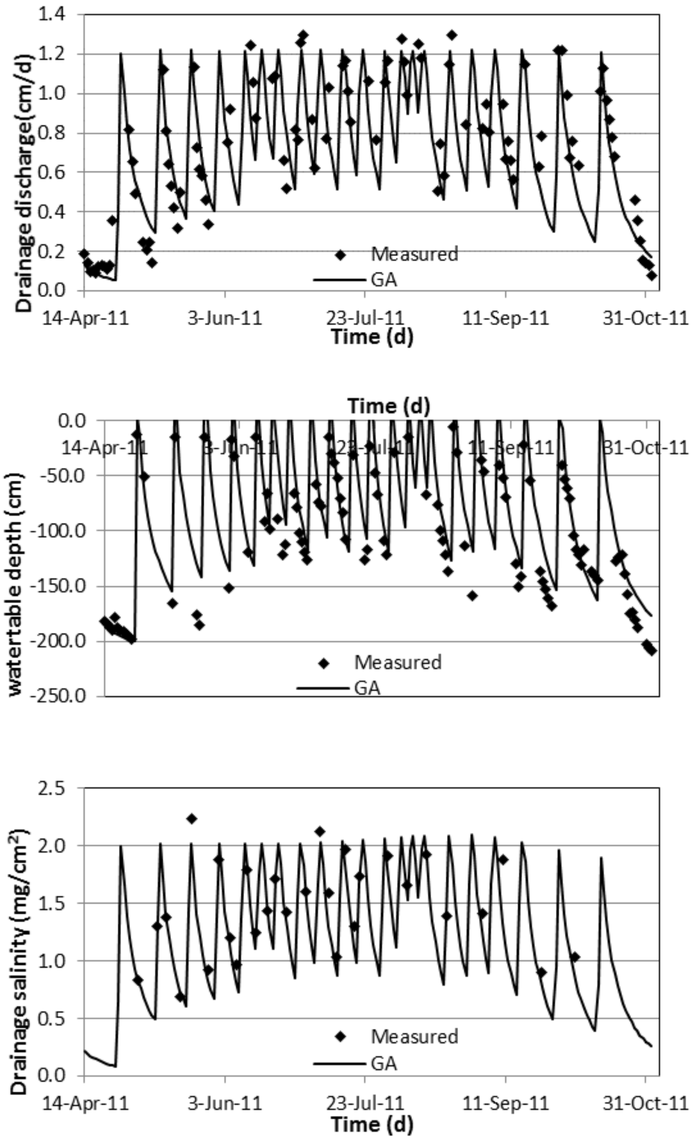

Figure 2. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF4 in Shoeybiyeh **site**

The results of OF7 which are based on minimizing the differences between simulated and measured values of drainage discharge, the watertable depth and drainage salinity indicate that the optimized parameters resulted into the most accurate estimation of all outputs in the Shoeybiyeh study area (Table 7, Figure 3). *NSE* values for drainage discharge, watertable depths, and drainage salinity were 0.83, 0.95, and 0.89, respectively which were rated as excellent based on the figures provided in Skaggs et al. (2012) This was consistent with Ritter et al. (2004), Sedaghatdoost and Ebrahimian (2015) findings which showed that the best parameter sets came from an objective function using all the measured data. Finally, the results proved that although inverse modeling using all measured data gives the best results, monitoring of drainage discharge in combination with watertable depth proves to be sufficient.

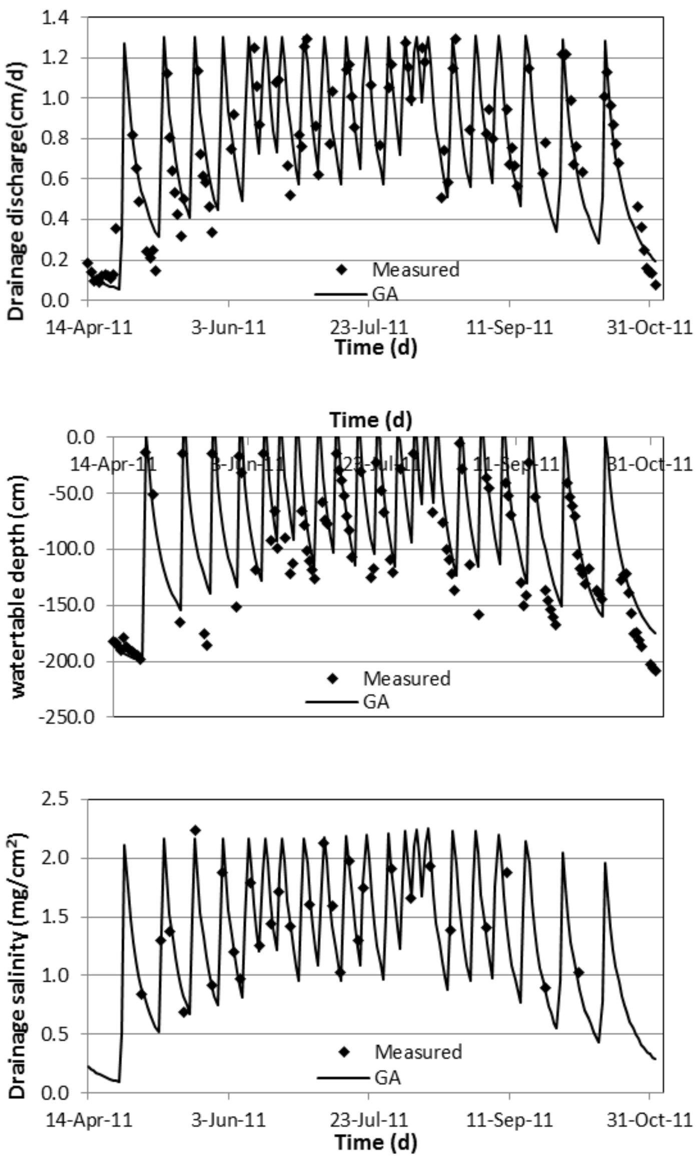

Figure 3. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF7 in the Shoeybiyeh **site**

In the Amir Kabir study area, OF5 which is based on minimizing the differences between simulated and measured values of drainage discharge and drainage salinity estimated parameters resulted into the best estimation of all outputs. In this objective function, θ_s, α and n were estimated as being higher than initial values whereas D and K_h were significantly lower than initial values. In the Amir Kabir site, NSE values for drainage discharge and drainage salinity were 0.63 and 0.79, respectively which were rated as good and excellent, respectively, as perto Skaggs et al., (2012) recommendation. As seen in Table 7, the accuracy of simulations was better in Shoeybiyeh as compared to the Amir Kabir site. This may arise from the fact that objective functions were not included watertable data in the Amir Kabir site. According to Table 5, watertable predictions were highly sensitive to soil hydraulic parameters; hence, they provided watertable data as objective functions which helped the inverse modeling approach to find soil properties more precisely.

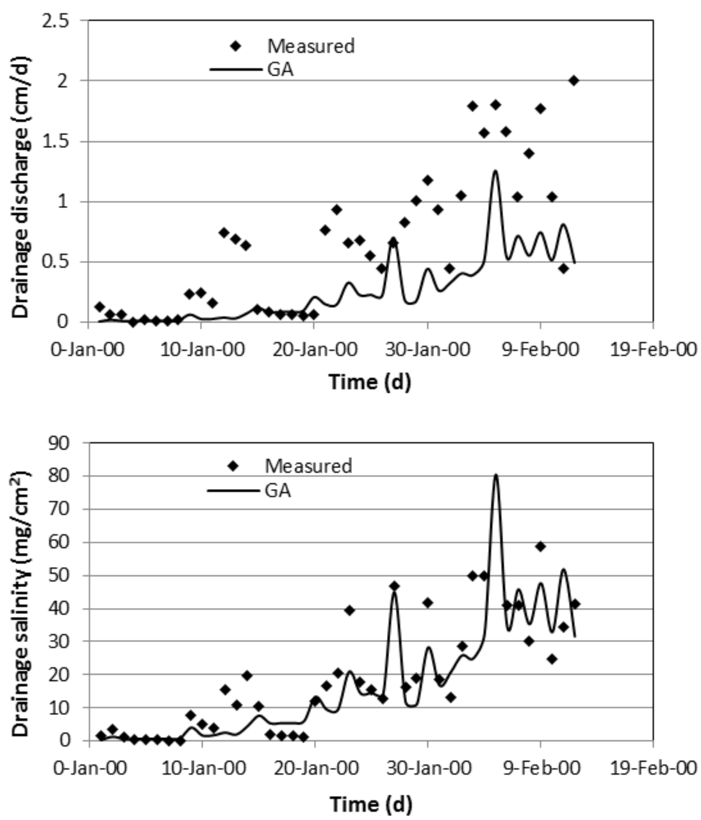

Figure 5. Simulation of drainage outputs via parameters derived by inverse modeling approach using OF5 in Amir Kabir site

Conclusion

In this study, an inverse modelling approach with GA algorithm was introduced to estimate the soil hydraulic parameters in two subsurface drainage systems located in the Khuzestan province, Iran. This approach combined drainage discharge, watertable depth data and drainage salinity data with seven objective functions to identify the optimal values of these coefficients by minimizing differences between simulations of the SWAP model and measured data. The result of the sensitivity analysis showed that the most sensitive parameters were n, K_h, D, θ_s and α in both study areas. In the Shoeybiyeh site, both OF4 and OF7 could precisely find soil parameters and were thus able to simulate all outputs perfectly. However, from a practical point of view, one prefers to use OF4 since it applies less measured data. In the Amir Kabir site, the OF5 algorithm which used drainage discharge and salinity had the best performance, but, the accuracy of model predictions at the Amir Kabir site was less than Shoeybiyeh since it did not have any watertable data. To sum up, in this study, the inverse modelling approach utilizing a GA algorithm has been identified as a robust tool to estimate soil hydraulic parameters that are very important when designing, evaluating and simulating subsurface drainage systems.

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THE IMPACT OF REDUCING SUB DRAIN DEPTH ON ESTIMATED DRAINAGE COEFFICIENT AND SALINITY OF DRAINAGE WATER

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Abstract

The drainage coefficient is a determinative criterion in subdrain network design. Over estimation of this coefficient results in congested subdrain network and costly design. On the other hand, underestimation of it may cause a rise in the water table in the root development zone, limiting uptake of appropriate combination of water, air and nutrients by the roots and the reducing of soil workability conditions for agricultural practices. Therefore optimizing the drainage coefficient is done with the objective of preparing the most economical and efficient applicable method, which in addition to keeping the water table at an appropriate maximum level to provide better conditions for the aeration of plant roots, while salinity remains at its highest desirable level in the soil profile, without any salinity build up and plant yield reduction.

Based on the obtained calculations, drain spacing is inversely proportional to the square root of the drainage coefficient. Recently Jahad-e-Nasr Institute, the implementing agency for land reclamation projects in the Khuzestan & Ilam provinces is implementing the sub drain network in an area of 550, 000 hectares. In the above said provinces. The drain spacing is determined on the basis of recommended cropping patterns and the calculated drainage coefficients.. In contrary with to the designed specifications, the implementing agency has made some changes in the network, ,of which the most important one is the reduction of the depth of lateral installation from an average of 1.5 – 1.7 to 1.3- 1.5 meters. Based on the calculations, as the result of these changes the drain spacing must be reduced by 20%, But, the changes for drain spacing have not taken into account during execution works for installing subdrains.

In this research in order to assess the impact of reducing subdrain depths on the calculated drainage coefficient and drainage water salinity loads, two implemented subdrain network laterals in the Mianab-e-shushtar and Shoeibieh plains with areas of 14000 and 10000 respectively were selected. In order to measure the drainage coefficient and compare it with the calculated drainage coefficient, some parts of the above mentioned plains were selected. In addition, by measuring the water level between the sub drains, the role of drainage for reducing ground water table was evaluated. The findings of the research are as follows:

1- the rise of water table exceeds the allowable design 2- the outflow of laterals were reduced 3- electrical conductivity decreased 4- the final water table dropped from one meter to 89 cm 5- a few days after irrigation the electrical conductivity of drain outflow experienced a reduced trend, yet that of ground water and open collectors showed an increasing trend. 6- Glover-dumm

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performance index was calculated as 0.035 7- salt outlet index (SEI) was negative and 8- the amount of salt entering the environment decreased.

KEY WORDS: drainage coefficient, Glover-dumm, salt outlet index, sub drain depth

Introduction

The drainage coefficient is defined as the amount of discharge of ground water, arising from losses due to deep percolation of irrigation water, rainfall, losses from canals and seepage from nearby areas, which should be drained from plant root zone within a specified time. The Subsurface drainage coefficient is used for determining the spacing and capacity of subsurface drains. In order to precisely determine the subsurface drainage coefficient in any region, the identifying of thesources of deep percolation is of prime importance. Due to the slightness rainfall in arid and semi-arid regions, losses and deep percolations from irrigation water are the most important factors contributing to the recharge of ground water.

In most parts of the Khuzestan province, due to the scarcity of rainfall , the irrigation requirements of various plants with different cropping patterns is supplied from irrigation. Therefore, the main factor in determining the drainage coefficient in the region is considered to be deep percolation from the application of irrigation water.

In a study conducted by Safwat and others,(1998), the North Eastern regions of the Nile Delta were assessed. They concluded that the amounts of real drainage coefficient and the depths of the impermeable layer exceeds the estimated amount obtained in the design.

In a research conducted by Mansoori(2005), for assessing the performance of the drainage system in the regions where sugar cane development is taking place in the Khuzestan province, he concluded that by reducing the depth of the sub surface drains,the volume of drainage water will be reduced and as a result environmental impacts on the downstream side can be mitigated.

In other study, Mansoori, (2005) in assessing parameters for designing drainage system in sugar cane development plantations has shown that drains perform exceedingly well in controlling water level depth.

Naseri and Arvahi, (2009), assessed the performance of subsurface drainage at a pilot palm date farm in the Abadan area, using 4 different envelopes including locally available sands, standard sand cover, and poly propylene synthetic cover (PP700 and PP 450). They indicated that by implementing a subsurface drainage system using propylene synthetic covers with a 450 index in addition to using standard sand cover, results into the desirable performance for the controlling of the water level and salinity. In addition, subsurface drainage with drains at a depth of less than 1.5 meters, using synthetic filters of PP450, have been shown to provide good performance and to produce less drainage water.

In other study conducted by Feser et al. (2010), in Minnesota ica, on a field with loamy soil, a comparison was made between two subsurface drainage systems, one with controlled drainage ,and the other with free conventional drainage systems, where the amount of drainage discharge the amount of nitrogen and phosphate was compared and measured. The study concluded that the amount of discharge and the annual volume of outflow of nitrogen and phosphate in the controlled drainage system when compared to an uncontrolled system was significantly reduced.

Materials and methods

The Khuzestan province with an area of 64000 km^2 is situated in the South west of Iran. Due to the abundance of water resources and fertile agricultural soil it is considered to be potential major agricultural zone in the country .Nevertheless, due to high water table and salinity, crops grown in the area, experiences low yields as compared to potential yields. Therefore, for improving crop yield and production of different crops grown in the area, it is vital to implement subsurface drainage projects and assess the performance of existing subsurface drainage systems and better utilization of these systems in areas prone to and encountered with salinity built up and rising water table.

During recent years, the Jihad-e-Nasr, as the implementing agency for rehabilitation of 550000 hectars of land in Khuzestan and Illam provinces, has started to construct subsurface drainage networks. For construction of drainage system the drain spacing is determined based on recommended cropping pattern and the calculated drainage coefficient. In contrary with the designed specification, the implementing agency has made some changes in the network, inter alia, the most important one is reduction of the depth of laterals installation, from average 1.5 – 1.7 to 1.3- 1.5 meters. Based on the calculations, drain spacing is inversely proportional to the square root of drainage coefficient. Nevertheless, no change was made for subsurface drain spacing during the installation of drains.

In this research for assessing the impact of reducing the subdrain depth on calculated drainage coefficient and drainage water salinity loads. Two implemented subsurface drainage network laterals in Mianab-e-shushtar and shoeibieh plains with areas of 14000 and 10000 respectively were selected. In order to measure the drainage coefficient and compare it with the calculated drainage coefficient, some parts of the above mentioned plains were selected. In addition, by measuring the water level between the sub drains, the role of drainage for reducing ground water table was evaluated. For this purpose, from Mian Ab Shushtar two farm, with subdrain spacing of 35 and 70 meters and two farms in east of Shoeibieh with subdrain spacing of 50 and 95 meters were selected. The soil texture in these lands are loamy clay or silty clay loam and were under cultivation of wheat. Drainage system in the above said farms were equipped with perforated PVC carrugated pipes and synthetic cover of PP450 type of 100mm diameter. Drains outflow was measures from early November 2015 to 4 February 2016. During this period all farms were irrigated 4 times. Measurement of drains outflow was carried out from the beginning of flow in the drain till the end of flow, on daily basis and two times (morning and afternoon) per day. The specification of the farms is given in the table1:

Table 1. Farms specifications

Plain	Area (ha)	Farm name	Lateral Spacing (m)	Lateral length(m)	Slope	Crop
Mianab	14000	Farm 1	35	400	0.001	Wheat
		Farm 2	70	325	0.001	Wheat
Shoeibieh	10000	Farm 3	50	200	0.001	Wheat
		Farm 4	95	275	0.001	Wheat

The hydraulic head between laterals in farm1 in the Mian e-Ab-e –Shushtar was measured during the irrigation period. In addition, the electrical conductivity of the ground water in farm 1 was also measured. The EC of the outflow from the subsurface lateral and the outflow of the open collectors in all farms were measured. The design of the subsurface drainage in the above mentioned farms was based on the drainage coefficient of 3 mm/day with the depth of installation at 1.5 m and a 1 m water table depth.

Results and discussion

Drainage coefficient:

Tables 2 through 5 illustrate the results of measuring the drainage coefficient in the 4 envisaged farms with different lateral spacing, carried out over 4 irrigation periods, from early November 2015 to 4 February 2016. Figures 1 to 4 indicates a decreasing trend of drainage intensity during the period after irrigation. As shown, in all four farms the amount of measured drainage coefficient is less that of the designed one.

Table 2. Measured Drainage coefficient in Farm 1 (mm/Day)

Day / Irr.No	1	2	3	4	5	6	7	8
1	4.145	3.275	2.222	1.918	1.261	0.936	0.317	0.228
2	4.606	4.146	2.547	2.192	1.540	1.019	0.349	0.256
3	3.951	3.692	2.772	1.886	1.235	0.935	0.309	0.216
4	3.800	3.065	2.006	1.756	1.188	0.957	0.198	0.046

Table 3. Measured Drainage coefficient in Farm 2 (mm/Day)

Day / Irr.No	1	2	3	4	5	6	7	8	9
1	3.057	2.570	2.222	1.902	1.704	1.401	0.541	0.430	0.276
2	3.735	3.272	2.926	2.374	2.099	1.837	0.932	0.417	0.108
3	3.025	2.624	2.340	2.056	1.769	1.485	0.580	0.185	0.000
4	3.781	3.192	2.466	2.028	1.614	1.130	0.790	0.253	0.059

Table 4. Measured Drainage coefficient in Farm 3 (mm/Day)

Day / Irr.No	1	2	3	4	5	6	7	8	9
1	3.293	2.599	0.915	0.540	0.395	0.292	0.257	0.232	0.232
2	4.414	3.494	1.142	0.685	0.624	0.549	0.444	0.414	0.278
3	3.679	3.649	2.698	1.296	1.080	0.667	0.191	0.093	0.000
4	3.105	2.976	2.476	1.346	0.969	0.580	0.198	0.136	0.056

Table 5. Measured Drainage coefficient in Farm 4 (mm/Day)

Day / Irr.No	1	2	3	4	5	6	7
1	2.822	1.796	0.599	0.525	0.429	0.380	0.321
2	4.661	4.309	3.161	2.167	1.210	0.605	0.241
3	2.741	2.797	2.395	1.951	1.278	0.673	0.136
4	3.482	3.260	2.945	1.352	0.747	0.284	0.086

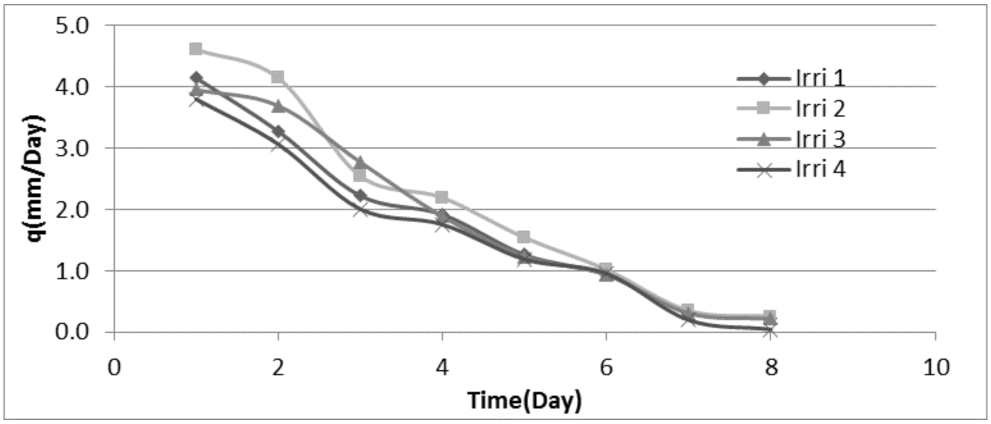


Figure1. Drainage coefficient in Farm 1

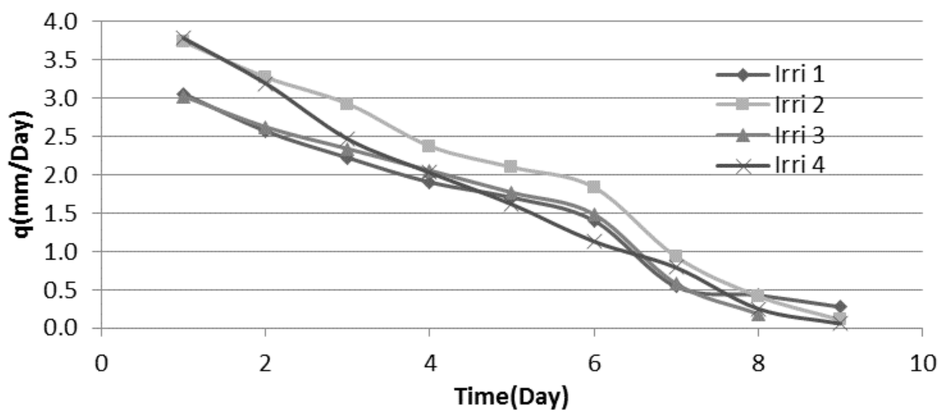


Figure2. Drainage coefficient in Farm 2

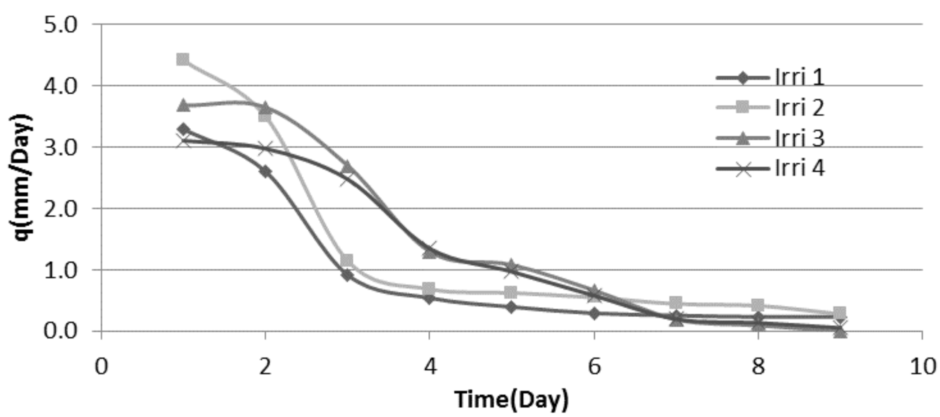


Figure3. Drainage coefficient in Farm 3

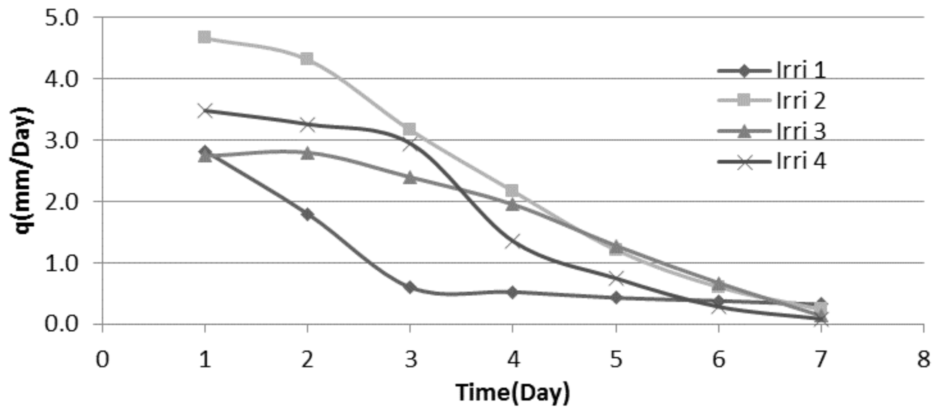


Figure4. Drainage coefficient in Farm 4

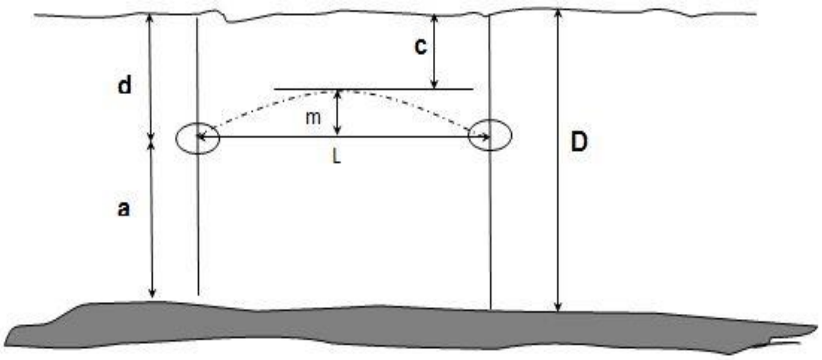
Hydraulic head

The fluctuation of water table in farm 1, in Mian Ab, during the test was recorded. Table 6 illustrates the results of the water table fluctuations. Moreover, fig.5 reveals that during the early days after irrigation, the water table remains at its highest level and gradually decreases and finally stands at depths of 89 cm from ground level.

In spite of assuming that the design for the spacing and depth of the drain are based on a "Dynamic Balance"method and the tolerance of the fluctuation of the water table is considered as being 5 cm. The results indicate that the magnitude of the observed fluctuation is 46 cm which is more than the design allowance.

Table 6. Measured Hydraulic head in Farm 1 (m)

Day / Head	1	2	3	4	5	6	7	8
m	0.850	0.760	0.690	0.620	0.580	0.530	0.450	0.390



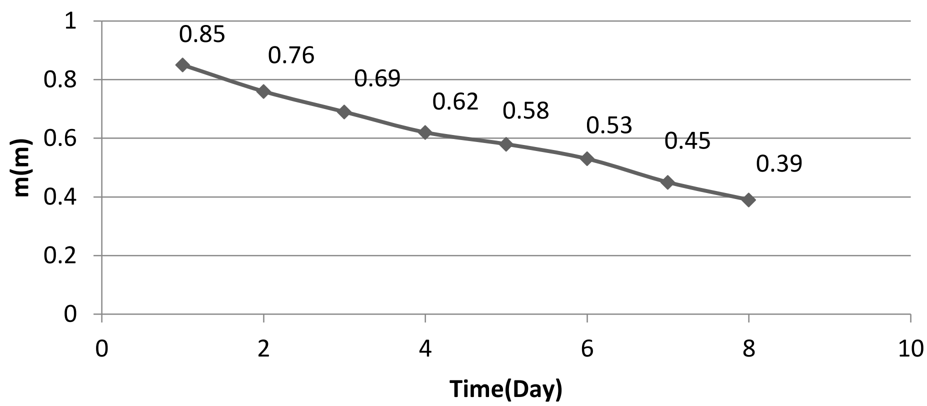


Fig.5. Fluctuation of water table in farm 1

Electrical conductivity

Tables 7 to 10 show the results of the measured EC of outflow from the laterals and open collectors in each farm and the EC of ground water in farm 1. The results reveal that the EC of the outflow in the laterals during the early days was at its highest level and gradually decreased; however, it was observed that this event occurred inversely in open collectors and ground water. In fact, observations show that in the early days the EC density from the outflow was low and after cutting off irrigation water, the EC density gradually showed an increasing trend.

Table 7. EC (ds/m) Measured in Farm 1

Day / Outlet	1	2	3	4	5	6	7	8
Lateral	**22.00**	**20.90**	**17.60**	**15.20**	**11.90**	**11.40**	**11.02**	**10.58**
Collector	**2.88**	**3.10**	**3.41**	**3.92**	**4.52**	**4.54**	**4.87**	**5.60**
Ground water	**2.90**	**3.41**	**3.92**	**4.57**	**5.32**	**6.50**	**7.90**	**8.50**

Table 8. EC (ds/m) Measured in Farm 2

Day / Outlet	1	2	3	4	5	6	7	8	9
Lateral	21.6	19.07	17.1	16	15.99	14.92	10.54	10.41	10.4
Collector	5.2	4	4.65	4.2	5.02	6.58	4.3	4.2	4.12

Table 9. EC (ds/m) Measured in Farm 3

Day / Outlet	1	2	3	4	5	6	7	8	9
Lateral	15.3	17.1	19.4	16.44	12.94	11.6	11.97	11.01	10.33
Collector	3.6	3.8	4.6	4.65	4.65	5.5	5.5	8.55	7.42

Table 10. EC (ds/m) Measured in Farm 4

Day / Outlet	1	2	3	4	5	6	7
Lateral	16.04	16.14	12	14	10	10.62	10.32
Collector	3.55	3.85	5.52	4.81	4.76	4.25	4.87

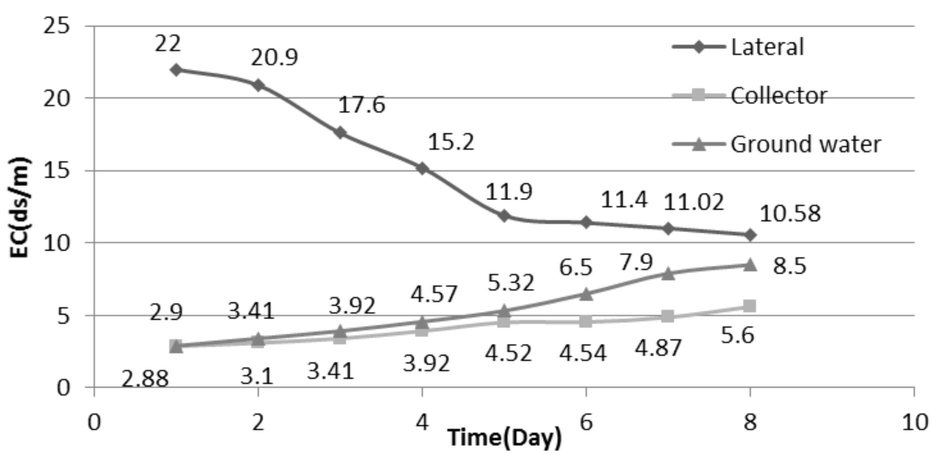


Fig.6. Electrical conductivity in farm 1

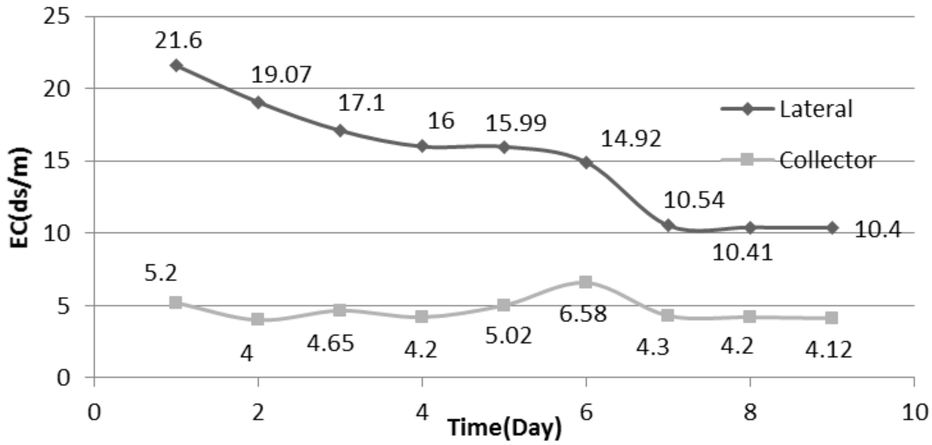


Fig.7. Electrical conductivity in farm **2**

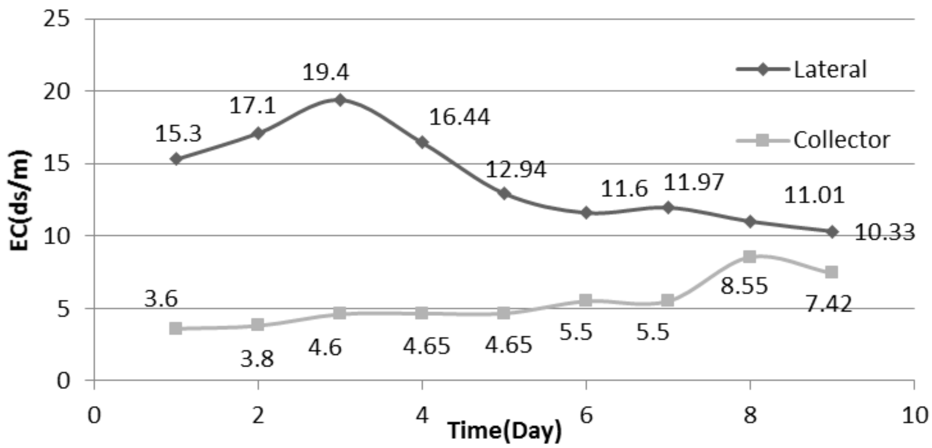


Fig.8. Electrical conductivity in farm 3

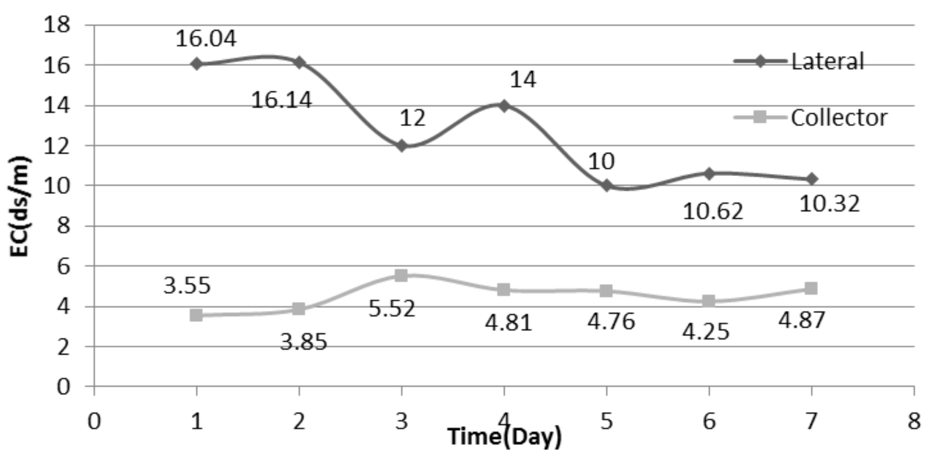


Fig.9. Electrical conductivity in farm 4

Salt outlet index (SEI)

$$\text{SEI} = \frac{inflow\ salt - outflow\ salt}{inflow\ salt} \quad (1)$$

SEI is a dimensionless index which is either negative or equal to zero, meaning that outlet salt is more than inflow salt. Considering the fact that the source of irrigation water in the area under the study is the Karunriver and the EC of the river in the vicinity of the study is less than 2 ds/m, therefore, based on the results of this research, the SEI for the area under consideration is always negative, which in itself is an indication of the suitable performance of subsurface drains in removing salt from the soil profile in the root zone.

The Glover - Dumm reaction coefficient

$$\alpha = 2.3 \left[\frac{\log(h2) - \log(h1)}{t2 - t1}\right] \quad (2)$$

Considering the data on fluctuation of the water table in farm 1, the decline of the water table is shown in fig.5

Where

α = Glover- Damm reaction coefficient

h_1 and h_2= hydraulic head at t_1 and t_2 in m

The amount of reaction coefficient for farm 1 was determined as 0.035. This is an index, indicating changes in drainage intensity due to recharging and in areas with low reaction; this coefficient varies from 0.20 to 0.30.

The results obtained from farm 1 reveals that the farm has low transmissibility and high drainage porosity.

Conclusion and Recommendation

With due regards to the reduction of the lateral depth installation, without any change to the lateral spacing , in addition to the results of the measurements carried out, the following observations were made:

- The water table rise is more than the design's permissible level
- As a result of the reduction in the depth of installation, the drainage coefficient is reduced

- The designed water table depth was considered as being 1m, while in practice it remained at 89 cm
- The electrical conductivity of laterals showed a decreasing trend over time, but the electrical conductivity of the collector outlet and ground water experienced a decreasing trend
- The reduction of the depth of drain installation, resulted into a reduced drainage coefficient which consequently mitigated the load of salt content and pollutants
- In terms of implimentation, installing laterals at lower depths is more convenient
- In the study, crop yield was not taken into consideration, it is recommended that in future studies crop yield measurement be considered and both cases (ie., different depths of lateral installation) be compared.

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EGYPTIAN EXPERIENCE IN AGRICULTURAL DRAINAGE IN MORE THAN 40 YEARS AND FUTURE NEEDS

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Abstract

In arid countries such as Egypt, irrigation and drainage are essential factors for the sustainability of agricultural production. The need for drainage of agricultural lands in the Nile Valley and the Egyptian Delta was realized once the conversion to the perennial cropping system occured.

Among developing countries, Egypt is considered as a country with subsurface drainage systems extending over large areas th. At the time strategic vision and governmental planning were behind the decision to launch a program to develop drainage infrastructures to cover all the irrigated lands (then about 6 million acres).

The implementation of a phased program starting in 1970 and continuing to cover more than 5.8 million acres up to the present time has been carried out consecutively. The implementation of such a large scale program imposed huge financial, institutional and technical challenges. It also involved significant operational challenges including the necessary implementation capacity and the need to complete the construction in cropped fields without interruption the growing season, mainly for social and economical reasons. Experience has shown that drainage has many effects and multiple impacts that go beyond the sole objective of agricultural productivity.

More than four decades have passed since the government of Egypt initiated its present program to develop effective drainage systems to cover almost all the agricultural land. Nowadays Egypt is facing great challenges such as water shortage, drought, water quality deterioration, climate change and its unexpected impacts, all of which are threatening the sustainability of the irrigated crops. This paper identifies and synthesizes the Egyptian experience in the field of agricultural drainage and the future need to cope with global challenges.

KEY WORDS: Subsurface drainage, Drainage materials, Controlled drainage, Drainage design criteria, Drainage technology, Future Vision and Developments in Drainage

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Introduction

The total area of Egypt is 1.001,450 km^2, the majority of which is desert lands representing 96%. The present population of Egypt is strongly concentrated in the Nile Valley and the Delta. 97% of the population lives on 4% of land of Egypt. Egypt's climate is hot, dry, desert and is getting warmer. During the winter season (December– February), Lower Egypt's climate is mild with some rain, primarily over the coastal areas, while Upper Egypt's climate is practically rainless with warm sunny days and cool nights. During the summer season (June-August), the climate is hot and dry all over Egypt.

The growing population of Egypt and related industrial and agricultural activities has increased the demand for water and land to a level that reaches the limits of the available supply. The population of Egypt has been growing in the last 50 years from 19 million in year 1947 to about 91 million in the year 2016. The annual increase is about 1.8 million and it is expected to be about 105 million by the year 2025.

Food security of a fast growing population in Egypt required measures to intensify crop production within the already irrigated area. The construction of the High Aswan Dam (HAD) allowed year round irrigation in the Nile Delta and Valley. This put the limited fertile land at risk of water logging and salinity. To relieve the pressure on the Nile Valley and Delta the government has embarked on an ambitious programme to increase the inhabited area by means of horizontal and vertical expansion projects in agriculture and the creation of new industrial areas and cities in the desert. All these developments require water and reclamation of both old and new lands

In Egypt there is a long history of irrigation. During last decades there has been a development in irrigation in conjunction with the construction of reservoirs. Aside from huge benefits of the irrigation projects they have also resulted in water logging and salinization. Therefore drainage systems are required at a large scale to enable irrigated agriculture on a sustainable basis.

Provision of effective drainage systems was an obvious mitigation measure included in the early planning of the HAD construction in the early sixties. A strategic vision and political decision were behind the decision to launch a program that covers all the irrigated lands (about 6 million acres at that time) with drainage infrastructure. The implementation of a phased program started in 1970 and continued to cover more than 5 million acres at present. Implementation of such large scale program imposed huge financial, institutional and technical challenges. It also involved significant operational challenges including the necessary implementation capacity and the need to complete the construction in cropped fields without interruption the growing season mainly for social and economic reasons.

Drainage benefits went beyond the direct objective of increasing agricultural productivity to improving health conditions, protecting built-up structure and archeological sights against rising water tables, and improving sanitation conditions in the rural areas. The impact of the drainage program is felt at local, regional, and national levels. Experience has shown that drainage has many effects and multiple impacts that go beyond the sole objective of agricultural productivity. The effects and impacts extend beyond the borders of the project to the whole drainage basin. Many stakeholders other than farmers share the benefits and may pay the cost of drainage inventions.

This paper identifies and synthesizes the Egyptian experience in the field of agricultural drainage and future needs to cope with great challenges

Development of Land Drainage in Egypt

Planning of drainage system

Planning of drainage projects is done according to a 5-years planning cycle. For each 5-year plan a number of main catchment areas of drainage pumping stations are earmarked for subsurface drainage implementation. A prerequisite for implementation is that the drainage pumping station is operational and that the network of main open drains is upgraded to cope with the increased drainage discharge from the drainage project areas.

A sub-surface drainage system is required, when the following drainage conditions exist:

- Water table depth is less than 1 meter below ground level in more than 10% of the surveyed area;
- Soil salinity of the saturation extract, expressed in ECe is more than 4 dS/m (mmhos/cm) in more than 10% of the surveyed area;
- A decline in crop yield of more than 20% as a result of poor drainage is reported in the considered area.

Pre-drainage investigations are made in sub-catchment areas of about 5000 to 7000 acres (2000 – 2800 ha) each and the need for drainage installation is assessed according to the above mentioned criteria. After the areas are selected for drainage implementation, the detailed design is made and tender documents are prepared.

The actual construction is done by contractors, who are supervised by Egyptian Pulic Authority for Drainage Projects (EPADP) staff of one of the five Regional Directorates of Drainage Projects. The total target of the surface drainage is 7.2 million acres, 4.9 million acres in the Nile Delta and 2.3 million acres in Upper Egypt.

Automation of the design of drainage projects

Automation of the design of drainage system becomes an important process for many reasons, mainly to reduce the manual computations and errors related to the design of the drainage system. Steps were taken to improve the quality of maps for the drainage design. Also the storage and retrieval of data were improved and the further improvement of quality of maps, by using digital basic maps and up grading drawing technique.

Introduction of (GIS)

The introduction of GIS causes a number of changes in the way the automation is organized. The main task of a GIS is the production of maps, delineating the design of a drainage network, which includes providing assistance in the design and computation of the drainage design parameters. The software was developed for drainage design into what is called "Drain GIS". The set up of the main menu of Drain-GIS follows the step of the manual design process. The Drain GIS programme is the Core program of the design activities. It combine the computation of the longitudinal profiles with the drawings of the layout of a drainage system in an Arcinfo-GIS .

Rehabilitation of subsurface drainage systems

EPADP started to develop criteria to assess the need and priority for rehabilitation of drainage systems. Initially, EPADP would renew those systems, whose economic life time was exceeded more than 30 years and which were performing very poorly. Farmer complaints and difficulties of maintenance are important factors in deciding on the need for renewal.

Subsurface Drainage construction

The implementation of subsurface drainage consists of installation of covered collector pipes and the installation of buried lateral drains of corrugated PVC pipes with envelopes. The total area to be provided with subsurface drainage is 7.2 million acres. Some 4.6 million acres of this area is in the Nile Delta and the rest 1.8 million acres in Upper Egypt and the total executed area up till 31/12/2016 is 5.9 million acres**.**

Materials and machines used in drainage construction

At the beginning of the 1970's, important development have taken place in the use of : drainage materials, drain envelopes, and installation techniques (grade control equipment, drainage machinery).

Drain materials

Lateral pipes were first made of 10-cm diameter clay pipes (30-cm long), replaced in 1963 by concrete pipes (10-cm and 50-cm long), and in 1979 by plastic PVC pipes (ID 72 mm) were introduced and took over. PE lateral pipes (ID 75 mm) were later introduced. Laying the plastic corrugated pipe (rolls) improved both speed of installation and quality control. PE/PVC collectors were introduced in 1985. Since 1998 all new collector systems are to be constructed with PVC or HPPE pipes, which is suitable for installation in the unstable soils (sandy with upward seepage) in the reclaimed areas and on the fringes of the old lands. With the shift from concrete to plastic pipes, the connecting pieces between laterals and collectors also changed.

Connection between lateral and collector drain

The type of connections has changed with the introduction of the corrugated PVC/PE pipes. An improved connection was introduced in 1980's with the use of a plastic T-joint (figure 1).

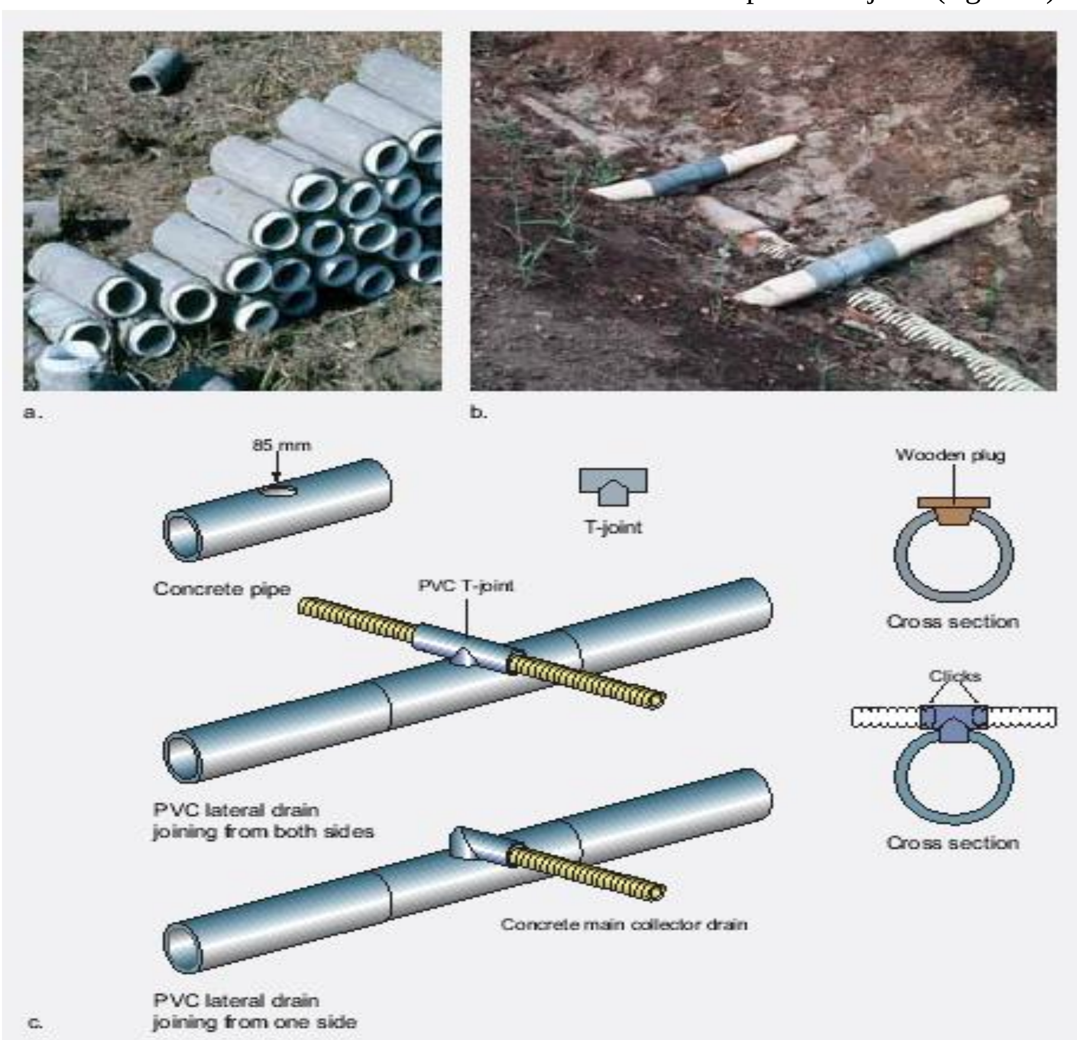

Figure 1. Connections between (a) field drains and (b) collector drains

Manholes

Manholes are constructed along the collector lines at a maximum distance of 180m so far, only manholes of plain concrete with diameter of 75 to 100cm have been installed on large scale.

Manholes were originally cast in situ; later, prefabricated elements were used. Plastic manholes are also being experimented with (much lighter in weight and quicker installation but expensive).

Installation techniques

Since the late seventies, all drainage construction is done by lateral-laying machines and collector laying machines. Hydraulic excavators are used for the installation of very large diameter collector pipes. Since 1997, a trenchless lateral laying machine had been engaged in construction of laterals in silty soils and quick Sand area soils in the North-west Delta. Before 1988, the leveling and grade control was done manually, using standard survey instruments and simple sights. The use of laser-guided grade control was 1992 mandatory equipment on every lateral and collector laying machines. Different drainage machines(figures 2-a,b)

Figure 2-a. Lateral machine

Figure 2-b. Laser with Lateral machine

Drain Envelopes

Graded gravel has been widely used to protect the laterals against the intrusion of soil particles that can clog pipes laid in soils with a clay content of less than 30 percent. Because gravel is costly to apply, there has been a shift to using pre-wrapped synthetic envelopes for the laterals. The use of pre-wrapped synthetic drain envelopes was introduced successfully in 1990 on a pilot scale. In 2000, it was decided to use only synthetic envelopes, where needed. Drain envelopes are mainly required in silty soils, that have less than 30% day fraction. Currently the pre-wrapped synthetic envelopes are applied in large scale implementation and are replacing the gravel envelopes in new contracts (figure 3, 4).

Figure 3. Envelopes can be made of wrapped polypropylene fibres (a, f & g), polystyrene granules (b) and coconut fibres (c), non-woven nylon (d) and woven typar (e)

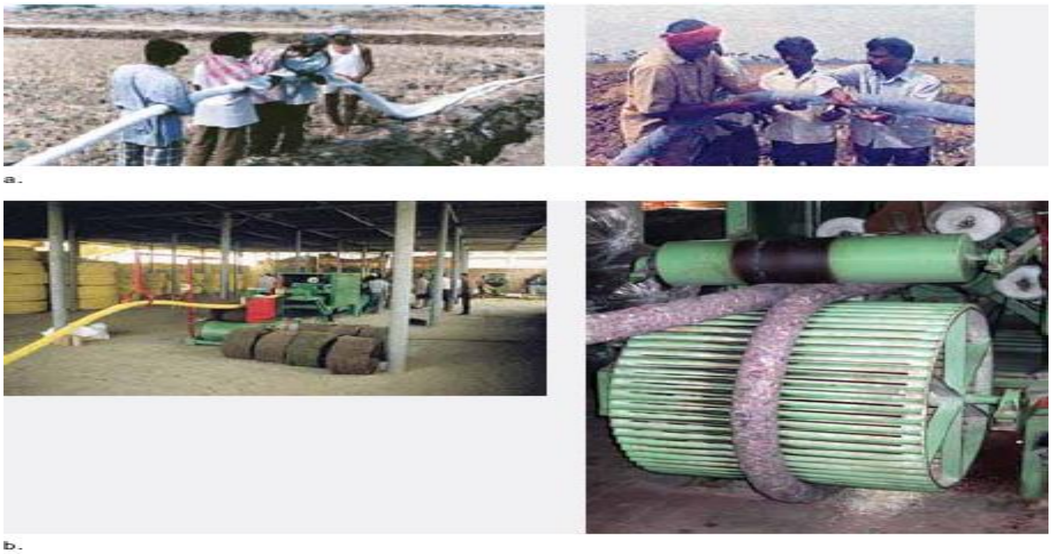

Figure 4. Pre-wrapping drain pipes manually (a) and mechanically (b

Drainage Machinery

Mechanized installation started in the 1960s with three imported lateral laying machines. Large-scale use started in the 1970s, and many more drainage machines have since been imported. These were of the trencher type with a digging chain to dig a trench in which the pipe was laid in one operation and subsequently backfilled. A modification was made because of the sticky clay soil and water tanks were installed on the machine. Since 1976, collector-laying machines (deeper installation depths and bigger pipes) were introduced (figure 5). The trenching type of installation causes considerable crop damage. At the end of the 1990s, trenchless installation was introduced for lateral laying with a V-plough type and may well continue to be used. Grade control of the laid pipes was greatly improved with the introduction of laser-guided grade control equipment in 1990.

Criteria for Water Table Control in Egypt

A typical criterion to satisfy objectives of water table control is indicated in figure (6). The criteria for leaching H – 1.0m and q=1-2mm/day are satisfactory for groundwater drainage projects in the Semi-arid areas of Egypt. The criteria for capillary salinization control also apply to the fairly typical case where there is a small seepage coming from canal leakage and the soils have fine sandy or silty subsoil's with high capillary capacity.

For aeration drainage the criteria H=0.80 and q=4mm are fairly typical. Suitable drain depths have also been indicated for all cases where there are no objections. The drain depth (W) has been taken equal to the least cost depth, generally to be in the order of 1.40m. For aeration drainage, W=1.25m

(see table 1)

Table 1 Water Table depth criteria

Objectives	Water table depth H(m)	Design discharge q(m/d)	Drain depth W(m)	Differential water table h(m)
Leaching	1.0	0.002	1.40	0.40
Salinity Control	1.25	0.005	1.40	0.15
Aeration	0.80	0.004	1.25	0.45

- Modification of the required water table depth should involve rate of evapotranspiration during the season. The water table depth will be affected and will result in larger drain design spacing.

Figure 5. Collector machine

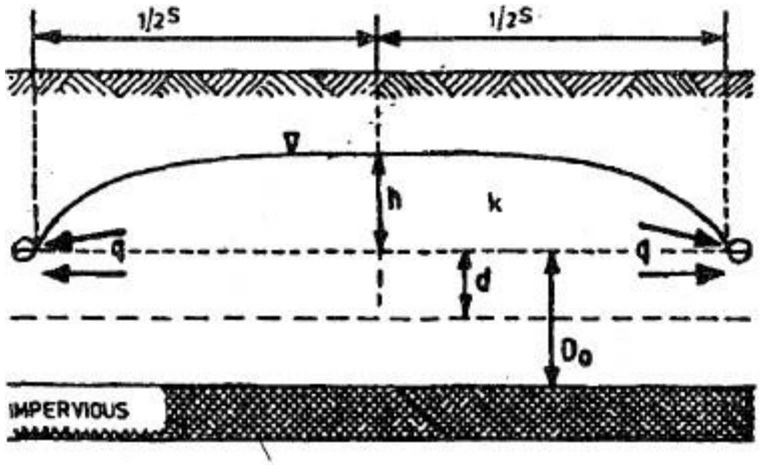

Figure 6. Water table depth criteria

Current Drainage Practices

A horizontal composite subsurface drainage system is used. The lateral drain spacing currently varies from 20m – 80m and is dependent on specific drainage design criteria and soil hydraulic properties. Lateral depth is approximately 1.35m. Average lateral slope is between 0.1 and 0.2%, with a length of 200m. The drainage coefficient for calculating drain spacing is 1mm/day for a dewatering zone of 1.0m. Pipe capacity is calculated according to a drainage coefficient of 3mm/day in non-rice areas, and 4 mm/day in rice areas.

There are 7 pipe factories producing subsurface drain pipes, all owned and controlled by the Egyptian Public Authority for Drainage Projects (EPADP). Lateral drain pipes have a diameter of 80mm, and are made of PVC, although HDPE is now being produced at the Aga Pipe plant. Collector drain pipes with a diameter of 15 to 40 cm were until 1997 generally constructed of plain concrete pipes, but since 1998 the Tanta pipe plant produces sufficient PVC collector pipes to supply all the ongoing drainage contracts. Moreover, the Aga pipe plant produces HDPE collector pipes as well. Reinforced concrete pipes are used when the collector diameter exceeds 40 cm. Collectors can be up to 2km in length. It should be noted that EPADP is both a producer and user of drainage pipes. In areas of sand and silt soils, synthetic, pre-wrapped envelopes are installed with the pipes during installation.

Rehabilitation of the System

The life time of drainage systems have been estimated between 30 and 40 years. Since drainage started in Egypt more than 30 years ago, the existing drainage systems are gradually due for rehabilitation. The lifetime of the systems depend on the quality of the used material, quality of the construction, design factors and external factors, such as vandalism, penetration of plant root in pipes, rodents, etc.

Normally a drainage system has to be renewed when:

- Groundwater table is rising to unacceptable levels;
- Soil salinity is increasing;
- Costs to maintain the hydraulic performance of the system become unacceptably high.

Decisions to rehabilitate a drainage system are based on actual information about the lifetime and the performance of the system. Regions in which pipe drains installed before 1970, need to be assessed on its drainage performance. It is expected that the pipes and associated material have deteriorated due to age and need to be renewed. Renewal will be done according to the current drainage criteria.

Changes in cropping patterns and rotations might also impose new irrigation and drainage regimes. New information on drainage coefficients, pipe, and envelope materials and installation equipment and techniques should be incorporated in system design.

Technology and Research Development

Egypt is the first country outside Europe and North America to implement large-scale agricultural drainage projects. It was therefore necessary at all times to seek and use the latest technical and technological development in implementing its drainage projects. Research over the past sixty years was behind the successful progress of drainage projects, the development of design criteria, and design concepts and specifications for machinery and materials.

The use of heavy drainage machinery, the Egyptian experience has played an important role in more powerful machines being produced. It is true that Egypt's drainage projects stand behind many of the technological developments made by the international drainage industry. The benefits have not only been limited to drainage in Egypt, but have extended to many other parties around the globe. The local production of drainage pipes and envelope materials has developed and increased to meet the project needs, and can also cover the requirements of other countries in the region.

Behind Research development support is the Drainage Research Institute (DRI) which was established on January, 1975. The institute is considered the supporting arm to the Drainage Authority for implementing projects i.e. (EPADP). As a result of research improvement on drainage survey and design has been taken place. Introduction of computerizing the drainage system started since 1987, on wards. Research on drain performance, varying depths and spacings revealed that change in the conventional design criteria. Therefore a range of drain spacing adopted by (EPADP) in its projects has been increased from 40-60m to 20,30,40,50,60,70,80m.

After with the research conducted by DRI, (EPADP) stopped applying gravel envelopes around the drain pipes in 1978 in heavy clay soils with a clay content of 40%. After further research, the clay content limit was decreased to 30%, in 1985. This resulted in cost saving during a research for almost 10 years. The application of a modified layout for drainage system in rice growing areas was included. The study revealed that the restriction of the out flow from sub collector unit with rice would save about 2.5m/day. Saving of water would be approximately 10 million m3 per day per/million acres of rice areas.

Farmer's Contribution to cost of drainage

Cost of drainage (main infrastructure and subsurface drains) is borne by the Government. However, farmers repay the cost of subsurface drainage system in 20 years interest free annual installments, which only starts 3 years after installation.

Economic benefits from drainage

Benefits of improved drainage have a direct positive affect on the income of farmers. The project's key benefits will be: (a) Increased crop productivity and production; (b) Increased land area available for agriculture; and (c) Increased household incomes for the farmers. Crop productivity is expected to increase by between 17-21% for a number of key crops. Financial analysis done during project preparation showed that for a typical one acres farm model, the annual net farm income of the traditional farm increased by US$200/ha to US$375/ha, depending on the initial level of salinity before providing subsurface drainage. With total construction costs of US$1500/ha and maintenance costs of US$20/ha/year, the payback period is only four years.

Re-use of drainage water (non-conventional water resources)

The main and almost exclusive source of water in Egypt is the River Nile. The available annual water available from High Aswan Dam is 55.5 billion m3. Agriculture accounts for the largest share of water use in Egypt. The total which amounts to 84% of available water resources, this share corresponds to about 50 billion m3 per year. The other uses of water cover industrial, municipal and navigational demands. Current estimates indicated the total annual water use is expected to increase in the year 2025 to about 75.3 billion m3.

The gap between the available water resources by the River Nile and the different demands was partly filled by abstraction of groundwater (2.6 billion m3/year). Drainage water emerged as an important source to provide the rest of water needed to meet the demands on short term basis. The amount of water that return back to drains from irrigated lands is relatively very high. The agricultural drainage water of the southern part of Egypt returns directly to the Nile River Nile where it is mixed with the Nile fresh water. The drainage water in the Delta region is emptied to the Sea and Northern lakes via drainage pump stations. The amount of drainage water pumped to the Sea was estimated as average to be 12.41 b.c.m and the total amount of drainage water of official re-use was 7 b.c.m per year .

Controlled Drainage

Controlled Drainage for rice areas

The concept of controlled drainage for the purpose of controlling the water table depths in rice areas is another way to save water.

- A temporary closure of the subsurface drains in rice fields was practiced, with the following advantages saving of water.
- Saving of other crops from damaging effects of a blocked system.
- The modified layout of the drainage system was introduced, as shown in Figure (7)

The saving from this system stem from the fact that they operate without allowing excessive water losses during the rice season. The areas provided with this system required approximately 35% less irrigation water compared to the area with a conventional layout.

Irrigation improvement water use efficiency

Controlled drainage has the potential to improve water use efficiency, maintain crop yields in periods of water stress and ensure that land drainage systems work to the maximum benefit of farmers.

A new perspective for managing the drainage system as a key part of integrated water resources have been developed to improve irrigation water use efficiency. The management concepts were:

- To change the effective drain spacing between drains.
- To change drain depth from soil surface using water table control device (figure 8).

These management options were applied and compared with the conventional drainage system. The result indicated that it is possible to improve the existing irrigation water use efficiency by 15-20% without any yield reduction.

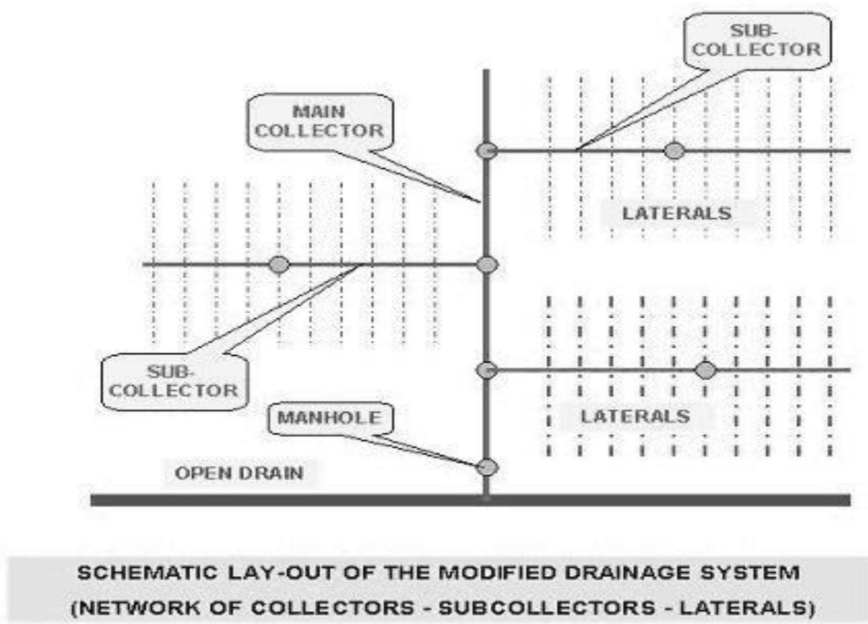

Figure 7. Modified drainage system

Figure 8. Water table control device

Challenges for future drainage system

- Gaps in capacity building in the field of irrigation and drainage
- Lack of understanding the multi-functions of Agricultural drainage
- Needs for innovative technology
- Climate change effects
- Water scarcity
- High cost of agricultural drainage system
- Lack of a sustainable maintenance for the drainage systems
- Water quality degradation

Future Vision & Developments in Drainage

Improved Information and Installation technology

Application of new technology will lead to a longer lifetime of drainage networks and less maintenance requirements. Throughout the last 30 years, Egypt has acquired the latest drainage technology. However, further developments of the (MIS) management information system that were defined in the basic system design have to be made. The production of plastic lateral and collector pipes with the latest pipe extruder plants guarantee high quality pipes larger diameter collector pipes can be used. The application of synthetic Envelope material, pre-wrapped around the lateral pipes minimizes the incidence of sedimentation. The introduction of pre-fab modules for manholes and the application of plastic connectors between manholes and collector pipes are still an area for improvement.

Drainage of Oasis and closed basins

The New Valley is a large depression located between the Nile Valley and Libya. In this depression there are five main Oasis which are Paris, Kharaga, Dakhla, Farafra and Bahariya. The total area of the New Valley is 458,000 km^2. Generally drainage problems are created from excess irrigation water discharged from free flowing springs and uncontrolled wells. This causes increases in subsurface water level and soil salinity of top soil layers. Disposal of drainage water in the Oasis depends mainly on the topographic features of the depressions. This poses and creates serious drainage problems. The need to develop unconventional drainage systems in these areas is highly important.

Drainage of the New Lands

The areas of the "New Lands" are rather different than the flat and homogeneous soils in the Old Lands. The main characteristics of the new lands differ from the old Delta lands. Facing these differences with all its complications, there is a needs to develop a new and flexible approach to pre-design investigations, inter-disciplinary planning, design and implementation that ensures the efficient and effective performance of the water management infrastructure. Moreover, it will be essential to ensure that any intervention is environmentally sound and sustainable. Therefore, any development plan should commence with a comprehensive Environmental Impact Assessment.

Future Research Requirements

Development of research needs in subsurface drainage would cover mainly the future vision and drainage developments issues which can be summarized as :

- A new design criteria for agricultural drainage under drought and water scarcity conditions must be considered and its effect on water quality.
- Improvement in information, installation technology, and operation, management and maintenance.
- Management of subsurface drainage systems in the arid and semi-arid areas as it is developed in humid areas
- Farmer's involvement in drainage planning and operation, maintenance and management of drainage system.
- In already drained lands, evaluation of the performance of existing drainage systems will also be needed in order to determine the need for rehabilitation.
- Field research is necessary to examine modern water management for agricultural production focuses on the management and enhancement of existing drainage systems to benefit water quality and the profitability of agriculture
- Protection of drainage water quality for the re-use of irrigation.
- Disposal of drainage water in the oasis and closed basins.
- Environmental and ecological impacts of drainage system.
- Application of new technology for Bio-drainage and dry drainage
- Impact of climate change on drainage planning, design, construction, operation and management.

Conclusions and recommendations

- In spite of the great achievements and benefits of agricultural drainage in Egypt, there are many challenges which threat the sustainability of agricultural drainage and drainage has to break out of its isolation caused by narrow agricultural perspectives and make itself instrumental in meeting many different objectives and interests.
- A new role for private and governments sector is needed. The private sector can offer a wide range of products and services which can promote agriculture production and growth.
- Farmers association and participations is a key elements for future development and management of drainage system
- GIS can be a very useful and helpful decision making tool at the pre-investigation stage for technical and financial analysis with limited funds.
- Integrated management of irrigation and drainage would mean:
  - Acknowledging the multiple objectives served by the management of shallow water tables and the disposal of excess surface water, and the need to maintain the resources system over time (resources sustainability)
  - Improving the scientific knowledge base through a major move from operation and maintenance of drainage system toward the fields of management, sustainability, multifunctionality, and stakeholder representation in governance and decision making.
- New approaches for water table control must be developed. The use of modified land drainage systems or dual-line irrigation/drainage systems may also afford the recycling of nutrients and chemicals that would otherwise leach to the water table, providing another tool to reduce chemical / nutrient leaching.
- There are usually several water management alternatives that can be used to satisfy agricultural objectives. The challenge is to select those methods that will minimize negative environmental impacts.

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4

Topic 4: Application of Alternative Drainage Methods

SOIL SALINITY CONTROL UNDER BARLEY CULTIVATION USING A LABORATORY DRY DRAINAGE MODEL

Shahab Ansari [1,*], Behrouz Mostafazadeh-Fard [2], Jahangir Abedi Koupai[3]

Abstract

The drainage of agricultural fields is carried out in order to control soil salinity and the water table. Conventional drainage methods such as lateral drainage and interceptor drains have been used for many years. These methods increase agriculture production; but they are expensive and often cause environmental contaminations. One of the inexpensive and more environmental friendly methods that can be used in arid and semi-arid regions to remove excess salts from irrigated lands to non-irrigated or fallow lands is dry drainage. In the dry drainage method, natural soil system and the evaporation of fallow land is used to control soil salinity and the water table of irrigated land. There are few studies about dry drainage concepts. it is also important to study soil salt changes over time because of salt movements from irrigated areas to non-irrigated areas especially under plant cultivation. In this study a laboratory model which is able to simulate dry drainage was used to investigate soil salts transport under barley cultivation. The model was studied during the barley growing season and for a constant water table. During the growing season soil salinities of irrigated and non-irrigated areas were measured at different time. The Results showed that dry drainage can control the soil salinity of an irrigated area. The excess salts leached from an irrigated area and accumulated in the non-irrigated area and the leaching rate changed over time. Soil surface salinities of non-irrigated areas increased with time. At the end of the experiment, the increase of the mean soil salinity of the non-irrigated area was 2.81 times more than the increase of the mean soil salinity of the irrigated area. In arid and semi-arid regions where suitable conditions exist, dry drainage can be used as a useful management tool to control soil salinity.

KEY WORDS: Barley, Dry drainage, Salt movement, Shallow ground water.

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Introduction

During the last 3-4 decades, as the demand for agricultural productions increased the irrigated lands also increased up to 300%. This has imposed a further increase in soil salinization and a relative decrease in crop yield (Poustini and Siosemardeh, 2004). In arid and semi-arid regions, farmers often use saline water to irrigate their fields because of shortage of good quality water resources. This causes soil and water contaminations and reduces agricultural productions. Drainage is a common method to reduce salt accumulation in soil especially when irrigating with saline water. Salt leaching is one of the most important aims of the drainage systems, but it causes fertilities and pesticides to be removed from soil profile and pollute surface water and ground water resources (Deng, 1998). In recent years, researchers have tried to find more suitable and environmental acceptable method for drainage of agricultural fields. For example subsurface irrigation and controlled drainage are irrigation methods which can reduce pollution and still provide sufficient irrigation requirement (Ragab, 2002; Skaggs, 1999). Results of different researches have shown that it is beneficial if crop rotation is considered for land reclamation programs to decrease soil salinity. The subsurface drainage systems in agricultural fields are expensive and cause environmental pollutions. Dry drainage is a new concept for drainage of agricultural fields which has less environmental impacts and with low cost as compared to subsurface drainage systems can reduce soil salts and leach excess salts (Konukcu and et al., 2006). Greenwood et al. (1994) first have introduced dry drainage. In this method part of the field is considered as irrigated area and another part is considered as non-irrigated area or fallow land. Drainage occurred through soil of irrigated area and salts will leach to the non-irrigated area or fallow land. The gradients from irrigated area to non-irrigated area cause salts and excess water movements (Khouri, 1998). Dry drainage is efficient and applicable for conditions of high water table, high capillary rise and high potential of evaporation. These conditions are visible in many arid and semi-arid regions that suffer from salinity problems (Khouri, 1998). Konukcu, et al. (2006) reported that dry drainage is a sustainable solution to water logging and salinity problems in irrigated area. There are few researches about dry drainage and its practical use (JingWei and et al., 2009; Khouri, 1998). Previous studies had confirmed that dry drainage is more economical and environmental acceptable drainage method for agricultural fields. Therefore, the objective of this study was to simulate soil salinity under dry drainage with barley cultivation using a laboratory model.

Materials and methods

In this study a laboratory dry drainage simulation model was used to investigate soil salinity control under barley cultivation at Isfahan University of Technology, Isfahan, Iran. The model was made from galvanized sheet with thickness of 4 mm and with dimensions of 2 m length, 0.5 m width and 1 m height as shown in Fig.1.

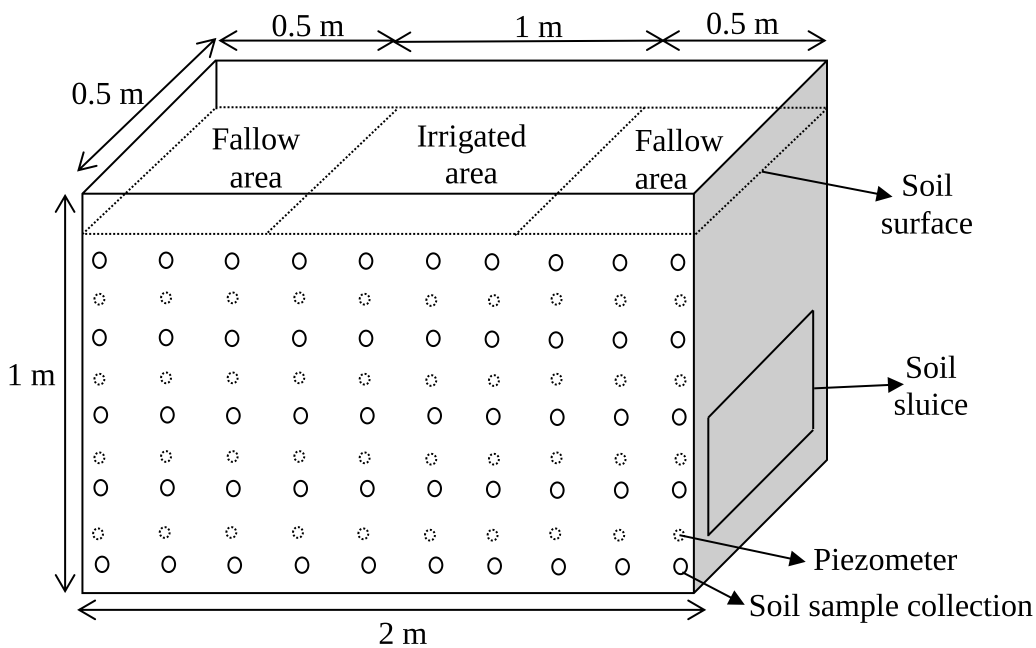

Figure 1. The schematic of the laboratory dry drainage simulation model

To observe water flow and ground water level in the model, one side of the model was made of the Plexiglas with thickness of 8 mm. Another side of the model had a grid system with vertical distance of 0.2 m and horizontal distance of 0.1 m. Half of these grid points were connected to polyethylene piezometers with inside diameter of 5 mm to measure and monitor groundwater level and other half were used to collect soil samples for soil moisture and soil salinity measurements. To drain water and to obtain desire water table, a drainage valve was installed at the bottom of the model. To obtain uniform water table, sand filter was placed at the bottom of the model. A water level controller connected to the drainage valve at the bottom of the model. It was able to raise water from the bottom to the top smoothly until it reaches the desire water level which was 0.6 m from the soil surface. The soil used for the study was loamy which was taken from an agricultural field. The physical and chemical characteristics of the soil are given in Table 1. The model was filled layer by layer by the soil and each layer was compacted uniformly to reach the bulk density which is close to bulk density of actual field. Model was divided into two equal sections of irrigated and non-irrigated (fallow) areas in such a way that due to hydraulic gradient changes, soil water and salt movements occur naturally between these two sections. The irrigated area was cultivated by barley and was irrigated with irrigation water which its characteristics are shown in Table 2. Irrigation water salinity was obtained by mixing good quality irrigation water with the saline water. The maximum irrigation interval was 3 days and irrigation amount changed with time. With irrigation, soil moisture was raised to field capacity and water table was raised to 0.6 m depth below soil surface. The experiment was carried out for one complete growth season of the barley and mass soil water and salinity of irrigated area and non-irrigated area were measured at five different times of 0, 21, 42, 63 and 84 days after planting using soil samples taken at different locations of the model.

Table 1. The characteristics of soil

Characteristics	Sand	Silt (%)	Clay	Bulk density (gr/m^3)	EC (dS/m)	pH
value	52	28	20	1.6	3	8

Table 2. The characteristics of irrigation water

Characteristics	Na^+	Ca^{2+} (meq/L)	Mg^{2+}	K^+	EC (dS/m)	pH
value	5.99	9.15	8.14	2.94	3	7.5

Results and discussion

Fig. 2 shows soil surface moistures of irrigated and non-irrigated areas for 0, 21, 42, 63 and 84 days after planting. Soil moistures of irrigated area and non-irrigated areas were equal at the beginning of the experiment. After plant cultivation, for first few weeks the difference between soil surface moistures increased due to irrigations. The differences decreased because of water movements from irrigated area to the non-irrigated area. Water movements occurred due to hydraulic gradient between two areas. Irrigations of irrigated area and also evaporation of soil surface of non-irrigated area increased the hydraulic gradient and caused water movements from irrigated area to non-irrigated area.

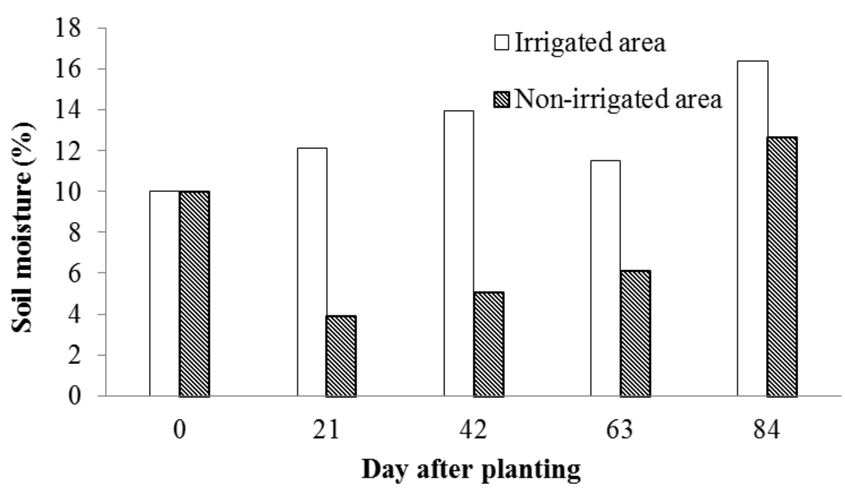

Figure 2. Soil surface moistures for different times after planting

Fig. 3 shows soil moistures at different depths for 84 days after planting for irrigated and non-irrigated areas. Soil moistures in both areas increased by soil depth due to capillary rise from water table. Soil moisture at each depth for the irrigated area was more than the non-irrigated area. The difference of soil moisture at each depth of irrigated and non-irrigated areas increased as soil depth decreased due to irrigation of irrigated area and evaporation of non-irrigated area.

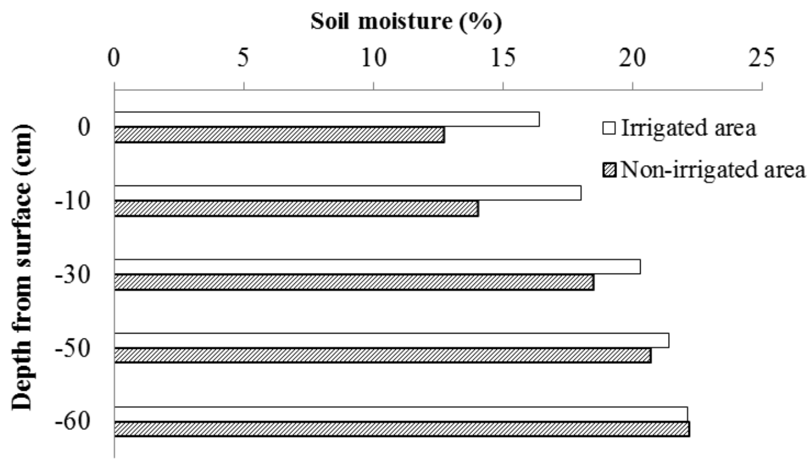

Figure 3. Soil moistures at different depths for 84 days after planting

Soil surface salinities for 0, 21, 42, 63 and 84 days after planting during the growing season are shown in Fig. 4. Soil surface salinities of both irrigated and non-irrigated areas increased with time. Soil surface salinities of non-irrigated area increased more than the irrigated area. Increase of soil surface salinities of irrigated area and non-irrigated area were 45 and 170 percent respectively. Irrigation by saline water caused salt accumulates in irrigated area. The considerable amount of these salts leached from irrigated area to the non-irrigated area because soil water movements from irrigated area to the non-irrigated area due to evaporation of non-irrigated.

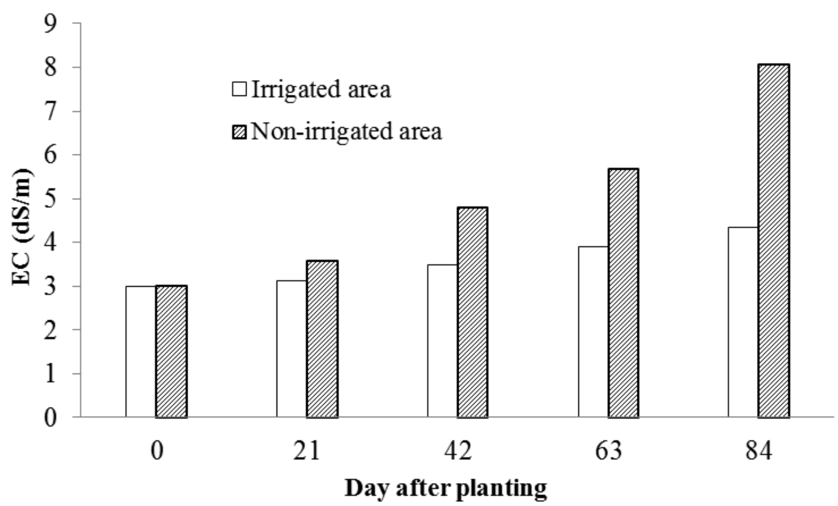

Figure 4. Soil surface salinities for different times after planting

Soil salinities at different depths for 21 and 84 days after planting are shown in Fig. 5. Soil salinity of the non-irrigated area was more than the irrigated area. Soil salinities decreased as the soil depth increased due to water and salt movements. Water movements and consequently salt movements occurred from irrigated area to the non-irrigated area due to hydraulic gradients.

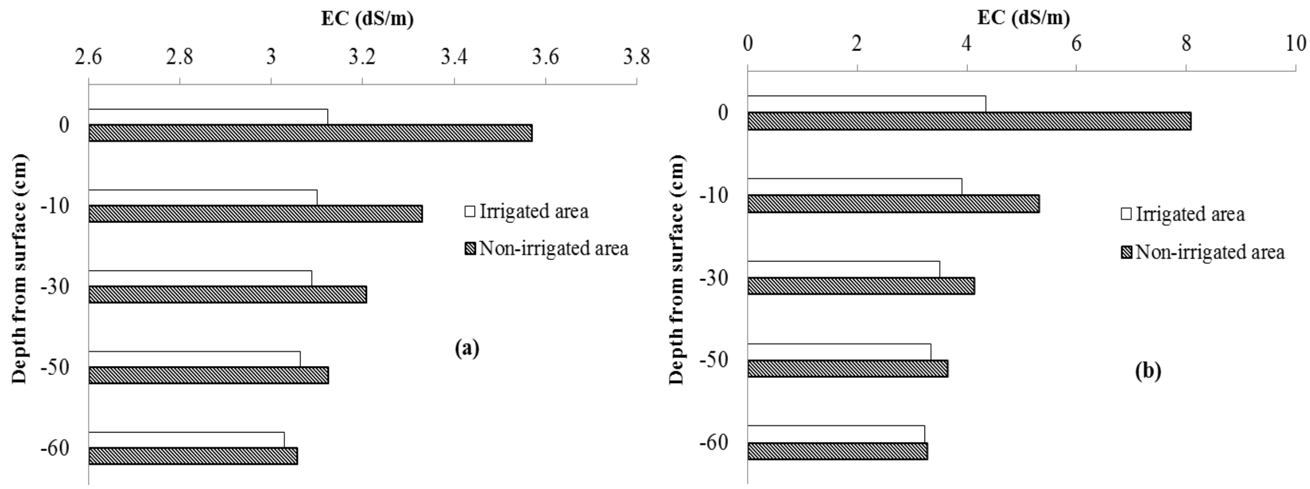

Figure 5. Soil salinities at different soil depths, a) for 21 days after planting and b) for 84 days after planting

Conclusion

Dry drainage is a new method that can be used in arid and semi-arid regions to remove excess salts from irrigated lands to the non-irrigated or fallow lands. In this method, natural soil system and evaporation of fallow lands are used to control soil salinity. Dry drainage is more applicable for conditions of high water table, high capillary rise and high potential of evaporation. In this study, soil salinity under dry drainage with barley cultivation was simulated using a laboratory model. The hydraulic gradient between irrigated area and non-irrigated area caused excess water and salt movements from irrigated area to non-irrigated area. The concept of dry drainage can provide better conditions for plant growth by reducing excess salts from irrigated area. Further studies of dry drainage under different conditions of soil types, water table depths, salinities and crops are recommended.

Acknowledgement

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IN-STREAM WETLAND AS A POTENTIAL LOW COST TREATMENT TECHNOLOGY IN RURAL AREAS

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Abstract

The countries of the Middle East and North Africa region have 5% of the world's population but have less than 1% of the world's renewable fresh water. The region is one of the driest in the world and poorly endowed with natural freshwater supplies. The annual per-capita water availability in 1960 was about 1550 m3 and has fallen by 40% to about 650 m3 today and it is expected to be about 450 m^3 in 2025.

Wastewater treatment in Egypt's rural areas as well as in many other countries lags far behind potable water supply. Only urban centers and some larger rural villages possess wastewater treatment facilities. Economics of scale makes conventional wastewater treatment cost prohibitive in smaller more dispersed rural settlements. Domestic wastewater is typically discharged directly or indirectly to drainage canals. This practice has contributed to widespread degradation of drainage water quality, thus negatively affecting the reuse of drainage water plans in Egypt. Several treatment alternatives that vary in efficiency and costs are available. The natural wastewater treatment requires relatively low capital investment when flat land is available at reasonable price. Among the natural treatment systems, in-stream wetland has a high potential for application in rural areas of Egypt where the treatment process takes place within the drain. Thus, it needs much less land, which is easily maintained, and which can absorb shock loads with relatively less capital and operational costs. All these features have made in-stream wetland a very attractive option for rural communities. Pilot studies in the Nile Delta drain system were conducted to demonstrate the technical feasibility of the in-stream study and adopt the design criteria suited for the Egyptian environment. One pilot area was selected among several potential sites in the Nile Delta using multi-criteria analysis. Baseline studies have been conducted to collect the data/information required for the design of in-stream wetlands. The studies included an intensive water quality monitoring program, hydraulic characteristics, physical survey, socioeconomic survey, developing public awareness program and others related activities.

The HEC-RAS modeling system is used for the calculation of water surface profiles for steady gradually varied flows of the selected drain. MATLAB software is used to develop an external transport module to simulate the convection, advection, diffusion and decay of different pollutants. A group of 25 numerical runs in a matrix were simulated to test the impact of physical interventions on drain surface water profile, detention time and pollutants removal efficiency. The baselines

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studies show that the self-purification capacity of the selected drain without any physical engineering intervention varies within a narrow range from 29% to 37% for BOD removal with the treatment of detention time from 6 to 8 hours. The proposed system could have a detention time up to 68 hours using limited physical intervention such as sedimentation traps, weirs and baffles. Simulation of different design alternatives indicate that the removal efficiency of such a system can reduce 60% of BOD and 70% of TSS. Introducing aquatic plants would improve the removal efficiency especially for nutrients and pathogens. The performance of the in-steam wetland treatment system under similar conditions in Egypt is expected to be equivalent to the advanced primary to secondary conventional treatment.

KEY WORDS: Drainage water reuse, Natural treatment system, Water quality modeling.

Introduction

The emphasis on increased reuse of drainage water for irrigation is essential as Egypt expands its agricultural land base to meet the food supply requirements of a rapidly growing population. The sanitation facilities of Egyptian rural areas far behind potable water supply. This situation has contributed to widespread degradation of drainage water quality and so, the reuse of drainage water plans in Egypt. A major concern when considering drainage water reuse is whether the drainage water quality is within the allowable limits for different uses as outlined by the water quality standards. Thus, more attention needs to be directed to improve drainage water quality [El Sayed A., 2009]. Introduction of in-stream wetland treatment system on existing drains is an effective, cheap, and simple treatment alternative to improve drainage water quality. More studies on using this approach on the tertiary drain level are required. The current research study aims at verifying the design criteria and demonstrating the effectiveness of the in-stream wetland treatment system under Egyptian or similar conditions. Implementation of such experiment involves selection of the pilot area site, conducting baseline studies, design and construction of the wetland treatment scheme and carrying out environmental management plan for the scheme operation. The objective of this paper is to present the site selection process, major finding concluded form the baseline & design studies and potential of having a successful in-stream wetland treatment scheme.

In-stream Wetland Treatment System

Main Elements of In-Stream Wetland

Wetland system can reduce high levels of BOD, suspended solids and nitrogen as well as significant levels of metals; trace organic and pathogens [Reed et al., 1988]. The removal of settable organic is very rapid in all wetland systems due to the quiescent conditions in the free water surface types and the deposition and filtration in the vegetated submerged bed systems. Similar results have been observed as the over flow of systems where close to 50% of the applied

BOD removed in the upstream reach. Figure (1) illustrates a typical in-stream wetland treatment system which consists of the following elements [Harza, 2000]:

- Sedimentation zone to reduce suspended matter load;
- Two aquatic plant zones to enhance biological treatment process;
- Number of submerged berms to manage the required detention time for treatment;
- Floating vegetation barriers (two to three) to avoid weed and vegetation spreading;
- Control weir to manage drainage water discharge and detention time for treatment.

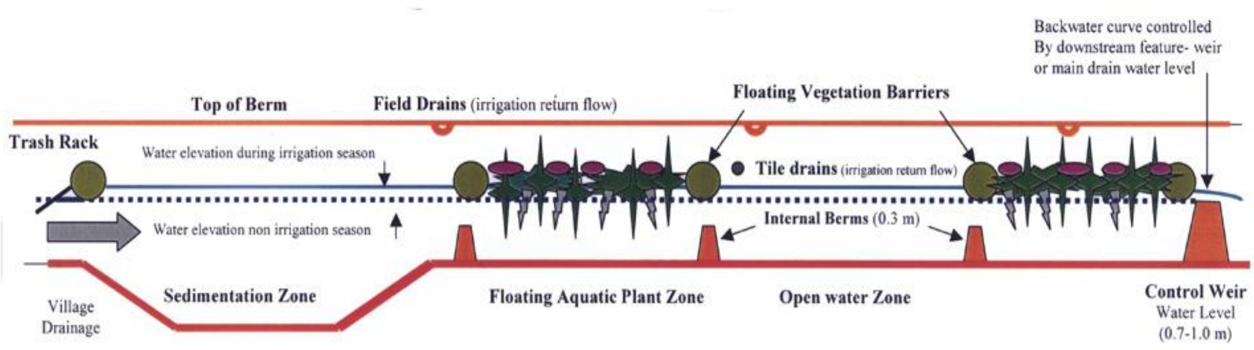


Figure 1: Profile view of an in-stream wetland treatment system

In-Stream Wetland Design Criteria

The design equation of wetland systems considers the environmental conditions especially the evapotranspiration losses since it affects on the large surface area of the basin. Also, filter media condition is taken into consideration. Therefore, the equations would be as mentioned as follows [Reed et al., 1988, Hammer, 1990].

$$\frac{C_e}{C_i} = 0.52 \exp\left[- \frac{0.7\, K_t\, (A_v)^{1.75}\, L\, W\, d\, n}{Q}\right] \qquad (1)$$

$$K_t = 0.0057\,(1.1)^{T-20} \qquad (2)$$

Where:

C_e = effluent BOD (mg/l)

C_i = influent BOD (mg/l)

K_t = the rate constant at water temperature (day^{-1})

A_v = specific surface area for microbial activity (m^2/m^3)

n = porosity of system (decimal fraction)

T = temperature (^0C)

L, W, d = length and width of pond at surface water and depth (m)

When the bed slope or hydraulic gradient is equal to 1 percent or greater it is necessary to adjust the equation to:

$$\frac{C_e}{C_i} = 0.52 \exp[-\frac{0.7 K_t (A_v)^{1.75} L W d n}{4.63 s^{1/3} Q}] \quad (3)$$

The next assumptions will be used as design criteria for the free water surface wetlands:

- The specific surface area (A_v) for attached microbial growth = 15.7 m^2/m^3
- Porosity (n) of wetland flow path = 0.75
- Aspect ratio (L/W) > 10:1
- Water depth in warm months < 10 Cm and in cool months < 45 Cm

Then the hydraulic residence time will be as follows:

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{65 K_t} \quad (4)$$

If the bed slope or hydraulic gradient is equal to 1 percent, then

$$t = \frac{(\ln C_i - \ln C_e) - 0.6539}{301 s^{1/3} K_t} \quad (5)$$

The surface area of the wetland is given by

$$A = \frac{Q(\ln C_i - \ln C_e - 0.6539)}{65 K_t d} \quad (6)$$

And if the bed slope or hydraulic gradient is equal to 1 percent, then

$$A = \frac{Q(\ln C_i - \ln C_e - 0.6539)}{301 s^{1/3} K_t d} \quad (7)$$

Selection of Pilot Area

To evaluate the suggested alternative drain sites for in-stream wastewater treatment, several criteria have been adopted. These criteria reflect the diversity of the issues and dimensions associated with the in-stream wastewater treatment. Three main categories are used to evaluate the alternative sites: the drain conditions, water quality input to the drain, and the area's community. Under each category, few selected sub-criteria are considered. That selection of the sub-criteria is based on relevance, data and possibility of quantification. The selected sub-criteria are:

- ***Drain Type:*** A tertiary open agricultural drain that managed by Ministry of Water Resources and Irrigation. So, any physical required intervention on the drain can be implemented.
- ***Physical Condition of the Drain Cross-section:*** A well-formed drain cross-section, with regular bed, berms and banks is very important, in addition to the existence of sufficiently wide side-road(s) for vehicle accessibility.
- ***Accessibility:*** The selected reach of the drain must have no physical objects that may obstruct accessibility and/or equipment movement. Infrastructure facilities on the drain banks or side roads.
- ***Population and Pollution Load:*** A small rural community should exist very close to the drain.
- ***Wastewater Disposal Location and Disposal Point:*** The municipal wastewater effluent should be dumped at the selected drain through limited point sources.
- ***Absence of Industrial Wastes:*** It is highly important that no industrial activities take place at the selected rural community to avoid any disposal of industrial wastewaters to the drain, which may include toxic substances affecting the biological process.
- ***Community Appreciation and Acceptance:*** The local governorate, municipalities and the community will have no objection for construction of in-stream treatment system.

A maximum score has been assigned to each of the selection criteria indicators such that the total maximum score is 100 points to make the comparison among the total scores of potential drain sites. It can be concluded from the analysis that the selected drain "Bahwo drain" meets most of the selection criteria with score of 95%. The total drain length is about 2 km with area served 1,270 feddans of agricultural lands and drainage water duty of 30 m^3/feddan/day.

Baseline Studies for the Selected Site

Baseline studies include the fieldwork and data collection such as site detailed investigations and monitoring activities. The major tasks implemented under the baseline studies phase are presented in the following sections.

Drain physical survey and land-use survey

The selected drain is surveyed in order to build the topographic map for the area (land terrain, boundaries, and natural features). This will include the geometric survey of the selected secondary drain itself (width, bed level, slopes, … etc.). Other investigations will also be made including but not limited to: soil classification, drainage conditions, cropping pattern, and irrigation technologies used. Land-use is defined (agricultural lands, roads, industrial facilities, trees, rural areas, villages and community areas, … etc.) in terms of: areas occupied, nature of activity, crop rotations, irrigation water requirements, population density, and geographic location.

Socioeconomic survey

The community's characteristics including but not limited to: population, profession, degree of education, health care level, social facilities and services offered in the community, traditions, and transportation will be addressed. In addition, the water supply quantities used and sewage water released (quantities and qualities), and types of wastewater disposal methods (sanitation system or septic tanks) will be identified.

Subsurface water level

The subsurface water is monitored through a group of observation wells constructed at three sites; residential area, fallow land and agriculture land. Each site has three observation wells and the level is measured daily.

Drain flow

Flow measurements at downstream reaches of the drain are conducted weekly and level recorder is installed with several staff gauges to monitor the drain water level continuously.

Quality

A quality monitoring program was designed and implemented for sampling drainage water and sediment in the selected drain. The monitoring scheme covered the period of a year and four sites along the drain. Water sampling frequency was bimonthly at each of the monitoring sites as indicated in Figure (2).

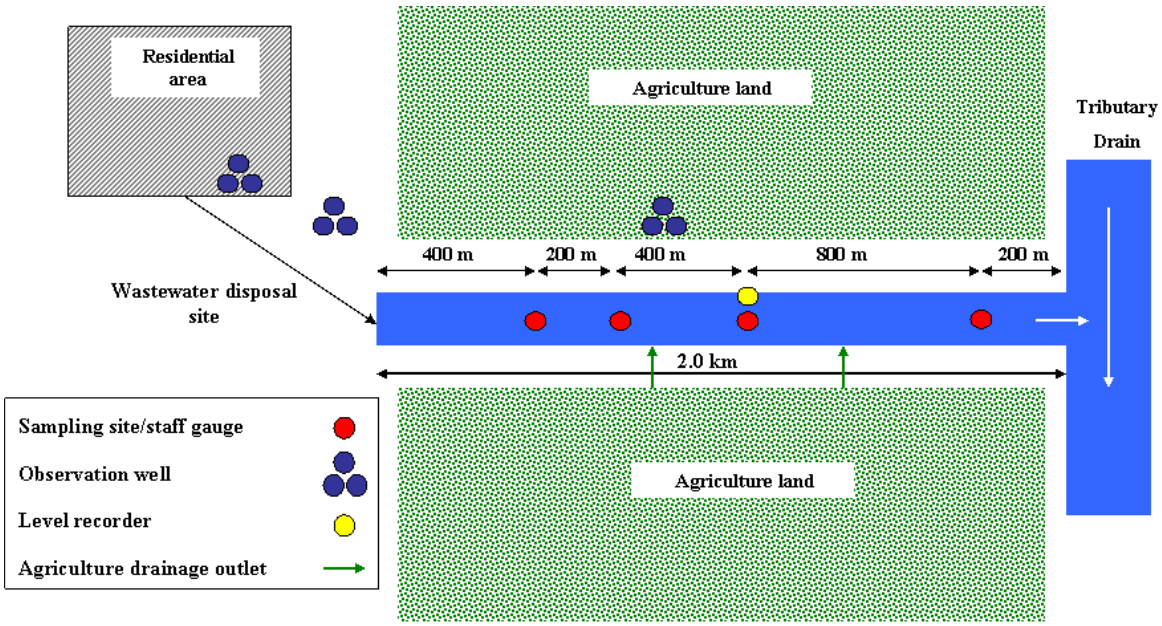


Figure 2: Schematic diagram for the monitoring scheme along the study area

Analysis of Baseline Data

Flow

A relation between flow and drain water depth with satisfactory correlation coefficient has defined. The minimum and maximum flows are found to be 0.018 m^3/s and 0.08 m^3/s and the corresponding water depths are 0.15 m and 0.4 m respectively.

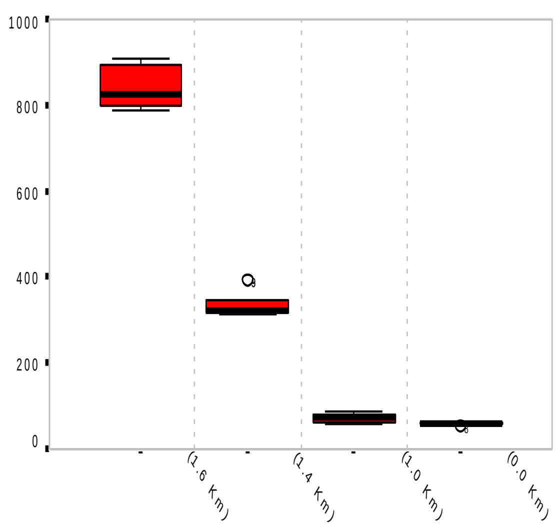
Subsurface Water Level

There is remarkable difference in subsurface water table for the three monitored areas where the subsurface water level at residential area is almost stable and varies around 2.0 m. The subsurface water level should not reach 1.5 m below the ground surface to avoid any impact on the house's foundations. The subsurface water at the fallow land, which is located between the residential area and the agriculture land, varies in narrow range between 1.3 m to 1.7 m below ground surface. The subsurface water at the agriculture land varies in wide range between 0.5 m to 1.5 m below ground surface depends on the irrigation period. The variation almost has the same pattern. The drain water level should not any way reach the subsurface water table at the agriculture land after operation of the wetland system to avoid any water logging.

Quality

The conducted monitoring program includes physical, chemical, biological and heavy metals parameters. The following section focuses on critical parameters which are considered matter of concerns during the wetland system design process including DO, BOD/COD, TSS, fecal bacteria and TDS.

The upstream reach of drain is subject to anoxic condition where the untreated domestic waste from residential area is discharged. Further downstream, DO levels of the drainage water is changed to be aerobic around 2.0 mg/l to 3.5 mg/l at 1.2 km and 1.8 from the upstream site respectively. The BOD values reach the maximum values further upstream of the drain (about 900 mg/l) and decrease to about 300 mg/l after 600 m to reach the minimum level at the drain outfall (80 mg/l) as shown in Figure (3). Remarkable reduction in organic waste takes place at the upstream reach which functions as sedimentation chamber. Further improvement is due to dilution with agriculture drainage water in the downstream reaches. The same conclusion is valid for COD and TSS (Figure 4) and follows the same pattern of BOD where the sedimentation is the dominant process. Nitrate is found to be below 1.0 mg/l and increases in the downstream direction to reach 6.0 mg/l while Ammonia is decreases in the downstream direction due to nitrification and denitrification process. Pathogens indicated by fecal bacteria are found to be extremely high further upstream reach of the drain at wastewater damping site (about $2*10^6$ MPN/100ml) and subjected to remarkable decrease in the down stream direction to be about $20*10^4$ MPN/100ml. The TDS is stable and varies in narrow range down stream reaches where more drainage water is mixed with the wastewater. The TDS upstream values vary between 1500 to 2500 mg/ and is reduced downstream varying between 1000 mg/l to 1500 mg/l. The heavy metals presented in drainage water samples are within allowable limits according to national law (48/82) and FAO recommended guidelines for reuse in agriculture.



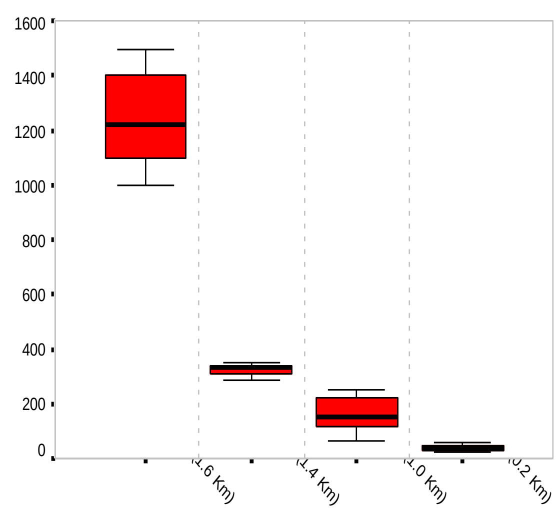


Figure 3: BOD levels along the drain **Figure 4: TSS levels along the drain**

Simulation Tools

HEC-RAS Package

HEC-RAS is an integrated system of software developed by US-Army Corps of Engineers designed for interactive use in a multi-task environment (USA Army, 2002). HEC-RAS system contains one-dimensional hydraulic analysis components for steady and unsteady flow water surface profile computations. These components are intended for calculating water surface profiles for steady and gradually varied flows. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated from Manning's equation and the consideration of contraction and expansion form losses. The effects of various obstructions such as bridges, culverts, weirs, and in-stream structures may be considered in the computations. The steady flow system is designed for application in assessing the change in water surface profiles due to different channel improvements. HEC-RAS has also the advantage of considering vegetation induced the surface resistance.

MATLAB Package

The HEC-RAS package does not contain a module to simulate the transport of different pollutants and substances such as TSS or BOD. Therefore, it was necessary to build an external transport module to simulate the convection, diffusion and decay of pollutants. This is done within the environment of MATLAB package. MATLAB (**Mat**rix **Lab**oratory) is an interactive software system for numerical computations designed for matrix computations: solving systems of linear equations, computing eigen-values and eigen-vectors, factoring matrices, and so forth. MATLAB is designed to solve problems numerically, that is, in finite-precision arithmetic (David F, 2001).

Hydrodynamic Simulation Process

The proposed typical elements of the PIW channel consist of three main zones. The first zone is sediment trap proposed for the collection of deposited suspended particles. The sediment trap zone is followed by two floating aquatic plant zones separated by an open water zone. The objective of the floating aquatic plant zones is to make use of the aquatic plants to take up nutrients and to support microorganisms that can convert them and other pollutants into less harmful forms. Each zone is separated by internal baffles and/or an end weir.

Different Design Scenarios

In order to understand the hydrodynamic effects of each element in the typical PIW channel system, a group of 25 numerical runs have been proposed as listed in Table (1). In each run, one or more variable is/are changed, as given in the table. The listed runs can be reclassified into sets of runs as follow:

Without aquatic plant

This set of runs includes runs 1 to 3 where no aquatic plants or open water zones are considered in the simulation. The first run is considered as the basic run where the actual surveyed bed profile of the pilot drain is used in the simulation. The second run assumes a modified smoothed bed profile. The third run considers the effect of having a sedimentation zone 400 m in length and 50 cm in depth.

Set 2: With weir or baffles

This set of runs includes runs 4 to 10 and considers the effect of having a sedimentation trap zone and one weir on the hydraulic performance of the system. No aquatic plant zones are considered in this set.

Set 3: With aquatic plant

This set of runs includes runs 11 and 12 and is the same as those of run 10 except that immersed plants are considered in the analysis. For run 11, immersed plants are assumed to cover the first aquatic zone only whereas run 12 assumes the existence of immersed plants in two reaches.

Set 4: Typical PIW

This set of runs includes runs 13 to 22. The conditions of this set of runs are the same as those of set 3 except that floating aquatic plants replace the immersed plants at the positions indicated in the table. The floating plant thicknesses and roughness are given in the table.

Set 5: Variable discharges

This set of runs includes runs 23 to 25 and is similar to those of set 4 but with different discharge flux. The objective of this set of runs is to check system response to discharge variability.

Results Summary

Based on the aforementioned results listed on Table (1), it can be concluded that:

- The end weir plays the most important role in controlling the detention time throughout the PIW channel system. The higher the crest of the end weir the longer the produced detention time of the system.
- Interior baffles do not have significant effect on the produced detention time of the system.
- Aquatic floating plants have small effect on the produced detention time. It is found that, as the thickness of the aquatic floating plants gets bigger and or the plants' aerial density gets higher, the detention time gets longer.
- Also, it has been noticed that discharge variation has a nonlinear response to the detention time. For example, an increase of 50% in Q will cause the detention time to decrease by 36% whereas a decrease in Q by 50% causes the detention time to increase by 91%.

Table (1): List of numerical runs and calculated detention time

Run	Q%	Depression	Weirs height (cm)		Baffles height (cm)		Vegetation		Time (hr)
			A	D	B	C	A→B	C→D	
1	100%	No							
2	100%	No							9.29
3	100%	Yes							12.92
4	100%	Yes	30						14.46
5	100%	Yes	50						24.43
6	100%	Yes		30					14.66
7	100%	Yes		50					30.8
8	100%	Yes		75					66.55
9	100%	Yes	50	50					35.11
10	100%	Yes	50	50	25	25			35.11
11	100%	Yes	50	50	25	25	n=.06		35.11
12	100%	Yes	50	50	25	25	n=.06	n=.06	35.54
13	100%	Yes	50	50	25	25	n=.03, t=5 cm		33.78
14	100%	Yes	50	50	25	25	n=.03, t=5 cm	n=.03, t=5 cm	34.06
15	100%	Yes	50	50	25	25	n=.02, t=5 cm	n=.02, t=5 cm	33.85
16	100%	Yes	50	50	25	25	n=.01, t=5 cm	n=.01, t=5 cm	33.7
17	100%	Yes	50	50	25	25	n=.01, t=10 cm	n=.01, t=10 cm	35.14
18	100%	Yes	50	50	25	25	n=.02, t=10 cm	n=.02, t=10 cm	35.3
19	100%	Yes	50	50	25	25	n=.03, t=10 cm	n=.03, t=10 cm	35.51
20	100%	Yes	50	50	25	25	n=.03, t=20 cm	n=.03, t=20 cm	45.01
21	100%	Yes	50	50	25	25	n=.02, t=20cm	n=.02, t=20cm	44.56
22	100%	Yes	50	50	25	25	n=.01, t=20cm	n=.01, t=20cm	44.23
23	100%	Yes	50	50	25	25	n=.02, t=10 cm	n=.02, t=10 cm	19.19
24	150%	Yes	50	50	25	25	n=.02, t=10 cm	n=.02, t=10 cm	24.35
25	50%	Yes	50	50	25	25	n=.02, t=10 cm	n=.02, t=10 cm	68.66

Transport Modeling Results

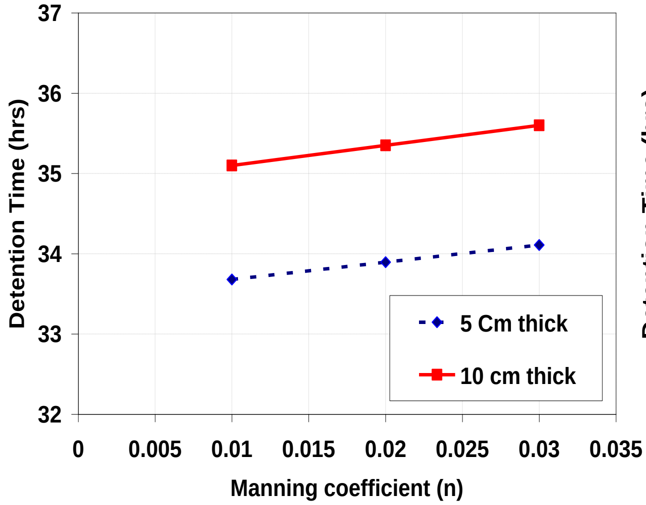


Figure 6: Vegetation response to detention time

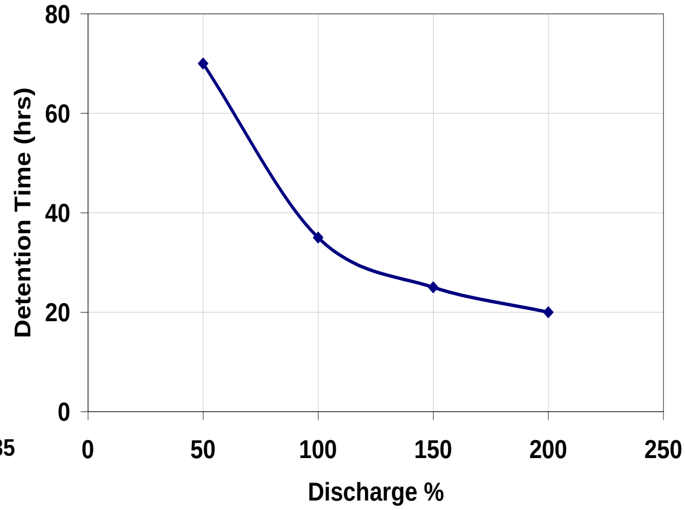


Figure 7: Effect of discharge variation on detention time

Simulation of TSS Transport

The spatial variation of the total suspended solids can be obtained by applying a sort of transport equation that includes the advection, diffusion and decay terms. The governing equation is a second order parabolic of the following form (Reed et al., 1988, Hammer, 1990):

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} - w_s\frac{\partial C}{\partial z} = D_x\frac{\partial^2 C}{\partial x^2} + D_2\frac{\partial^2 C}{\partial x^2}$$

Where:

C	=	TSS concentration
U	=	downstream convection velocity
Ws	=	settling velocity of the suspended particles
Dx, Dy	=	diffusion coefficients in the x and y directions

In order to solve the previous equation, an explicit finite difference MATLAB code has been written. By using the aforementioned code, it was easy to determine the settling length for different soil classification. It is clear that the sedimentation trap zone length should not be less than 400 m.

Simulation of BOD Transport

Because the pilot drain receives untreated sewage water besides the agricultural water, it is of interest to simulate the decay/growth of the biological oxygen demand which is considered as the most important parameter for describing the quality of wastewater. BOD removal efficiency of the system could be obtained by solving the BOD transport equation (Reed et al., 1988, Hammer, 1990):

$$\frac{d(BOD)}{dt} + \frac{ud(BOD)}{dx} = -k(BOD)$$

Where:

BOD = biological oxygen demand concentration

U = local velocity of the system obtained from the hydrodynamic part

K = decay coefficient

An explicit finite difference MATLAB code has been written to solve the previous equation to determine the removal efficiency of the typical design scenario. Moreover, sensitivity analysis of the decay coefficient has been conducted to measure the effect of uncertainty in k on the BOD removal efficiency as presented in Figure (7).

It is noticed that the average BOD removal efficiency is about 65%. It is also clear that the results are sensitive to the decay coefficient value as an increase of 25% in k resulted in a variation of 22.5% in the outlet BOD.

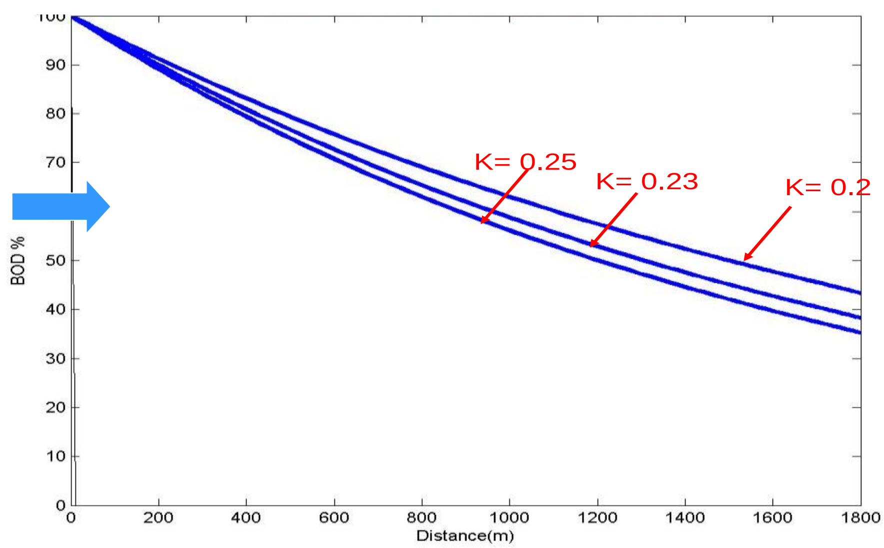


Figure 8: BOD spatial decay along the drain pilot

Fecal Transport and Decay/Growth Simulation

The survival of Fecal Coliform (FC) in an aquatic environment depends upon their ability to tolerate a set of alien biological, physical and chemical conditions. The most important factors that control the rate of decay are temperature, solar intensity, and pH (Auer and Niehaust, 1993). In order to consider the spatial variation of the fecal concentration in addition to the time response, a mathematical model based on the traditional advection-diffusion equation is adopted. The model governing equation is given by the following equation:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left[Dx\,\frac{\partial C}{\partial x}\right] - u\,\frac{\partial C}{\partial x} + \sum_{z=1}^{np} r_z$$

Where:

C	=	FC count (MPN/100 ml)
t	=	time (day)
x	=	longitudinal distance (m)
u	=	average speed in the x direction (m/d)
r_z	=	term describing each one of the physical, chemical or biochemical processes responsible for modifying the polluting concentration (MPN/100 ml/d)

The spatial variation of FC with the distance downstream for two different values of the decay rate of 1.2 and 0.4 day^{-1} have been selected to cover the expected range of k. It has been noticed that the FC count is highly sensitive to the assumed value of k and the expected removal efficiency of FC is from 40% to 70%.

Pilot Area Drain Design

Based on the aforementioned results of the hydrodynamic simulation and the transport analysis, it is proposed to carry out the following steps to modify the drain to work as in-stream wetland treatment scheme.

Reformation of Drain Bed Profile: The bed profile of Al-Bahoo drain is proposed to be smoothly reformed to form the sedimentation trap. The sedimentation trap is proposed to extend from the drain inlet (Station: 1+720) to (station: 1+200) with a length of 520 m. The sedimentation trap needs to be rehabilitated and maintained regularly (minimum rate of reformation and excavation is bimonthly). A nearby area of about 0.5 acre should be allocated for the project to receive dredged sediment from the sediment trap.

Planting of Aquatic Plants: Two types of aquatic plants are proposed; the first type is the phragmites to be implanted downstream of the sedimentation zone between stations (8+50) and (7+50). The second type of plants is the water Hyacinth and it will be used 185 m downstream of the aforementioned aquatic zone between stations (6+50) and (5+50). A trash screen at station (5+50) is highly recommended to control the booming of water Hyacinth and regular maintenance is still required.

End Weir: The end weir plays the most important role in controlling the detention time throughout the in-stream wetland channel system. Since the water level of the drain is expected to vary with the time, it is proposed to build an adjustable-crest end weir. The weir consists of a 25 cm sill and a number of timber logs (5 logs) each of height 10 cm. In case of fixing all the logs, the total weir height reaches 75 cm. The proposed system is provided with a cheap lifting system for fixing/removing logs in accordance with the situation and the need.

Detention Time: It is important to estimate the expected detention time of the proposed system considering the aforementioned details. Therefore, a final run using HEC-RAS has been conducted and the detention time was found to be 3.0 to 5.0 days (considering the full height of the end weir).

Conclusions

The detention time has been selected to be a critical design criterion for in-stream wetland channel systems. The higher the detention time the better the quality of the effluent water. The study proposed different design alternatives. The detention time could be significantly increased from its typical current value of 6-8 hrs to more than 68 hrs (about 3 days) by using simple elements (such as sedimentation trap and end weir).

After examining the significance of each element (sedimentation trap, end weir and baffles) in the typical arrangement, it has been found that:

- The end weir plays the most important role in controlling the detention time throughout the PIW channel system. The higher the crest of the end weir the longer the produced detention time of the system.
- Interior baffles do not have significant effect on the produced detention time of the system.
- Aquatic floating plants have small effect on the produced detention time. It is found that, as the thickness of the aquatic floating plants gets bigger and/or the plants' aerial density gets higher, the detention time gets longer.
- The discharge variation has a nonlinear response to the detention time. An increase of 50% in Q will cause the detention time to decrease by 36% whereas a decrease in Q by 50% causes the detention time to increase by 91%.

The preliminary computational results of this study showed that a removal efficiency of 60% for BOD could be easily achieved using the proposed design arrangement. Moreover, the preliminary analysis found that the expected removal efficiency for the Fecal Coliform is expected to reach 70%. The proposed in-stream wetland requires at least a bimonthly removal of deposition material from the sediment trap. A reduction of the efficiency of the system might take place if the depositions are not regularly removed.

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ENVIRONMENTAL CAPABILITIES AND CONSTRAINTS OF HALOCULTURE: ALTERNATIVE STRATEGY TO USE SALINE WATERS IN MARGINAL LANDS

Farhad Khorsandi[1,*]

Abstract

Disposal of saline agricultural wastewaters is a complex environmental challenge for agronomists and irrigation managers. The rise in world population, shortage of premium agricultural lands, and scarcity of fresh water resources, particularly in arid regions, makes it necessary to use non-conventional saline water resources and marginal lands to meet the escalating demand for food and drinking water needs. *Haloculture* offers a strategy for sustainable use of highly saline soil and water resources to provide some of the future human needs. Haloculture is sustainable production of different agricultural and industrial products in saline environments. A saline agricultural drainage water Haloculture agro-industry model is presented, which serves as an economic option for their reuse, and thus, reducing their negative environmental impacts. Along with development of strategies for sustainable and profitable production of bio-products, Haloculture also emphasizes on providing energy and drinking water as the basic needs of rural societies who are going to implement those strategies in less developed, salt affected regions. Haloengineering is briefly introduced as a complementary component of Haloculture. Various activities in Haloculture depends on the input of waters with different salinity levels. Thus, a new guideline for utilization of saline waters in Haloculture is presented. Several cases of Haloculture projects with various degrees of success and failure operated nationally and internationally. The mega project on Haloculture undertaken by Iran Water and Power Resources Management Company in four southern coastal provinces of Iran, are described in more details. Haloculture is recommended in areas where conventional agriculture is not physically and/or economically feasible. Environmental stewardship is an important component of a sustainable production system. Thus, the main objective of this article to evaluate the environmental services and constrains of Haloculture. Haloculture has significant environmental potentials in salt-affected arid regions, in terms of combating desertification and erosion, sustainable use of agro-biodiversity, restoration of rangelands, remediation of degraded lands, and greening of coastal areas, reforestation of marginal and degraded lands, restoration and rehabilitation of wildlife and marine habitats, and carbon sequestration. Possible environmental constraints of Haloculture should be considered in development of Haloculture projects. The main possible negative impacts of Haloculture on environment are escalating soil salinity, introduction of invasive exotic plant and aquatic species, degradation of local ecosystem, and possible adverse effects of saline water irrigation on ground water quality. Development of Haloculture projects in previously

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undeveloped inland salt affected regions and coastal zones, should be done with thorough ecological and environmental impact assessment.

KEY WORDS: Biosaline agriculture, Desalination, Drainage waters, Haloengineering, Halophyte, Haloventure, Saline aquaculture, Seawater agriculture

Introduction

Management and disposal of saline agricultural wastewaters, comprised mainly of saline waters from drainage projects, aquaculture ponds and desalination plants, has always been a critical social and environmental challenge for agronomists and irrigation managers. Reusing saline wastewater resources for crop irrigation and saline aquaculture activities for their disposal and conservation of fresh water supplies for other activities, has been of interest for decades, particularly in arid regions and when other water supplies become scarce during drought (Grismer and Bali, 2015). Many wheat farms in southern regions of Khuzestan, Iran, are irrigated using saline drainage waters (4-15 dS/m) directly or in combination with fresh waters, to reduce the impacts of drought stress on wheat (Akbari Fazli et al., 2013).

Saline agricultural wastewaters and other saline water resources (i.e. seawater, saline surface and groundwater resources) are considered as non-conventional waters. Non-conventional water is defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose (Pescod, 1992). Therefore, the use of non-conventional water requires adoption of more stringent and prudent environmental management practices and monitoring procedures. The use of highly saline waters, unusable by common agricultural crops, may be feasible for production of halophytes, which could be consumed for human and animal consumption, as well as, production of other useful products such as algae, saline aquaculture and energy. Hence, this approach will turn highly saline water resources from waste product to a valuable asset.

According to FAO statistics, global food production needs to increase up to 70% by 2050 to ensure adequate and safe access to food for the burgeoning population (Panta et al., 2014). This is also true in arid and semi-arid regions, where fresh water resources are scarce and are in high demand for urban consumption. As most of the productive soils are being used for agricultural production and inter-sectoral competition between agriculture and other segments of economy are increasing, there is little scope for agricultural expansion in prime lands (Qadir and Oster, 2004).

About 950 Mha of land surfaces and 50% of irrigated lands (230 Mha) are salt affected in the world (Ruan et al., 2010). In addition, out of 1386 million cubic kilometers of total world water resources, less 1% (about 10.6 million cubic kilometers) are actually available for human use. The rise in world population, will also put more pressure on available good quality water resources, to meet the escalating demand for urban use and drinking water needs. It is believed that the need for increased food production cannot be achieved merely by cultivating the currently available arable lands (Shabala, 2013). Consequently, using marginal areas, such as salt affected lands, and alternative water resources, such as saline waters, for agricultural production, could be an inevitable option to achieve the human food needs in future. Therefore, it is necessary to expand the utilization of more salt tolerant plants, particularly halophytes, and livestock that can tolerate saline drinking waters and halophyte forages, such as camel, as well as, expanding saline aquaculture to provide the necessary human food supplies in future.

Cultivation of salt tolerant crops and halophytes is seen as a practically feasible and economically viable option for utilizing the saline soil and water resources, and conserving fresh water for other much needed purposes (Glenn et al., 1998, 1999; Ladeiro, 2012; Ventura and Sagi, 2013; Panta et al., 2014; Agnihotri and Kumar, 2015; Sharma and Singh, 2015; Ventura et al., 2015). Under these circumstances, the need for a technology that is practical, requires low inputs and is sustainable in longer runs becomes imperative. *Haloculture* can be a sensible and practical option under such conditions. Environmental integrity and stewardship is an important aspect of sustainability. Thus, the main objective of this article is to evaluate the important environmental services and constraints of Haloculture as an integrated system for productive use of saline soil and water resources.

Principles of Haloculture

Haloculture is proposed as a holistic approach for (i) sustainable management and utilization of saline soil and water resources for increased agricultural production, (ii) combating the damages caused by desertification, erosion and dust storms, and (iii) generating employment opportunities and socio-economic improvements in the less developed regions. Haloculture is defined as the sustainable production of different agricultural and industrial products in saline environments (Fig. 1). Agricultural products include diverse outputs from plants (agronomic, horticultural, forestry, pasture, ornamentals and medicinal plants), animal (small and large livestock, poultry, honey bees, etc.) and aquaculture (fishes, shrimps, seaweed, algae, artemia, halophiles, etc.). Similarly, industrial products refer to processed forms of the agricultural products as well as the production of water, salt and energy. Genetic biodiversity is the key to the productive use of saline environments. It includes plant, animal and microbial resources that can be grown in saline lands and/or aquatic environments. Due to the significant differences in agro-climatic conditions, Iran boasts rich genetic diversity of crops, animals and microorganisms for profitable Haloculture under variable saline conditions in different geographic locations. Availability of diverse potential resources, either individually or in combination with each other, literally means a diversified Haloculture. Based on empirical evidences regarding the shortcomings of crop monocultures (Hennessy, 2004; Suárez and Emanuelli, 2009), it is always desirable to have an integrated Haloculture production system. This will enable the efficient use of the available resources and will minimize the risks caused by adverse conditions (such as extreme climatic events) by enhancing the resilience of the system (Hendrickson et al., 2008; Manjunatha et al., 2014).

Seawater agriculture and Biosaline agriculture, which have been proposed in the past, are somewhat similar concepts as to Haloculture. However, what sets Haloculture apart from these similar perceptions, is the emphasis on human factor. Similarly, Haloculture utilizes both saline soil and water resources. Usually these resources are found in less developed regions with harsh climatic conditions, where lack of infrastructures such as roads and electricity, and shortage of drinking water is evident in the life of local inhabitants and rural societies. If Haloculture, or similar concepts in this matter, is going to be extended and promoted for sustainable development of salt affected regions, particularly in arid and desert areas, one must consider that who is going to actually implement these strategies in those harsh climates, with shortage of basic human needs (i.e. drinking water and energy)? Therefore, Haloculture not only aims at economic and sustainable production of useful bio-products, but also at the same time, aims at producing the energy and drinking water needed for human societies who are going to implement such strategies, as well. Thus, a complementary and crucial component of Haloculture that addresses this important issue, is the engineering aspects of Haloculture, so called *Haloengineering*. Haloculture engineering or Haloengineering is the harmonic, interdisciplinary application of concepts, methods and tools of all engineering fields, for sustainable development and improvement of living standards of mankind in arid and salt affected regions, with the use of locally available, basic resources for production and management of energy and water. The engineering aspects of Haloculture for providing the basic human needs in salt and drought affected areas will be discussed in another occasion with further details.

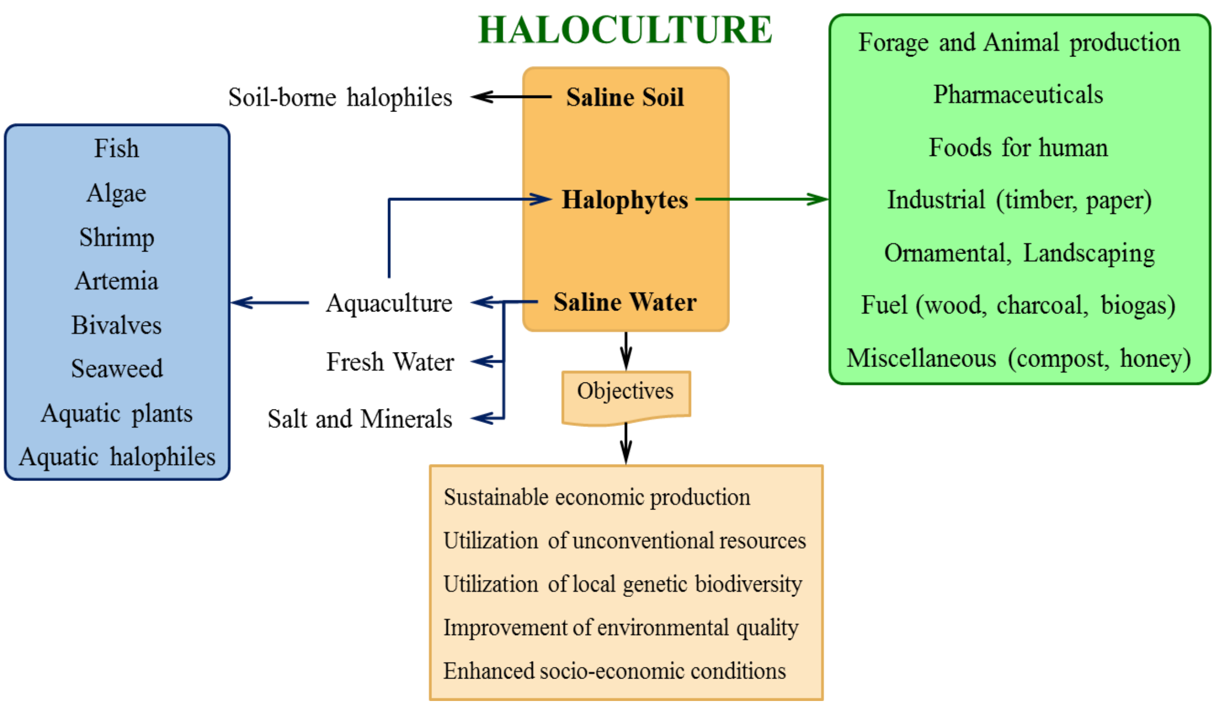

Figure 1. Schematic representation of the principles and objectives of Haloculture.

Guidelines for saline water utilization in Haloculture

The salt-affected water resources that can be used productively, include saline surface and ground waters, sea water, agricultural drainage waters, discharged effluents from saline aquaculture ponds and brines from desalination plants. A Haloculture Agro-Industry Complex is called *Haloventure*.

The first phase of Haloventure starts with saline aquaculture with fish, shrimp, algae or other marines. The water discharged from aquaculture is used for halophyte production. In fact, halophytes are regarded as new agronomic crops with various economic uses in Haloculture (Fig. 1). Most often, the salinity of such lands is too high for profitable production of conventional agronomic crops. The drainage water from halophyte farms, which has more salinity than the water used in previous phases, may be collected and reused in hypersaline aquaculture production, such as artemia and highly salt tolerant microalgae. The brine discharged from this phase should be disposed properly to make economic uses, and more importantly, prevent the environmental harms. The economic activities in this phase may include salt and mineral harvesting (Ahmed et al., 2000, Surinaidu et al., 2016) or producing clean energy by technologies such as salinity gradient solar ponds (Malik, 2011, Saifullah et al., 2012).

Various activities in Haloculture depends on the input of waters with different salinity levels. Several water quality classification systems that are based on water salinity, has been proposed for conventional agriculture in India (Tanwar, 2003), Australia (Mayer et al., 2005) and by FAO (Rhoades et al., 1992). One of the most popular saline water classification systems is the one by FAO, which is presented in Table 1. All of aforementioned systems recommend only saline waters of up to 10-12.5 dS/m for agricultural purposes. However, it is now evident that through strategies such as Haloculture, water salinities even higher than seawater may be used for production of various bio-products. Therefore, a new guideline is needed to help farmers and entrepreneurs with exploring the extensive capabilities of saline waters for agricultural products that could be produced profitably. Table 2 offers a guideline for utilization of saline waters in Haloculture.

Table 1. Saline water classification by FAO (Rhoades et al., 1992).

Water class	Water salinity (dS/m)	Salt concentration (mg/l)	Type of water
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7 - 2	500-1500	Irrigation water
Moderately saline	2 - 10	1500-7000	Primary drainage water and groundwater
Highly saline	10-25	7000-15 000	Secondary drainage water and groundwater
Very highly saline	25 - 45	15 000-35 000	Very saline groundwater
Brine	>45	>35 000	Seawater

Haloculture in practice

The Haloculture integrated production system may be practiced as Haloventure in saline lands by using high salinity waters in coastal areas that are available from seas and oceans. Brines discharged from coastal desalination plants can also be a viable resource in those areas. Inland Haloventure projects in saline areas may also be practiced using inland saline water resources, especially saline agricultural drainage waters (Fig. 2). Installation of drainage system in halophyte farms will greatly contribute to the sustainability of the project by controlling the salt load on the farms to reach above the salt tolerance of the highly salt tolerant and halophyte plants. It also contributes to the sustainability, economic profitability and environmental stewardship of inland Haloventure projects, by providing additional opportunities for the reuse of the saline water resources for various economic activities, rather than contaminating ground and surface water resources.

Table 2. General guidelines for utilization of saline waters in Haloculture.

Water class	Water salinity (dS/m)	Crop production	Aquatic plants, Microalgae, Seaweed	Aquaculture
Drinking water[§]	<1.5	Suitable[*]	Suitable[*]	Suitable[*]
Marginally saline	1.5-4	Suitable for most crops 30-50% yield reduction in salt sensitive and very sensitive crops	*Azolla* and *Lemna* aquatic plants Many species of *Chlorella* and *Spirulina* microalgae	Fresh water ornamental fishes up to 3 dS/m - Carp fishes (Common carp, Bighead, Grass carp, Silverhead), trout, tilapia, Asian sea bass and Sobaity seabream - White shrimp
Slightly saline	>4-8	Suitable for salt tolerant crops 50% yield loss in moderately salt tolerant crops	*Azolla* and *Lemna* species Some species of *Chlorella* and *Spirulina* microalgae	Some species of salt water ornamental fishes - Carp fishes, trout, tilapia, Asian sea bass and Sobaity seabream - White shrimp - Salt water crocodile
Moderately Saline	>8-12	30-50% yield reduction for salt tolerant and moderately salt tolerant crops Suitable for halophytes[**] Usually, increased growth in obligatory halophytes	*Azolla* and *Lemna* species Some species of *Chlorella* and *Spirulina* microalgae	Some species of salt water ornamental fishes - Carp fishes, trout, tilapia, Asian sea bass and Sobaity seabream Sturgeon (lower optimum level 10 dS/m) White shrimp Salt water crocodile
Saline	>12-25	Above 50% yield loss in salt tolerant crops irrigated with saline water >16 dS/m Suitable for most facultative halophytes and all obligatory halophytes	*Azolla*: reduced growth after 13 dS/m *Lemna*: reduced growth after 16 dS/m Some species of *Chlorella* and *Spirulina* microalgae	Some species of salt water ornamental fishes - Trout, tilapia, Asian sea bass and Sobaity seabream - Grouper and Sea breams from 19 dS/m Sturgeon (optimum up to 21 dS/m) - White shrimp Salt water crocodile
Highly saline	>25-45	Suitable for many facultative and obligatory halophytes	*Spirulina* microalgae up to 30 dS/m *S. platensis* up to 39 dS/m	Some species of salt water ornamental fishes - Salt tolerant tilapia, Asian sea bass, Sobaity seabream, Grouper and Sea breams - White shrimp and oyster - Sea cucumber from 32 dS/m - Salt water crocodile
Hypersaline	>45-65	30-50% yield loss for some obligatory halophytes	*Dunaliella tertiolecta* microalgae Seaweeds: *Gracilariopsis persica*, *Sargassum boveanum*, *Hypnea flageliformis* and *Cystoseira trinodis* - Seagrasses	Salt tolerant tilapia, Asian sea bass, Sobaity seabream, Grouper and Sea breams - White shrimp – oyster - Sea cucumber - Salt water crocodile
Slightly Brine	>65-200	More than 50% yield loss in obligatory halophytes	*Dunaliella salina* microalgae, optimum up to 150 dS/m Seagrasses up to 90 dS/m and reduced growth afterwards	*Artemia urmiana*: Optimum salinity range in polyethylene tanks and concrete pools is 65-80 dS/m Optimum salinity range in earthen pools is 70-195 dS/m
Moderately Brine	>200-350	Unsuitable	*Dunaliella salina* microalgae	*A. urmiana* can live up to 364 dS/m and *A. parthenogenetica* can live up to 286 dS/m
Brine	>350	Unsuitable	*Dunaliella salina* microalgae, grows up to 450 dS/m but may not be economical	*A. urmiana* has been seen in waters up to 442 dS/m, but may not be economical

§ based on World Health Organization drinking water classification (WHO, 2011).
* By considering the social priorities and considerations, supplying the local drinking water needs is the priority.
** Halophyte commercial cultivation if economically more feasible than conventional crops.

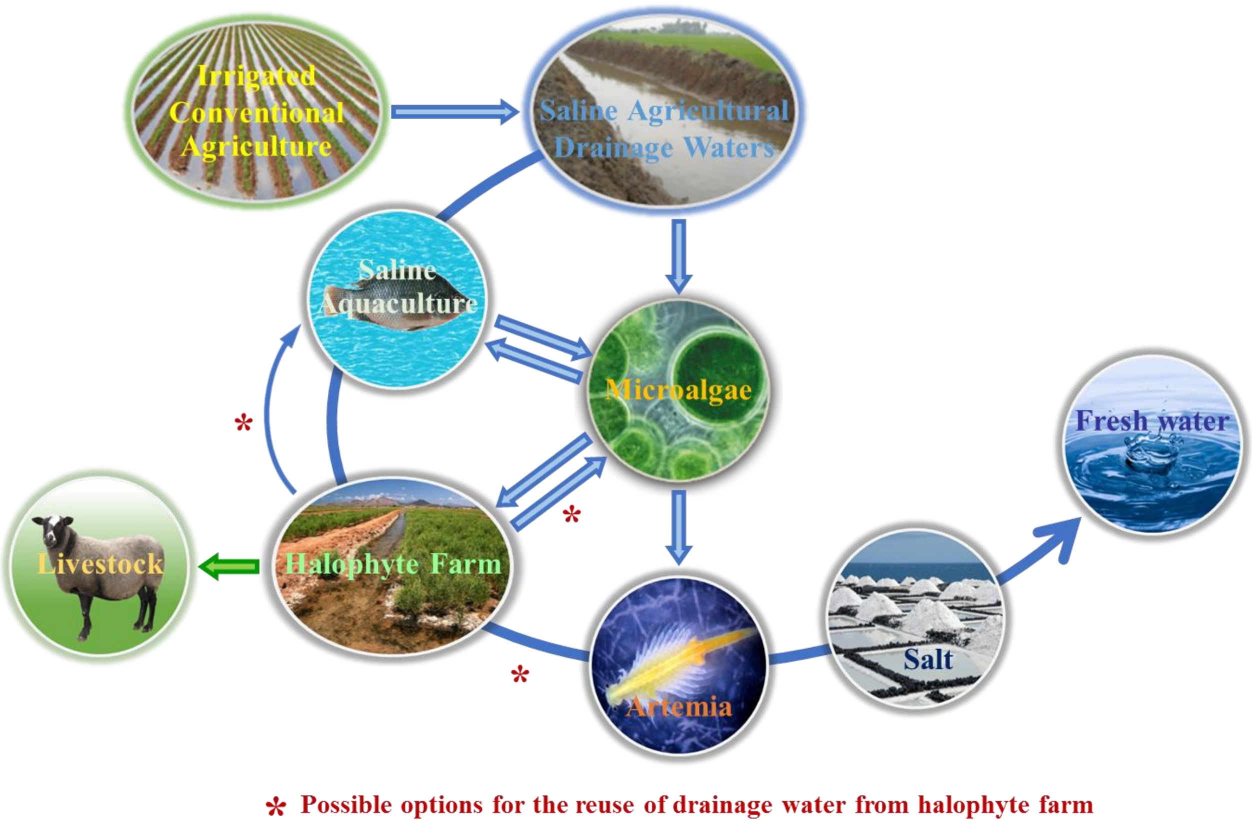

Figure 2. An inland Haloventure example model with saline drainage waters (>12 dS/m).

Salt water aquaculture and mariculture has been widely practiced, and is a prime example of economic utilization of saline water resources throughout the world. Traditional shepherds has used halophyte forages for their herds, particularly during winter season when there is shortage of forages. Australian livestock industry use halophytes extensively for grazing their cattle. The use of halophytic forages has also grown in Pakistan and India in the last decade. Indigenous tribes in many parts of the world, particularly in Australia and American continent, has consumed halophytes as fruits, vegetables, foods, timber, firewood and building materials. It seems that in the last two decades, commercial production of halophytic vegetables has grown, particularly in Europe, where there is a market for such products in human diet. Several companies specialize in production of sea vegetables, such as Salicornia, sea fennel, salsola, sea kale, sea aster and sea beet in Belgium and Netherlands.

Several Haloculture projects with varying degrees of success and failure operated internationally. Examples are given below.

International experiences

Manzanar Project, Eritrea: Manzanar Project, running since 1987, is one of the oldest and most successful non-profit Haloculture projects, which was implemented by an American scientist in

Eritrea (Sato, 2009). The main goal of this simple and low-technology project was purely humanitarian. Manzanar Project aims at utilizing seawater for coastal mangrove plantations by local poor-resource farmers, who use them as a sustainable source of forage for their goat herds. As a side benefit, mangrove plantations has improved the marine ecology at the seacoast, thus producing extra fishing opportunities for the farmers as well.

Integrated Seawater Agriculture System, Eritrea: Seawater Foundation was one of the active companies in sequential utilization of sea water for different products, known as Integrated Seawater Agriculture System (ISAS). They started their first seawater farm in Eritrea in the year 1998, producing shrimp, Salicornia and mangrove (Bailis and Yu, 2012). The farm, however, was shut down after 5 years in 2003 due to political instability within the government of Eritrea.

Integrated Seawater Agriculture System, Mexico: The second seawater farm was established in Bahia Kino, Mexico, with the aim of producing Salicornia for biofuel, as well as, shrimp and mangrove. The activities in Bahia Kino seawater farm was stalled by the year 2010 due to mismanagement and community opposition (Bailis and Yu, 2012).

Organization for Agriculture in Saline Environments, the Netherlands: Organization for Agriculture in Saline Environments (OASE) is the offspring of a successful and logical collaboration and investment by the government of Netherlands and private sector. Ministry of Agriculture, Nature and Food Quality of Netherlands completed a feasibility study on commercial use of highly saline waters for bio-products in the year 2000. They designated their priorities as halophyte production for renewable energy and food, biochemical extraction and salt water aquaculture (van Oosten and de Wilt, 2000). Consequently, OASE was established in the year 2005 and have been successfully active internationally since then. They are operating projects in the saline coastal areas of Mexico's Baja California and Colorado Delta on halophyte food and fodder production, as well as, Biosaline agroforestry in saline wastelands for energy, wood and charcoal.

The Sahara Forest Project, Qatar: More recently, a Norwegian based company has started The Sahara Forest Project, an ambitious sea water project in deserts of the Qatar. The main objective of the project is profitable production of food, water, biomass and clean electricity in desert areas (SFP Foundation, 2013). This project uses seawater for integrated production of desalinized water by a Concentrated Solar Power system, saltwater-based greenhouse crops, halophytes, microalgae and salt.

Integrated Multi-Trophic Aquaculture, China: Integrated multi-trophic aquaculture (IMTA) in Sanggou Bay, China, is a prime example of large scale, integrated marine aquaculture production system with seawater. This project produces more than 240000 tons of assorted seafood annually in an area of about 10000 ha, utilizing more than 30 marine species (Fang et al., 2016). The project seems to adhere closely to the basic principles of sustainability.

Haloculture practices in Iran

Various activities of Haloculture has been practiced in Iran, mainly as separate economic ventures but not as agro-industry complexes.

Saline aquaculture: Saltwater fish, shrimp and artemia productions have been common aquaculture activities in Iran for a few decades, although, commercial artemia aquaculture is relatively new within the country. Seaweed and microalgae production in Iran, as well as their processing for bio-products, has been successful at research and pilot levels in recent years. Management of nutrient rich and highly saline discharges from aquaculture, particularly from shrimp farms in the southern coast of Iran, is an important environmental issue and concern. This problem can be properly managed if they can be used for irrigated halophyte cultivation and/or microalgae and artemia productions.

Halophyte cultivation as new agronomic crops: Commercial halophyte production is very limited in Iran. Farmers in Borazjan (Boushehr Province) cultivate *Suaeda aegyptiaca*, a halophyte plant known locally as *Kakol*, in highly saline lands and irrigate it with saline waters. *Kakol* is highly popular in southern part of Iran as fresh vegetable. Iran participated in the International Atomic Energy Agency (IAEA) interregional project INT/5/144 “Sustainable Utilization of Saline Groundwater and Wastelands for Plant Production” in 1997 (Pedraza, 2009). The project lasted for 6 years and was completed successfully in Chah Afzal, Yazd Province. The importance of this project was that for the first time in Iran, halophytes were screened and considered as possible new agronomic crops. Since then, National Salinity Research Center of Iran has been involved with several international and national research projects with halophytes, particularly forage halophytes. However, the results has not yet led to introduction of any halophytes as a new agronomic crop, or to a commercial scale cultivation of halophytes. Nevertheless, ship, goat and camel shepherds has been traditionally using halophytes for grazing their herds in different parts of Iran for centuries.

Salt production: Water desalination is gaining popularity, even among farmers, who suffer from extreme shortage of fresh water and high salinity of their water resources. The main goal of these farmers is not to produce drinking water, but to reduce the water salinity to a level that is low enough for irrigation of their crops. However, due to shortage of drinking water and drought in many coastal regions of the country, mega scale desalination units are going to be constructed for the purpose of producing drinking water. Salt production has been practiced traditionally in various parts of the country for centuries. Salt production from discharged brines of desalination plants may be a viable strategy for reducing the negative impacts of the brine disposal to marine ecosystems.

Haloculture mega project in southern coastline provinces: More recently, a mega project on sustainable development of southern coastal regions of Iran by Haloculture technology, has been proposed and started by Iran Water and Power Resources Management Company (IWPCO), Ministry of Energy. One of the major significances of this project is their multi-disciplinary and integrated approach to the issue. This mega project is undertaking a feasibility study on

Haloculture expansion, and locating the appropriate areas for development of Haloculture agro-industrial complexes within the four coastal provinces of Iran (Khuzestan, Bouhehr, Hormozgan and Sistan and Balochestan) along Persian Gulf and Sea of Oman coastlines (Fig. 3). The project covers an area of about 38.5 million ha, and more than 3820 km of coastline, making it the largest project of its kind in the world. The comprehensive feasibility project covers various aspects of economic, social, environmental, natural resources (including halophytic flora), saline soil and water resources, tourism, and agricultural potentials of the four provinces. The available saline water resources that is considered includes seawater, underground and surface saline water resources, aquaculture discharges, brines from desalination plants and agricultural drainage waters. Along with feasibility study, a total of 10 pilot farms and experimental projects has started in all the four provinces. The pilot farms are engaged in Salicornia production as oil seed crops (both with sea water and shrimp farm saline discharges), and seaweed production in both sea and shrimp farm discharge canals. This mega project for the first time will institutionalize Haloculture in Iran as a new integrated agricultural system, and plays an important role in expansion of Haloculture among farmers and entrepreneurs.

Figure 3. Map of the Haloculture mega project by IWPCO.

Although various economic activities of Haloculture has been successfully practiced in Iran for many years, the holistic, integrated production system of Haloculture, or Haloventure per se, has not been implemented in the country thus far. Iran has immense and extensive potential for expansion of Haloculture. Environmental considerations will play a crucial role in sustainability of Haloculture production system.

Environmental services of Haloculture

The types of lands proposed for use in Haloculture are inland and coastal marginal wastelands, saline degraded lands, salt marshes and in general, the salinized lands that are not capable of producing conventional agronomic crops economically. Haloventure complexes may also be constructed in coastal areas that are heavily impacted by aquaculture or salt water intrusion due to groundwater withdrawals, sea-level rise or other factors (Bailis and Yu, 2012). As previously mentioned, cultivation of highly salt tolerant crops and halophytes is an important activity in Haloculture. Halophytes can be used either for environmental purposes or for biomass production. Environmental benefits and services of Haloculture are enormous. A self-explanatory example of such services is presented for a halophyte tree plantation program in highly saline lands of Chah Afzal area, Yazd (Fig. 4). Environmental benefits of Haloculture include:

- Combating desertification and soil erosion,
- Remediation of degraded lands (such as those contaminated by petroleum industries),
- Restoration of rangelands and greening of coastal areas,
- Reforestation of degraded salt-affected lands,
- Utilization of saline wastewaters thus preventing their environmental harms to sensitive and marine ecosystems.
- Restoration and rehabilitation of wildlife and marine habitats, and
- Carbon sequestration and soil quality improvement through addition of organic matter, salt alleviation and soil structure improvement.

High capability of halophytes for phytoremediation of heavy metal contaminated soils and saline soils has been demonstrated (Manousaki and Kalogerakis, 2011; Hasanuzzaman et al., 2014). Haloculture is also a practical method for the prevention of environmental damages that may be caused by the disposal of saline agricultural drainage waters, nutrient rich waters discharged from aquaculture farms, and saline and brine discharges from water desalination plants. Research studies demonstrated that *Salicornia europaea* is an effective halophyte for biofilteration of saline wastewaters from commercial marine fish and shrimp farms (Webb et al., 2012). Studies in South America has showed that integrated production of fish + halophyte forage + livestock production was a successful scheme for turning the environmental problem of brine reject disposal in inland areas, to a productive agricultural activity (Sanchez et al., 2015).

Figure 4. An example of valuable environmental services of Haloculture: left- a barren saline land and right- a rehabilitated saline land through halophyte planting (Tamarix as windbreak and Haloxylon for wood) in Chah Afzal, Yazd Province, Iran (Pedraza, 2009).

Adverse effects of discharged saline agricultural wastewaters on surface and ground water qualities, is an environmental concern in conventional agriculture. Haloculture offers a strategy for successive reuse of saline agricultural waters for economic production of useful products, and thus, discourages disposal of such waters to surface water bodies. With rapid development of desalination plants in arid regions, especially on the coastlines, discharge of hypersaline brines to ocean has become an alarming environmental issue. Haloculture can be a viable solution to this environmental problem as well, particularly in coastal areas.

Environmental constraints of Haloculture

There may be some unintended environmental impacts of Haloculture that should be taken into considerations before initiating such projects. Secondary salinization of soils, introduction of invasive exotic plant and aquatic species, and contamination of surface and ground water resources are the main environmental concerns about Haloculture. Haloculture is recommended in areas where conventional agriculture is not physically and/or economically feasible. Such areas include highly salinized agricultural lands, salt marshes, sandy coastal plains and deserts, and degraded desert lands with sparse vegetation. However, If Haloculture is going to be implemented in previously undeveloped coastal zones, then it may have negative environmental impacts (Bailis and Yu, 2012). Therefore, careful environmental impact assessment should be conducted under this condition.

It should be mentioned that sustainability and environmental considerations with respect to Haloculture and other similar activities such as Biosaline agriculture or Seawater agriculture, emerge from the damages caused by irrigated agriculture. In fact, many of the irrigation projects throughout the world have inflicted enormous damages to soil and environmental health. The fact that a great proportion of global irrigated lands are currently severely affected by irrigation induced salinization is a convincing evidence to this claim (Munns, 2005, Shabala, 2013, Sharma and Singh, 2015).

A legitimate concern about Haloculture, and in general about the use of saline water resources in agriculture, is the secondary soil salinization. In fact, if natural soil drainage capacity is low, the continuous use of saline waters for irrigation, may lead to high salt accumulations in root zone, harmful to even salt tolerant halophyte plants. Sanchez et al. (2015) reported progressive salinization of the land irrigated with saline water discharges from inland desalination plants. Therefore, it is strongly recommended that in areas having restricted soil drainage, artificial drainage systems should be installed to ensure the sustained reuse of the saline drainage water in activities such as saline aquaculture, artificial wetlands or solar salt ponds.

Utilization of endemic biodiversity in various bio-production activities of Haloventure is highly emphasized in Haloculture. That is because they are naturally adopted to local climate and ecological conditions. In addition, local farmers are more familiar with native and local halophytes and their economic values and uses, and thus, are more willing to adopt those species for agronomic production. However, in some cases utilization of exotic and non-endemic plant and animal species may be needed. In general, it is highly emphasized in Haloculture that introduction of new plant and animal species from other regions or countries should be done with caution and under the advice of experts in the concerned field. In addition to considering invasive species, when constructing Haloventure projects, the developers must also consider conservation values and ecosystem function, buffer zones and ecological corridors (Bailis and Yu, 2012). This is especially true in previously undeveloped coastal areas.

Percolation of saline wastewaters and highly saline irrigation waters into ground water resources, and thus adversely affecting its water quality, is a valid environmental concern, that is not only pertinent to Haloculture, but also to conventional agriculture as well. Halophyte farms irrigated with various saline waters maybe established in three situations (a) farms with high levels of secondary salinization, (b) inland deserts situated on saline aquifers, and (c) coastal deserts and saline coastal plains. In the first case, soil physical and chemical characteristics should be evaluated to identify the reasons for development of secondary salinization, in order to adopt the best management practices for the intended halophyte farms. In this case, installation of drainage systems to collect and reuse the drainage water and prevent it from percolating to fresh water aquifers is highly recommended.

Irrigation of halophytes with saline waters on the farms situated above saline aquifers should not affect water quality of the ground water significantly. That is because the saline water pumped for irrigation of the farms, will drain back to the aquifers that were saline from the beginning. Studies with saline discharges from desalination plants in southern Arizona, United States (5% leaching fraction) revealed that these farms can be productively utilized through halophyte plants for at least 100 years without negatively affecting the groundwater quality more than conventional irrigated agriculture under the similar conditions (Riley et al., 1997). Soil texture of the intended halophyte farms in coastal deserts and plains is usually sandy and have adequate natural drainage capacity.

Irrigation of the farms with highly saline seawater most likely should not impose an adverse effect on the ground water quality, since it will move back to the ocean again. Halophytes usually require less fertilizers than conventional crops, and the seawater can provide most of the nutrients that they need. However, if the farms require high nitrogen fertilizers, then it might contaminate the ocean and cause coastal microalgae bloom. There was an unresolved dispute between Eritrean Department of Environment and Seawater Farms Eritrea (SFE) over the level of nitrogen and phosphorous concentrations in the effluents produced by SFE and its possible involvement in occurrence of coastal algal bloom (Bailis and Yu, 2012). In this case, installation of drainage system to collect and reuse nutrient rich saline waters from the farm for other economic or environmental operation, is recommended.

Conclusions and recommendations

Haloculture has significant potentials in salt-affected arid regions, in terms of combating desertification and other environmental services that it offers, sustainable utilization of saline soil and water resources, sustainable use of agro-biodiversity, generation of employment and income opportunities for the resource poor farmers, and improving the socio-economic conditions of communities in salt affected areas. Environmental integrity is one of the key issues in sustainability of Haloculture. Besides its significant environmental benefits, possible environmental constraints of Haloculture should be considered in development of Haloculture operations. The main possible negative impacts of Haloculture on environment are secondary salinization of soils, introduction of invasive exotic plant and aquatic species and degradation of local ecosystem, and possible adverse effects of saline water irrigation on ground water quality.

Haloculture is recommended in areas where conventional agriculture is not physically and/or economically feasible. However, development and implementation of Haloculture projects in previously undeveloped inland salt affected regions and coastal zones, should be prepared with thorough ecological and environmental impact assessment. For successful implementation of Haloculture in the country, some capacity building measures are recommended. Education of the policy makers, scientists, communities and farmers about the potential applications and shortcomings of Haloculture is necessary. Extension and demonstration of the applicability, practicality and the socio-economic and environmental benefits of Haloculture is highly recommended.

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A STUDY ON CAPILLARY RISE IN CONTROLLED DRAINAGE SYSTEM AND ITS COMPARISON WITH UPFLOW MODEL

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Abstract

Water flowing upward through the capillary pores of the water table in unsaturated soil is defined as capillary rise and it depends on the water table depth, evapotranspiration and the soil type. Controlled drainage is an appropriate management strategy to control the water table. In the present study, the capillary rise of two soil textures was measured in a number of controlled drainage systems. The rate of capillary rise was estimated using a model. The results show that the estimation of the model is in agreement with the measured values. In loam soil at depths of less than one meter, capillary rise with a relatively gentle slope increased; however when the depth of the water table is too low, it reaches potential evapotranspiration. In depths more than one meter, the capillary rise decreased with a steep incline. In depth of more than 6 meters, the capillary rise is actually close to zero. Constant upward flow of water into the soil surface is in balance with evaporation demand; therefore, it can be used to estimate the amount of irrigation water from shallow water tables.

KEY WORDS: Controlled drainage, Capillary rise, Upflow.

Introduction

The water flow from water level through the capillary rise into the plant root zone is called upward flow. The amount of flow to the water depends on the table depth, evapotranspiration and soil type Meyer and Green (1980) showed that wheat in loamy soil obtain 28% to 36% their water requirements from a depth of one meterthus their water needs are provided from the uptake of the groundwater.

Ayars and McWhorter (1985) concluded that when designing the drain, for a shallow aquifer almost 60% of the volume of leachate should be reduced.

Greenwood et al.(1985) in a research carried out in Australia showed that water abstraction as a result of water transpiration by trees in areas with a shallow water table at 8-5 meters below ground

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level (from 2300 to 1200 mm per year) is 3 to 6 times higher than average transpiration is pasture plants.

Kahlown and Ashraf (1998) found a linear relationship between yield and water table depth and described the optimum depth to abstract from the water table is less than 22.5 cm, however, if the water table depth reaches 2-1 meters then 5-30 cm of water is required.

By comparing water tables at depths of 50 and 75 cm with free drainage in underground water depths of one meter, the impact of water level's management on corn yield and soybeans (Mejia et al, 2000) were considered. The results showed that corn and soybean at water levels of 50 cm, have a yield increase of 13.8 % and 58 % and in water levels of 75 cm, have a yield increase of 8.2 % and 12.9 % in comparison with free drainage.

De laat (1980, 1995) assumed a steady stream from a shallow water level to the surface soil, and by rewriting Darcy's equation presented the upflows model used in this study.

Shao et al (2014) studied the water use, growth and yield effects of controlled irrigation and drainage (CID) of paddy rice.

Bonaiti and Borin (2016) research recommend that controlled drainage and sub irrigation can be best applied at farm scale in northeast Italy, which will provide benefits for water conservation.

Materials and methods

A. Controlled Drainage

Water control structures, such as a flashboard riser, were installed in the drainage outlet, allowing the water in the drainage outlet to be raised or lowered as needed. This water management practice has become known as controlled drainage. When the flashboards are lowered or removed, subsurface drainage occurs more quickly. When flashboards are added to the riser, the subsurface drainage rate decreases and the height of the water level in the ditches and surrounding fields rises. Managing field water through the use of controlled drainage allows for a more timely drainage; whatsmore it also maximizes the storage of water within the field for utilization by the crop.

The transport of nitrogen from drained fields can be minimized by managing the drainage system in as such that only the minimum drainage water necessary is allowed to exit the field.

In this study, a controlled drainage system in the form of a physical model which is relatively similar to the real conditions of the farm in terms of crop pattern, soil structure , drainage system and water table was created (Figure1).

This research was carried out at a research station located in the faculty of Agriculture and Water Research Tehran University, and affiliated by the Department of Irrigation and Reclamation. In the controlled drainage treatment method, the water level control is done through the application of the outputs valve. In addition to the irrigation water that the plant uses, there is the possibility of using underground water too. The amount of water was measured between the two irrigation periods and before and after each watering period water level readings were taken

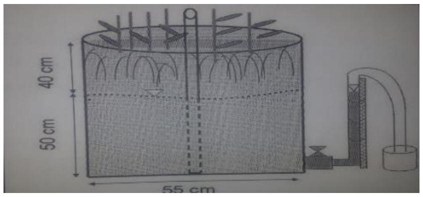

Figure1. Schematic layout of controlled drainage model

B. The Upflow model

The Upflow model estimates the amount of water that will move from a shallow water table to the topsoil for the specified environmental conditions under a steady state condition. The steady state condition assumes that the flow does not change with time.

The steady upward flow to the topsoil is estimated by means of a calculation procedure presented by De Laat (1980; 1995).

By assuming a constant flux from a shallow water table to the top soil, De Laat rewrote and integrated the Darcy equation as:

$$z = -\int_{0}^{h} \frac{k(h)}{q + k(h)} dh \quad (1)$$

Where z [m] is the vertical co-ordinate, q the constant upward flux [m3.m-day-1] of water, h the soil matric potential per unit weight of water (head) [m], and K (h) the hydraulic conductivity [m.day-1].

Input

The input for the UPFLOW model consisted of the specifying of the the environmental conditions that are valid during the period of the upward flow.

Output

For the given environmental conditions, UPFLOW displays.

-The Expected steady upward flow from the water table to the topsoil (if any).

-The Soil water content expected in the topsoil when no water flow occurs. This is referred to as field capacity in equilibrium with the water table.

-The Amount of salt transported upward during the given period, when the water table contains salts.

-The Degree of water logging in the root zone (if any).

-The Graphical display of the soil water profile above the water table.

Results and discussion

The measured fluctuations of the level of controlled drainage water taken during the study are presented in Figure 2.

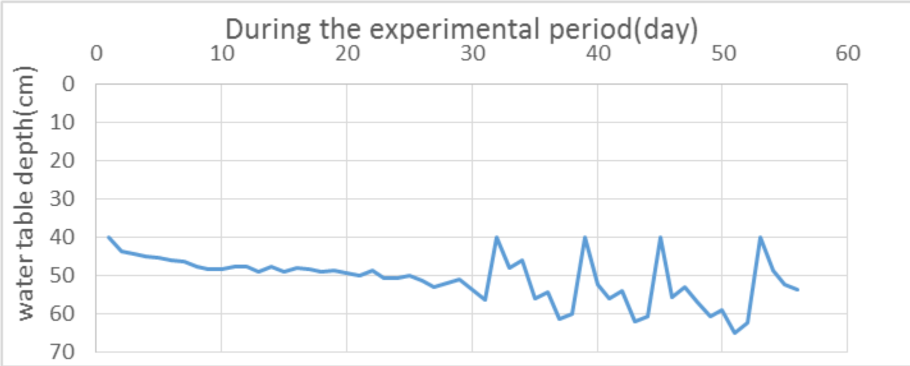

Figure 2. Fluctuation of water table for controlled drainage treatments during the experimental period.

Table 1. Amounts of water consumptive during the period (mm) through the capillary rise in a controlled drainage treatments.

treatments	WT0	WT1	WT2	WT3	WT4	total	average
CD - 1	168	7.51	30.61	54.41	65.26	153.79	38..45
CD - 2	168	69.96	38.86	38.86	33.91	173.59	34.40
CD - 3	168	58.66	30.61	38.86	28.96	157.09	93.27
						484.47	40.47

In this table, WT0 is the amount of water which was injected into the system initially applied to stabilize the water table at a depth of 40 cm, the other WT were applied to offset the declining water table due to the amount of water depleated by plant abstraction

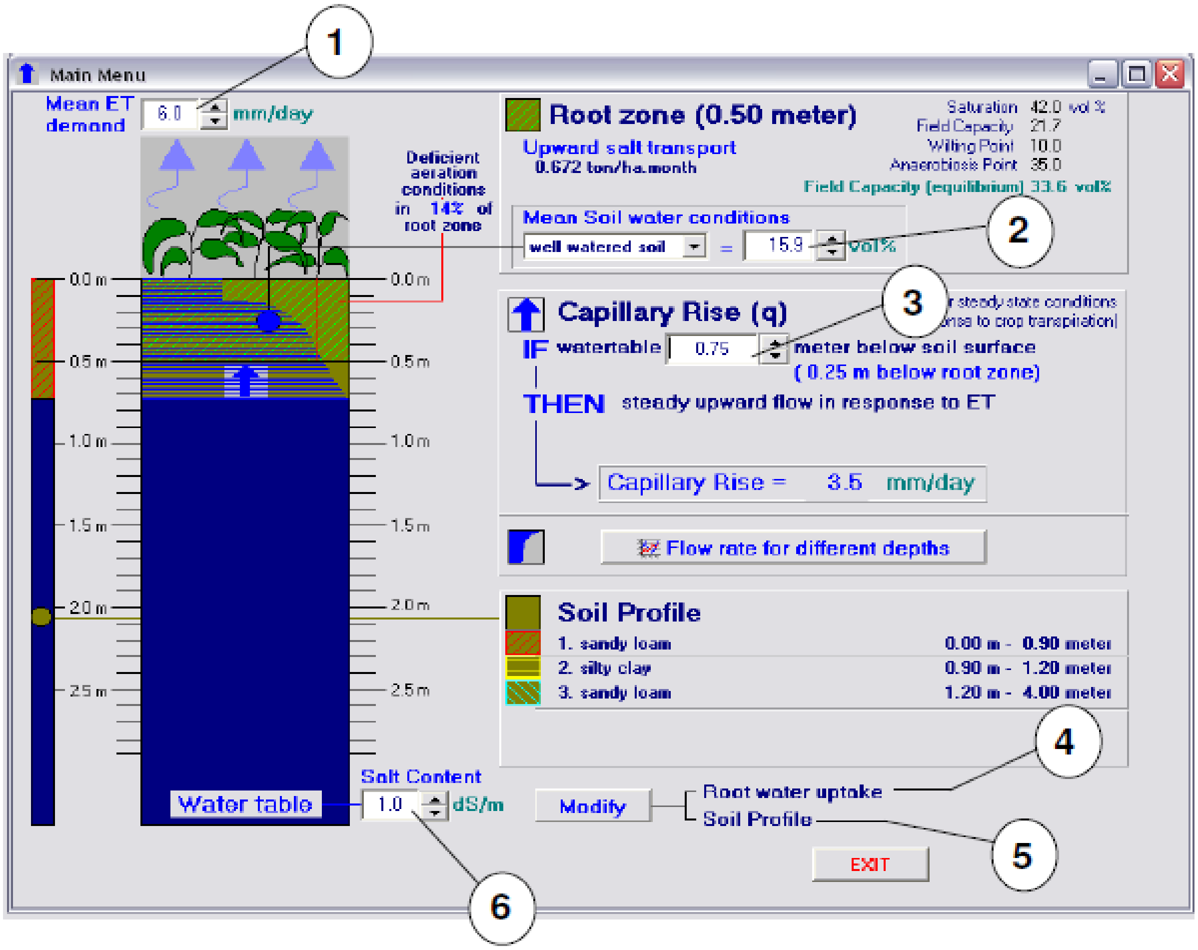

Figure 3. An example of a window model with its output

The Amount of capillary rise of the water level in the drainage control for measuring the depth of water over the soil surface and in millimeters on day two silt loam and loam soils is as per the figures provided below. Moreover, The capillary rise to the soil is estimated by the model shown in Fig 4..

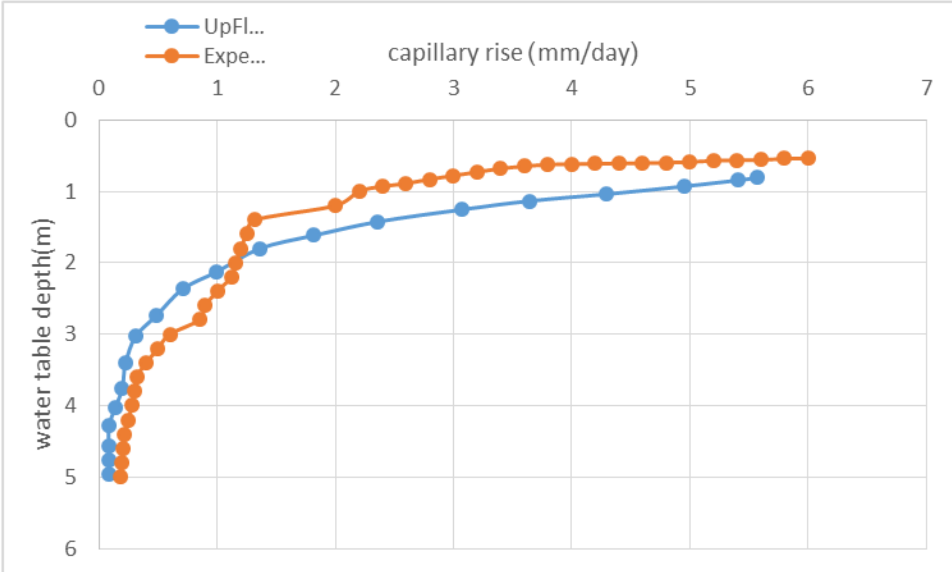

Figure 4. Capillary rise against water table in loam soil

Conclusion

Measurements show that the surface of the water table is almost constant during the experiment and small variations related to the drop in the water table before irrigation and the operation of the controlled drainage in this case is possible. The Measured results of the first series of drainage controlled trials show that approximately a third (28.2%) of the crop water requirement is provided through capillary creep, however in the second test the amount of creep increased. (38.82%). Perhaps one reason for such a rise in the amount of creep is due to the fine-textured soil of the second series as compared to the previous series. The model also showed a good estimate for both series of experiments in the investigation of the double curve (measurement and model) which shows that the model is similar to the measured values. In loamy soil and in depths of less than one meter, capillary rises with a gradient of a relatively mild increase in the depth of the water table is too low to reach potential evapotranspiration. At a depth of more than a meter with a steep climb this amount decreases and in more than 6 meters depth, the capillary rise is close to zero. The measured values are consistent with the values estimated by the model and therefore, can be used to estimate the amount of irrigation water from a shallow water table (drainage water).

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INVERSION OF PEAT SOIL: AN ALTERNATIVE DRAINAGE METHOD?

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Abstract

Many grasslands in Western Norway are situated on former bogs, posing agronomic and environmental challenges for crop production. Histosols with an intermediate (Hemist) or high (Saprist) degree of humification are challenging to drains, especially in areas with high precipitation in the boreal climatic zone. In peat soils the infiltration of water is low whereas waterholding capacity is high. Slow drying and loose physical structures make peat soils easily compacted by tractor traffic. Peat soils are traditionally tile-drained, but due to the aforementioned conditions, the efficiency of the drainage system is often reduced significantly shortly after operations.

In some regions of Norway, tile-drained peat soils are situated on top of a self-draining mineral soil covered by a thin layer of impermeable mineral soil. In such situations, peat inversion can be an alternative to a better drainage method. Inversion means that peat soil is covered with the underlying mineral soil while maintaining connectivity to the self-draining subsoil by means of tilted mineral soil layers. The objective of the present study was to investigate the effect of peat inversion relative to tile-drained peat on grassland yield, soil physical properties, greenhouse gas (GHG) emission and profitability.

Preliminary results from a field experiment in Norway suggest that the inversion of previously tile drained peat increases grassland yield. Mean dry matter yield for the years 2014-2016 was 9.3 and 10.95 t ha^{-1} on inverted and tile-drained peat, respectively. Top-soil physical properties of the inverted peat differ fundamentally from those in tile-drained peat and resembled mineral soil; moreover, inversion also lowered the water table.

GHG emissions during the growing seasons were less in inverted than in tile-drained peat. In 2015, this was due to a very large emission of methane (CH_4) from the tile-drained peat (4050 kg CO_2

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eq.ha^{-1}). In 2016 both CH4 and nitrous oxide (N_2O) emissions were much less in inverted than in tile-drained peat. Cumulative emissions in 2016 were -60 kg CO_2 eq. ha^{-1} CH_4 and 3000 kg CO_2 eq. ha^{-1} N_2O from inverted and 1500 kg CO_2 eq. ha^{-1} CH_4 and 9000 kg CO_2 eq. ha^{-1} N_2O from tile-drained peat. The large variation between the years could be attributed to weather conditions. In summary, the data from our field experiment suggests that the inversion of previously tile drained peat in boreal climates can lower the water table, improve soil physical properties, increase grassland yield and reduce CH_4 and N_2O emissions.

KEY WORDS: Grass yield, Soil physical properties, GHG emissions.

Introduction

Cultivation of peatlands traditionally relies on ditching and tile drainage. Histosols with an intermediate or high degree of humification are challenging to drain, especially in areas with high precipitation (Hovde & Myhr 1980). The water holding capacity of peat is high and infiltration of water is slow. High water tables in spring and the loose physical structure of peat limit its trafficability and easily lead to soil compaction (Myhr & Njøs 1983, Øpstad 1991). As a consequence, the effect of tile drainage systems is reduced at an earlier stage after establishment in peat soils than in mineral soils (Hovde 1986, Bakken 2012, Øpstad 2012).

In some regions of Norway, peat soils are situated on top of self-draining mineral soils covered by a thin layer of impermeable mineral soil. In such situations, inversion can be an alternative drainage method, especially for maintaining previously tile-drained peat soils. Inversion means that peat soil is covered with the underlying mineral soil while maintaining connectivity to the self-draining subsoil through tilted mineral soil layers (Fig. 1). The method is appropriate when the layer of peat is not too deep (<1.5 m) and has been used in Norway since 1970 (Solberg 1980, Hovde 1986 & 2001, Aandahl 2001).

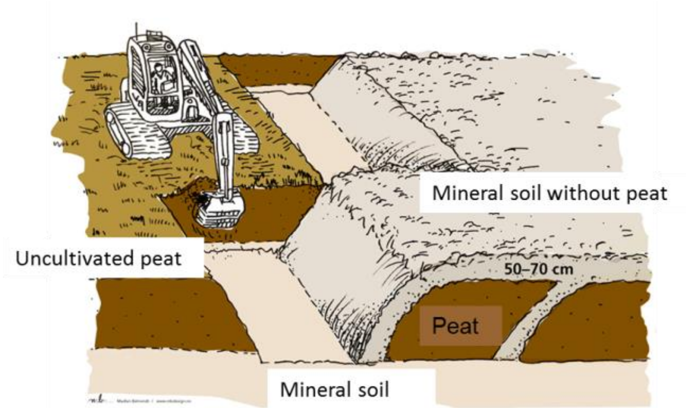

Figure 1. Principle for peat inversion.

It is likely that the inversion method has a potential to reduce the decomposition of peat, as it maintains high water tables in the peat body and protects the peat from drought and erosion. At the same time, it raises the cultivatable zone above the water table. Cultivation and fertilization of the initially nutrient-poor mineral top layer will build up soil organic matter from plant and root residues, while providing a habitat for methane oxidizing bacteria which scavenge CH_4 produced in the buried peat. Together, this will result in net C sequestration in the top layer until an equilibrium is reached (Six et al. 1998).

Preliminary measurements of GHG fluxes from inverted peat soil in Norway showed reduced emissions of CO_2 compared to tile drained peat as long as the peat was not mixed into the overlaying mineral soil (Grønlund et al., 2013). N_2O emissions were generally small and seemed to be independent of the drainage method. CH_4 emission was only detected at one of the tile-drained locations.

The objective of the present study was to investigate the effect of peat inversion relative to tile-drained peat on grassland yield, soil physical properties, greenhouse gas (GHG) emission and profitability.

Materials and methods

Site description

The experimental site is located at Fræna (62°96'N, 7°14'E) in Western Norway. The study was conducted during 2014-2016 (Figure 2).

Figure 2. Location of field site

The climate is cool and humid with an annual precipitation of 2257 mm (1961-1990) and a mean annual temperature of 6.2°C (1960-1979). Precipitation at the site varied between years and was smaller in the year of establishment(2014) than in 2015 and 2016. 2015 was wetter than normal, particularly in June (229 mm). Spring and early summer of 2016 were dry with 52 mm in May and 48 mm in June, whereas August was wet (300 mm) (Tab.1).

Table 1. Monthly precipitation (mm) during the experimental period and normal precipitation (1961-1990) at the site Fræna.

Year	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
2014	16	41	164	125	87	127	69	230	202	254	75	336	1726
2015	221	199	232	189	114	229	137	91	163	194	291	346	2406
2016	197	227	131	148	52	48	116	300	204	170	130		1720*
1961-1990	199	165	179	142	98	109	144	153	290	289	227	262	2257

*01.01-25.11

Peatlands in the study area are ombrotrophic and dominated by nutrient poor bryophytes such as Spaghnum mosses. Some decades ago, the peatland was tile drained for grassland production. During 2012 and 2013, half of the previously tile-drained peat was inverted as explained above (Figure 1 and 3).

Figure 3. Inverted (blue) and tile drained (red) peat at the field site. Photograph taken right after inversion.

Right after inversion, the mineral soil above the peat in the inversion treatment had a heterogeneous texture and a low content of organic matter (Table 2), whereas the tile-drained peat still was defined as organic soil.

Table 2. Soil classes and different soil parameters of two samples from the mineral soil cover above the peat body of the inverted peat at Fræna.

Sample	Soil class	Clay %	Organic matter %	pH	P-AL mg/100 g	K-AL mg/100 g	K-HNO$_3$ mg/100 g	CA-AL mg/100 g	Mg-AL mg/100 g
1	Loam	10-25	<0.1	6.1	8	10	230	47	5
2	Medium sand	<5	2.3	5.0	3	3	120	7	2

Experimental set up

In 2014, leys were established on the inverted peat and the neighboring tile-drained peat. The latter field represents the conditions typical for grassland cultivation before the inversion. N fertilizer was applied as 30 Mg cattle slurry (54 kg NH_4-N ha^{-1}) and 150 kg NH_4NO_3-N ha^{-1} in 2014. In the 2nd and 3rd ley year (2015 and 2016) only mineral fertilizer was used (260 kg N ha^{-1}), which was applied at spring (150 kg N ha^{-1}) and after the first harvest (110 kg N ha^{-1}). Three (spring, after 1st and 2nd harvest) wheel-by-wheel passes of a tractor (5.2 Mg) were performed in 2015 and 2016. For greenhouse gas (GHG) measurements, we used static chambers (Rochette & Bertrand 2008) deployed manually on permanently installed aluminium frames (52 cm x 52 cm x 25 cm). In inverted peat two chambers were located on the tilted layer (no peat underneath) and two on top of the buried peat, whereas the four chambers were placed randomly in tile-drained peat.

Measurements

During the autumn 2014, undisturbed soil cores (100 ml cylinders) were sampled from 5-10, 25-30 and 60-65 cm depth. In the inverted peat, three replicates were sampled at each four locations, whereas in the tile-drained peat two replicates were collected at two locations. The soil was analyzed for water retention (pF) at 20, 50, 100, 1000 and 15000 HPa suction, pore size distribution, pore volume, bulk density, air capacity (air volume at a matric potential of 100 HPa) and available water.

Dry matter yield (DMY) of ley was recorded in three replicates once in the establishing year 2014 and twice in the ley years 2015 and 2016. Energy content of herbage was estimated by near infrared analysis. To evaluate the effect of drainage on DMY, analysis of variance was applied using a General Linear Model (Minitab16).

N_2O and CH_4 fluxes were measured by closed chamber technique approximately weekly throughout the growing seasons 2014-2016. During a period of two weeks after fertilizer application, more frequent flux measurements were performed, whereas measurements were less frequent in autumn. Depth to the water table (WT) was measured at every gas sampling by tape measures in perforated vertical PVC tubes, permanently installed close to the chambers.

Results and discussion

Soil physics

Soil physical properties differed substantially between the mineral cover layer of the inverted peat and the tile-drained peat. Bulk density was larger and pore volume and available water a lot lower at the inverted than at the tile-drained peat. Air capacity did not differ a lot between the soils (Tab. 3).

Table 3. Bulk density, pore volume, air capacity and available water in three depths in a peat soil and an inverted peat soil at Fræna in 2014

	Bulk density (g/cm^3)		Pore volume (vol%)		Air capacity* (vol%)		Available water (vol%)	
Depth (cm)	Inverted peat	Tile-drained peat	Inverted Peat	Tile-drained peat	Inverted peat	Tile-drained peat	Inverted peat	Tile-drained peat
5-10	1.64	0.22	39.3	86.8	14.0	13.3	20.7	57.6
25-30	1.75	0.24	35.6	85.8	9.7	17.7	17.0	49.9
60-65	1.72	0.14	35.4	90.4	12.7	12.8	14.5	69.7

*: Air capacity = Air volume at a matric potential of 100 HPa

Water table

The water table was lower at the inverted than at the tile-drained peat during both growing seasons of 2015 and 2016. Mean of all measurements in 2015 was -103 and -65 cm for inverted and tile-drained respectively, whereas in 2016 it was -119 and -91 cm (Fig. 4).

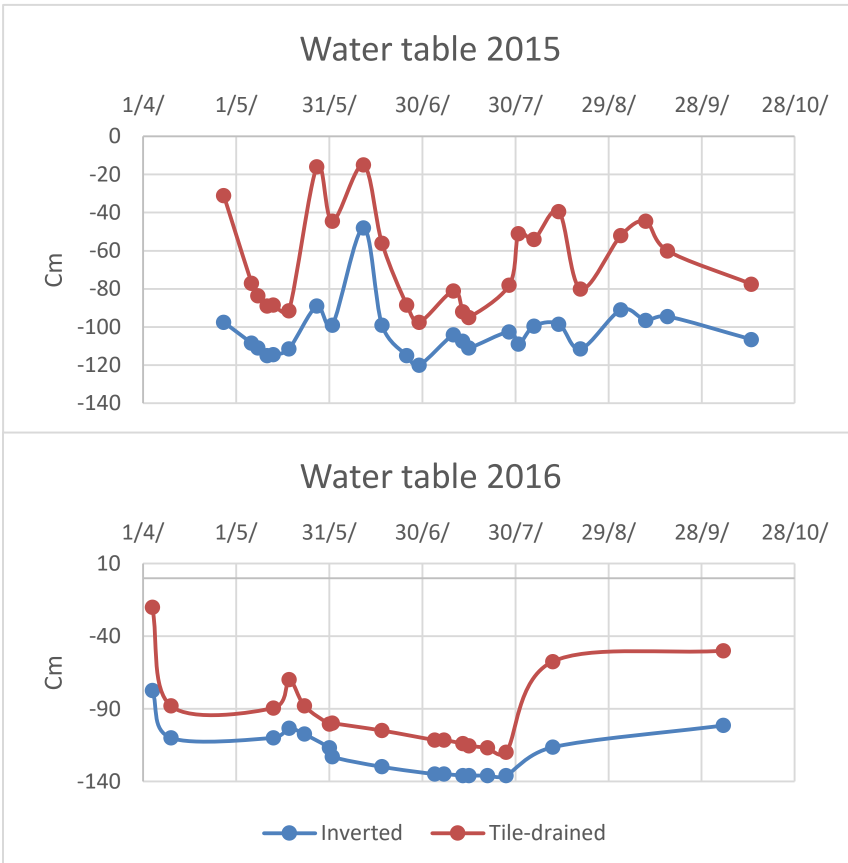

Figure 4. Depth to water table (cm) at inverted and tile-drained peat in 2015 and 2016

Grass yields

Mean DMY in the years 2014-2016 was significantly higher on inverted (10.95 t ha^{-1} yr^{-1}) than tile-drained peat (9.30 t ha^{-1} yr^{-1}). There was however a significant interaction between year and drainage method (p=0.029). Statistical analysis within each year showed that the effect of drainage method on DMY was significant only in the year 2015 (Tab. 4). It seems that inversion has the largest positive effect on yield in wet years. In dry periods, drought stress may occur due to the very low content of available water of the mineral soil cover of inverted peat (Tab. 3). Drought stress was observed in May and June 2016 when the precipitation was very low (Tab. 1). 1st harvest yield tended to be lower in inverted than in tile-drained peat (results not shown), but total yield did not differ significantly between the drainage methods (Tab. 4). Yield response to peat inversion was largest for the 1st harvest in 2015 with 36% higher yield compared to tile-drained peat (results not shown). In this year, the precipitation in June was more than double the normal amount, and the effect of better drainage shows.

Table 4. Effect of drainage method on DMY (t $ha^{-1}yr^{-1}$) of ley at Fræna in the years 2014-2016

Drainage method (DM)	Mean 2014-2016	2014	2015	2016
Tile-drained	9.30	4.67	11.19	12.03
Inverted	10.95	5.46	14.90	12.50
p-value				
DM	0.012	ns	0.04	ns
Year X DM	0.029			
Year	<0.01			

GHG emissions

Figure 5 shows that during the three months of gas measurement in 2014 differences in cumulative GHG emissions in inverted and tile-drained peat were small. More N_2O was emitted from the inverted (1883 kg CO_2 eq.ha^{-1}) than the tile-drained peat (1425 kg CO_2 eq.ha^{-1}), whereas CH_4 emission was lower (8 and 270 kg CO_2 eq.ha^{-1}, respectively). In 2015, measurements throughout six months showed a very large cumulative CH_4 emission from the tile-drained peat (4050 kg CO_2 eq.ha^{-1}), whereas CH4 emission from inverted peat was very low (5 kg CO_2 eq.ha^{-1}). April, May and June 2015 were very wet (Tab. 1), exceeding the drainage capacity of the tile-drained, thus causing anoxia by high water table and large CH_4 emissions. N_2O emission did not differ between the two drainage methods in this year, being 3365 and 3953 kg CO_2 eq.ha^{-1} for inverted and tile-drained peat respectively. The total cumulative GHG emission during the six months of measurements in 2016 was larger for tile-drained than inverted peat (Fig. 4). Even though the precipitation in May and June 2016 was very low, it was very wet after fertilization. This caused a very high emission of N_2O from the tile-drained peat (8973 kg CO_2 eq.ha^{-1}) whereas it did not affect N2O emission from inverted peat (3020 kg CO_2 eq.ha^{-1}) which was lower than in the year before. Inverted peat showed net-uptake of CH_4 (-63 kg CO_2 eq.ha^{-1}) whereas tile-drained peat showed net-emission of CH_4 (1533 kg CO_2 eq.ha^{-1}). A smaller CH_4 emission in 2016 than 2015 from the tile-drained peat may be due to less precipitation.

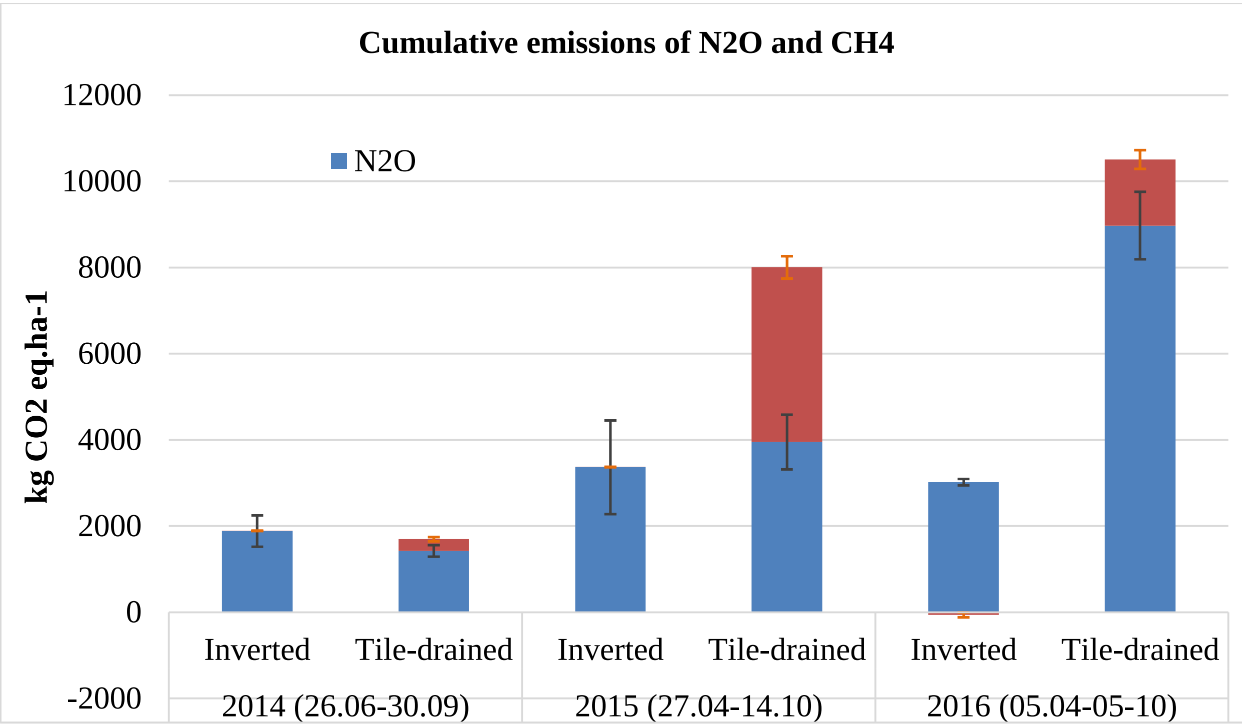

Figure 5. Cumulative emissions of N_2O and CH_4 from inverted and tile-drained peat during 26.06-30.09 2014, 27.04-14.10 2015 and 05.04-15.10 2016 calculated as CO_2 equivalents per ha and period. Bars represent means of four replicates, black and yellow lines represent standard deviation (n=4) of N_2O and CH_4 emissions, respectively.

Conclusion

The conclusion from our study so far is that inversion of previously tile drained peat lowers the water table, improves soil physical properties, increases grassland yield and reduces methane and nitrous oxide emissions.

Acknowledgement

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BIODRAINAGE: AN ALTERNATE DRAINAGE SYSTEM TO MANAGE WATERLOGGING AND SALINITY

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Abstract

In the absence of the provision of adequate drainage, waterlogging and associated soil salinity become major impediments to the sustainability of irrigated agriculture. Though, conventional engineering drainage technologies such as subsurface or vertical drainage are able to combat the problem, yet these methods are costly and generate huge quantities of drainage effluent which result into disposal problems. These conventional options are quite successful where large tracts of land are affected by waterlogging and a continuous salinity exists Biodrainage, which removes the excess soil water via deep rooted fast growing trees through evapotranspiration using bio-energy is proposed as an alternate to the abovementioned engineering approaches. Irrigation of high transpiring forest species has also been put forward for reuse of wastewater and the conservation of nutrient energy into biomass and thereby bringing multiple benefits such as fuelwood production, carbon sequestration, environmental sanitation and eco-restoration. Biodrainage potential of perennial vegetation in general and trees in particular is a cardinal component for designing and implementing biodrainage projects. Consumptive water use of plants varies with the age, geometry, soil properties, water table, salinity and climatic conditions. This varies between 6500 to 28000 m3 ha-1 year-1 and under ideal conditions, a tree canopy may lower water tables by 1–2 m over a time period of 3–5 years. Trees of the genes such as *Eucalyptus, Populus, Casuarina, Dalbergia, Syzigium, Acacia, Prosopis, Leucaena* etc. are reported as being effective to lowering a shallow water table and reverse salinity trends. Amongst different trees studied at different places, Eucalyptus was preferred because it grows fast in a wide range of conditions, grows straight thus creating a low shading effect on associated crops, and has luxurious water consumption in excess soil moisture conditions. Small and marginal farmers may not be able to set part of their farm aside for bio drainage activities therefore biodrainage technology may be more suitable on large farms or public lands. However, integration of trees such as *Eucalyptus* and *Populus* along with crops in a unified agroforestry system or on approach roads or field bunds or on dykes of ponds in an integrated farming system will be a viable preposition. For effective understanding and implementation, several case studies on the role of biodrainage for managing waterlogging and salinity are discussed in this paper.

KEY WORDS: Salinity, Water logging, Eucalyptus, Irrigated agriculture, Biodrainage, Case Studies.

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Introduction

Introduction of canal irrigation without adequate provision for drainage in arid and semi-arid regions results in water table rise leading to waterlogging and secondary salinization in large areas in irrigation commands. These problems are the result of a multitude of factors, including seepage from unlined canals, inadequate provision of surface and subsurface drainage, over irrigation and use of poor quality groundwater for irrigation. Globally about 10% of the land area is affected by waterlogging (Setter and Waters, 2003) and over 6% by salinity (FAO, 2008). In India, about 6.7 million ha of land is affected by different levels and types of salinity, out of which nearly half are under irrigated agriculture (ICAR, 2010). Severely waterlogged saline soils occur in about two million ha area in arid/ semi- arid north western states of Punjab, Haryana, Rajasthan and Gujarat and one million ha each in the coastal and black cotton Vertisol regions of India. It is projected that about 13 million ha area in irrigation commands of India will be affected by waterlogging and soil salinity by 2025. Use of saline/ alkali groundwater and climate change will further accentuate the threats (CBIP, 2015). Waterlogged saline soils apart from environmental degradation result in poor crop yields by reducing crop yields by as much as 80% (Shabala, 2011) and finally in abandoning the land from cultivation. In India, yearly crop loss due to waterlogging has been estimated to be more than 2 m tons (ICRISAT, 2009). The economic loss was estimated to be about Rs. 23,900/ha with a total annual loss of Rs. 1669 million (about US$ 37 million) from the waterlogged saline area of Haryana, India (Datta and Jong, 2002). The crop yields and relative yield loss caused due to waterlogging and soil salinity of major crops are presented in Table 1 (Joshi, 1994). Thus, twin menaces of waterlogging and salinization represent serious threats to the sustainability of irrigated agriculture and calls for appropriate reclamation measures.

For favourable plant growth, optimum balance of water, air and salt in the root zone is a primary requirement which can be achieved by providing adequate drainage. No doubt, the conventional technologies such as surface, subsurface or vertical drainage overcome the problem of waterlogging and salinity, but they have limitations like high cost of construction and subsequent maintenance cost and safe disposal of drainage effluent during reclamation and afterwards. Disposal of drainage effluent which contains nutrients, salts, agro-chemicals and other pollutants in water bodies had resulted in pollution of many river basins like the Indus basin in Pakistan, the Murray-Darling Basin Catchment in Australia, San Joaquin Valley in USA and various river systems in India. To combat drainage problem of such an extent, the technology needed to be less expensive, location specific, sustainable and environment friendly for its large scale adoption by the farmers.

Biodrainage could be a viable option. It is a combined drainage-cum-disposal system. Biodrainage can be defined as “pumping of excess soil water by deep-rooted vegetations through evapotranspiration using their bio-energy”. Reliance on capability of vegetation to reduce water table has been reported promising both in India as well as in other countries. The main physiological feature of such vegetation is profuse transpiration whenever the root system comes in contact with groundwater. The biodrainage technique is eco-friendly as the biodrainage plantations purify the environment by absorbing greenhouse gases and releasing oxygen into the environment, environmentally safe as it does not generate any drainage effluent to dispose, economically attractive because it requires only an initial investment for planting the vegetation, and when established, the system could produce economic returns by means of fodder, wood or fiber harvested and has an additional advantage in term of carbon locked in the timber. The first documented use of the term biodrainage can be attributed to Gafni (1994). Prior to that date Heuperman (1992) used the term bio pumping to describe the use of trees for water table control.

Table 1. Losses due to water logging and soil salinity

Crop	Normal lands	Salt affected lands	Waterlogged lands
Paddy	39.9	21.8 (45)	23.0 (42)
Wheat	26.0	15.8 (40)	18.6 (38)
Cotton	16.3	6.1 (63)	3.7 (77)
Sugarcane	636.8	330.2 (48)	247.5 (61)

Waterlogging and Soil Salinity

A soil is said to be water logged when the ground water table gets linked to soil water in the crop root zone and remains like this for the remaining period in a year (Michael and Ojha, 2006). It results restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon dioxide. The critical depth depends on the kind of crop, but waterlogging is commonly defined as light for a soil profile depth of 3 m for substantial parts of the year, and moderate for less than 1.5 m. The severe degree occurs with a water table at 0-30 cm depth, and also included is ponding, where it rises above the surface (FAO, 1994). As an illustration, rise in water table at different places in Haryana (north India) between 1974 and 2004 is shown in Figure 1.

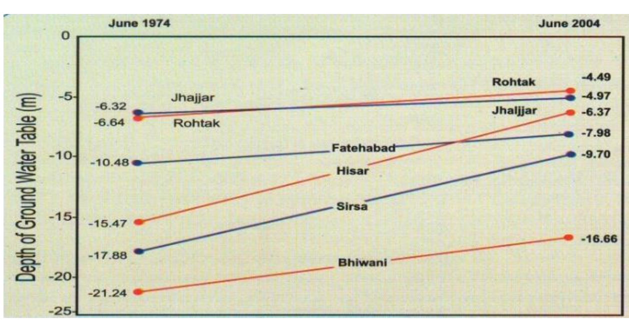

Figure 1 - Trend in rise in water table in Haryana. Source: Jeet Ram et al., 2008

Soil salinity is another problem in arid and semi-arid regions. It refers to presence of excess amount of soluble salts in soil water creating its high osmotic pressure which restricts crop water uptake and ultimately resulting in poor plant growth. Salinity occurs when salts are transported to surface by rising water and got concentrated with evaporation. Several species of trees and crops can be grown in alkali, saline and saline water logged soils. Relative tolerance of crops and trees to salt stress is reported in Tables 2 and 3.

Table 2: Relative tolerance of crops and grasses to soil ESP. Source: CSSRI, Karnal, 2007

Tolerant ESP, 35-50	Moderately tolerant ESP, 15-35	Sensitive ESP <15
Karnal grass *(Leptochloa fusca)*	Wheat *(Triticum aestivum)*	Gram *(Cicer arietinum)*
Rhodes grass *(Chloris gayana)*	Barley *(Hordeum vulgare)*	Mash *(Phaseolus mungo)*
Para grass *(Brachiaria mutica)*	Oat *(Avena sativa)*	Chickpea *(Cicer arietinum)*
Bermuda grass *(Cynodon dactylon)*	Shaftal*(Trifolium resupinatum)*	Lentil *(Lens esculenta)*
Rice *(Oryza sativa)*	Lucerne *(Medicago sativa)*	Soybean *(Glycine max)*
Dhaincha*(Seshania aculeate)*	Turnip *(Brassica rapa)*	Groundnut *(Arachis hypogea)*
Sugarbeet*(Beta vulgaris)*	Sunflower *(Helianthus annus)*	Sesamum*(Sesamum oriental)*
Teosinte*(Euchlaena maxicana)*	Safflower *(Carthamus tinctorius)*	Mung*(Phaseolus aureus)*
	Berseem*(Trifolium alexandrinum)*	Pea *(Pisum sativum)*
	Linseed *(Linum usitatissimum)*	Cowpea *(Vigna unguiculata)*
	Onion *(Allium cepa)*	Maize *(Zea mays)*
	Garlic *(Allium sativum)*	Cotton *(Gossypium hirsutum)*
	Pearl millet *(Pennisetum typhoides)*	

Table 3: Relative tolerance of tree species to soil alkalinity. Source: Singh et al., 1993

Average pH2 (0-120 cm)	Fuel-wood/Timber species	Fruit trees
More than 10.0	*Prosopis juliflora* (Paharikiker) *Acacia nilotica* (Kikar) *Casuarina equisetifolia* (Australian pine)	*Achras japota* (Chikoo)
9.0 to 10.0	*Tamarix articulate* (Frans) *Terminalia arjuna* (Arjun) *Eucalyptus tereticornis* (Safeda) *Albizzia lebbek* (Papri) *Pongamiapinnata* (SirisKaranj) *Sesbaniasesban (*Dhaincha) *Emblicaofficinalis (Amla)*	*Zizyphus maurtiana* (Ber) *Carissa carandus* (Karaunda) *Psidium guajava* (Amrood) *Syzygium cumini* (Jamun) *Phoenix dectylifera* (Khajoor) *Aegle marmelos* (Bael)
8.2 to 9.0	*Dalbergia sisoo* (Shisham) *Morus alba (Sehtoot)* *Grevilla robusta* (Silver Oak) *Azadirachta indica* (Neem) *Tectona grandis* (Teak) *Populus deltoids* (Poplar)	*Punica granatum* (Anar) *Prunus persica* (Aru) *Pyrus communis* (Nashpati) *Vitis vinifera* (Angoor) *Mangifera Indica* (Aam)

Mechanism of Biodrainage

The root systems of trees intercept saturated zone or unsaturated capillary fringe above water table and control shallow water table. The primary objective of a bio-drainage system is to lower a shallow groundwater table to below the ‘‘critical depth’’ (2 m below ground surface is generally accepted as a safe depth) of the capillarity-induced evaporative processes that cause salinization (Heuperman et al. 2002; Kapoor 2001). For efficient biodrainage system, trees should be fast growing having high rate transpiration system so that they absorb sufficient quantity of water from the capillary fringe located above the ground water table. The roots of herbaceous annuals have little or no contact with water table. The absorbed water is translocated to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata. Under ideal conditions, a tree canopy may lower water tables by 1–2 m over a time period of 3–5 years (Gafni and Zohar, 2001; Heuperman et al., 2002; Kapoor, 2001). This combined process of absorption, translocation and transpiration of excess ground water into the atmosphere by the deep rooted vegetation conceptualizes biodrainage.

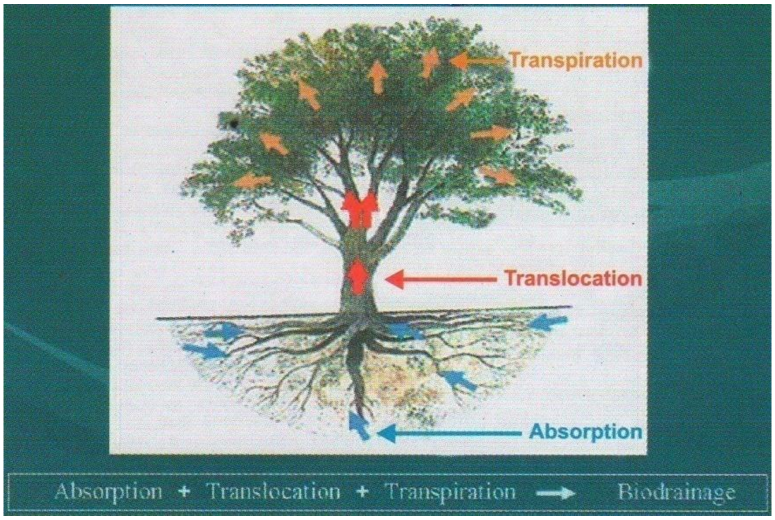

Figure 2 - Concept of biodrainage

Situations Suitable for Biodrainage Application

Depending upon land use, biodrainage mechanism can be applied both in dry land/rainfed and irrigated agriculture. In rainfed systems, bio-draining ability of vegetation can be utilized mainly for recharge control, interception of ground water flow and discharge enhancement.

Extensive clearing of area for agricultural development and cultivation of annual crops with shallow rooting crops may result in higher recharge and ultimately rise in water table and causing waterlogging and salinity as was observed in Kyabram, Australia. Re-vegetation of recharge areas by deep rooted tree plantation minimizes deep seepage losses in the higher parts of the landscape to minimize discharge problems referring recharge control and reduction of localized salinity and discharge problems in lower part of the landscape. Excessive evaporative demand of newly planted vegetation may lead to dry landscape causing reduced river flow, drying of well and increase in groundwater salinity. The interception of groundwater flowing through permeable layers overlying low permeability strata reduce discharge problems further down the slope. In dry land areas, extensive clearing upsets the hydrological balance, resulting in saline discharge in low lying land areas, which affects agricultural productivity and water quality in stream systems. Reclamation techniques for dry land salinity in waterlogged discharge areas focus on the restoration of the hydrological balance by planting biodrainage vegetation using the concept enhanced evapotranspiration (Heuperman, 2000).

In irrigated areas biodrainage can be useful for control of rise in water table, intercepting seepage water from channels and management of salinity as in convention drainage system as discussed below.

a. ***Water table control:*** Shallow water table causes root zone soil salinization which adversely affects crop growth. Biodrainage in irrigation areas lowers water tables below the critical depth, which is defined as the depth at which capillary salinization is negligible.

b. ***Channel seepage interception:*** Channel seepage can be a major contributor to water table rise and consequently can cause water logging and salinity problems in the adjoining land. Water quality of seepage water is normally good which if intercepted can be productively used by crops. In cases if seepage water is not intercepted and left to evaporate it will increase salinity.

c. ***Biodrainage cum conventional drainage systems:*** For the optimum growth of biodrainage crops also, salt accumulation in the root zone should not exceed the threshold level. Where biodrainage results in salt accumulation, engineering assistance is needed to make the system sustainable.

Planning & Design for Biodrainage Plantation

The primary requirement for planning and deciding the location for putting drainage plantings is the catchment water balance and precise identification of recharge and discharge areas in the landscape. The following issues should be considered in the development of biodrainage systems:

● Water balance: In irrigated areas due to net incremental recharge ground water table starts rising causing water logging. To overcome the above problem, the objective of any drainage scheme, is to achieve water balance before the ground water table rises up to the critical depth, which in general may be taken as 2.0 m below ground level. Plantations of deep rooted trees with high rates of transpiration should extract ground water equal or more than the net recharge so that water table is kept below the critical depth root zone. Tree plantations often use water at higher rates because of the high aerodynamic roughness which may be even more pronounced because of the so-called clothesline effect prevailing in rows of trees, substituting for a conventional drain pipe.

● Area under plantation for water balance: For sustainable water balance, the area to be covered under biodrainage vegetation should be the minimum but large enough so that amount water removed through evapotranspiration should equal the total annual recharge.

● Salt tolerance: Salt tolerance will be an important criterion for (potentially) saline discharge environments, water use considerations will prevail in recharge control situations where salinity is of no concern and in channel seepage scenarios with low-salinity water supply. Water use capacity of trees decreases with increase in water salinity. Therefore, biodrainage crops need to be salt tolerant.

● Drawdown of water table: Crops, including trees, act as bio pumps; they depress the water table directly underneath plantation areas and consequently lower the water table in the surrounding area. Draw down effect depends on water use capacity of trees, rate of recharge in surrounding area, soil hydraulic conductivity, depth of deeper barrier layers, root system of trees and salt-tolerance of tree species.

● Salt balance: Salt balance determines the sustainability of plant water use and lowering of water table. If the salts moving into the root zone are not either (i) taken up by the vegetation and harvested or (ii) removed from the root zone by leaching, the vegetation will succumb to salinity. Large volumes of irrigation water even of low salinity significantly increase salt imports. Salinity buildup beyond a threshold level will certainly hamper plant growth. To achieve the salt level below the critical level, drainage of these salts below the crop root zone is considered a necessity for optimum plant growth. The Israeli experience has shown that the bio-drainage technique can effectively lower a shallow water table and reverse salinity trends, provided that the overall water balance is negative, i.e. that the water inputs match the water use by the tree plantation and local drainage characteristics (Gafni and Zohar, 2007). In absence of conventional drainage, the irrigated crops and biodrainage vegetation should be salt accumulating so that salts introduced by irrigation can be removed through crop harvest. But the ability of the biodrainage system to maintain a salt-balance is not clear. The salt uptake by plants in general is negligible compared to the total salt applied in irrigation supplies as trees do not bio-harvest as the roots exclude salts during water uptake making a saltwater lens below the root zone (Chhabra and Thakur, 1998; Heuperman, 1999). Chhabra and Thakur (1998) reported that 3 year old Eucalypts *(Eucalyptus tereticornis)* and 4 year old bamboo *(Bambusaarundinacea)* having low groundwater salinity 0.4 dS/m and water table depth 1.5 m had very high biodrainage value (plant water use) up to 5.5 m and 4.2 m per year, respectively. Biodrainage values were lower at the higher groundwater salinities. In high-salinity environments plant salt uptake might be negligible in relation to the salts present in the system, under low-salinity scenarios salt balance by plant uptake and removal might be achievable (Heupermanet et al., 2002). On dry weight basis, mineral content in leafy vegetables is reported 14 % followed by other vegetables (8%), roots and tubers (6.5%) pulses and legumes (3.5%) and cereal grains (2%) (ICMR, 1989). Maximum soil water salinity which can be controlled by bio-drainage is around 3 dS m−1 in medium run (Akram et al., 2008). In cases where bio drainage results in salt accumulation, engineering assistance is needed to make the system sustainable.

● Economic aspects: Biodrainage plantations should be of high economic value so that costs associated with planting and maintenance can be covered from the sale of the tree produce. In direct benefits of planting trees on farm lands in terms of organic carbon build-up, carbon sequestration in biomass and other eco-system services should also be considered.

Suitable Plant Species for Biodrainage

The vegetations with profuse transpiration ability appear to be a promising tool for improvement of drainage situation through removal of excess water. Consumptive water use of plants varies with the age, geometry and soil water and salinity and climatic conditions. The rate of fall of the water table doubled with the development of the trees (Rodríguez-suárez et al., 2011). It has been demonstrated that under ideal conditions, consumptive use of trees varies between 6500 to 28000 m3 ha-1 year-1 and a tree canopy may lower water tables by 1–2 m over a time period of 3–5 years (Gafni and Zohar, 2001; Heuperman et al., 2002; Kapoor, 2001, NIH, 1999). For biodrainage, amongst different trees, Eucalyptus has been used the most for this purpose because of its luxurious water consumption (Dong et al., 1992). The roots of Eucalyptus penetrate in the soil at 2.5 meters per year and utilize ground water as well as water from upper vadose zone (Calder et al., 1997). It goes straight thus low shading effect, reduces groundwater recharge with minimal competition with adjacent crops for water and grows well under a wide range of climatic conditions (White, 2002). In waterlogged areas, it can be successfully grown by ridge planting. The world's Eucalyptus plantation area has increased to 19 million ha because of its fast growth rate, favourable wood properties and carbon sequestration and thus seems to be a good option for biodrainage (Iglesias Trabado et al., 2009). Eucalyptus species use more water than native species of trees (Zahid et al., 2010). Early studies in Australia (Greenwood et al., 1985) suggested that the rates of transpiration and groundwater uptake by Eucalyptus underlain by relatively shallow (5-8 m below surface) water tables were 3-6 higher than from pasture. In Israel, annual transpiration of three-year-old trees *E. Camaldulensis* was found to be 1,360 mm (Zohar et al., 2008). In Indian desert, plantation of *Eucalyptus camaldulensis*, *E. fastigata*, *E. rudis* and *Corymbia tessellaris* on raised bunds, improved vegetation cover with simultaneous decrease in water table. Performance of *E. rudis* was found to be the best with respect to growth, biomass, transpiration rate and overall bio-drainage potential (Bala et al., 2014). Average over a period of six years the evapotranspiration rate of Eucalyptus was reported to be 3446 mm per year. In Australia, 8 years old Eucalyptus plantation lowered the water table 2 meters or more and piezometric head by 1.5 m (NIH, 1999). In Western Australia, annual tree water use values for *Eucalyptus Camaldulensis* ranged from 0.6 A pan for irrigated Eucalyptus with full canopy cover (Marshall and Chester, 1991) to 1.9 Apan irrigated with seepage affluent (Morris and Wefner, 1987). Water use of 3-5 years old *Acacia nilotica* was found to be 1248 and 2225 mm per annum on severe and mild saline soils, respectively (NIH, 1999).

Studies conducted on abandoned waterlogged degraded land in Haryana, India to lower down water table found trees like Eucalyptus hybrid, *Eucalyptus tereticornis* C-10, *Eucalyptus tereticornis* C-130 and *Prosopis juliflora* fast biodrainers, *Eucalyptus tereticornis* C-3, *Callistemon lanceolatus* and *Melia azedarach* in the category of medium biodrainers whereas *Terminalia arjuna* and *Pongamia pinnata* slow biodrainers. An overall 20 cm decline in water table was recorded during the 5th year growth compared to control (without plantation). Leaf area was found to be a cardinal component of biodrainage potential. (Toky et al., 2011). To make use of unproductive land and lower the elevated groundwater table (GWT) suitability of 9 multipurpose trees *(Prunus armeniaca L.)*, black poplar *(Populus nigra*), black willow *(Salix nigra)*, Eastern catalpa *(Catalpa bignonioides)*, Euphrates poplar *(Populus euphratica Oliv.)*, Russian olive *(Elaeagnus angustifolia L.)*, salt cedar *(Tamarix androssowii)*, Siberian elm *(Ulmuspumila L.)*, swamp ash *(Fraxinus pennsylvanica)*, and white mulberry *(Morus alba)* for biodrainage were studied on sandy and loamy slightly saline soils on degraded agricultural landscapes in Khorezm, Uzbekistan, Aral Sea Basin. *E. angustifolia* ranked the highest, combining high water use, fast growth and production of nutritious feed. *Populus* spp. and Ulmuspumila L. ranked lower but still represented potential candidates for biodrainage purposes whereas fruit species such as *P. Armeniaca* and M. alba, though desirable from the farmer's financial viewpoint, showed low biodrainage potential. The annual stand transpiration amounted to 1830, 1470, and 730 mm for *E. angustifolia*, *U. pumila* and *P. euphratica*, respectively. Transpiration rates was highly correlated with length of fine roots whereas weakly correlated with leaf area and no correlations were found between salt content in plants and water uptake under conditions of slight-to moderate root zone soil salinity (Khamzina et al., 2006). In north-western China, *Lycium barbarum* and *Puccinellia chinamponsis* proved to be very effective in lowering shallow ground-water tables and facilitating some leaching of salts from the surface layers (Zhao et al., 2004). Other suitable species for block plantations are *Populus deltoides, Casuarina glauca, Terminalia arjuna*, *Pongamia pinnata* and *Syzygium cuminii* etc. Apart from the planted species, *Prosopis juliflora*, *Tamarix dioca* and *Saccharum munja* also have come up in the area with recession of ground water table as natural succession and contributed significantly for further lowering of ground water table and increasing productivity. The well managed multipurpose tree species on farm enhance the overall productivity, improvement in soil fertility, soil conservation and nutrient cycling, micro-climate amelioration, carbon sequestration, bio-drainage, bio-energy and bio-fuel production etc. There is consensus that biodrainage, when properly implemented, can lower the water table and solve problems associated with waterlogged areas and canal seepage (Ahmad et al., 2007).

Though problem of salinity can be managed by removal of excess groundwater through the transpiration by vegetation thus lowering down the water table below the root zone but the performance or suitability of biodrainage in saline conditions is still a debateable issue. According to Kapoor and Denecke (2001) biodrainage could be used in various regions ranging from humid to semi-arid areas, except when the ground water EC is greater than 12 dS m-1. However, Akram and Liaghat (2010) are of the view that biodrainage does have a high sensitivity to salinity in regions with arid and semi-arid climates. Biodrainage cannot be a good alternative to conventional drainage systems when the irrigation water is too saline. Due to increasing salinity over the time, evapotranspiration efficiency of the tree strips reduces to such an extent that actually will lose its applicability. Horticultural and landscape plants indicate 100% loss of relative growth or yield at 8, 16, 24 and 32 dS m-1 for sensitive, moderately sensitive, moderately tolerant and tolerant crops, respectively (Blaylock. 1994). Levels of 4 to 5 dS m-1 affect many crops and above 8 dS m-1 affect all but the very tolerant crops (Cardon et al., 2011). In the case of Eucalypt species, it reduces to about one-half of potential when the water salinity increases to about 8 dS m-1 (Oster et al. 1999). Yet there are many plant species which are tolerant to salinity and grows well.

Eucalyptus occidentalis performed better than *E. camaldulensis* under the more saline situation emphasizing selection of salt tolerant species. The annual transpiration of Eucalyptus in saline environment highlighted the ecological benefit of eucalyptus plantations in lowering the water table, even in a saline habitat, although their economic viability under such conditions remains limited (Zohar et al., 2008). Singh et al. (2013) were of the view that bio-control measures involving selection of more salt-tolerant crops, residue management, and biodrainage manages soil and water salinity for sustainable agriculture. The Central Soil Salinity Research Institute (CSSRI) at Karnal, India, presents data on the tolerance of tree species to soil salinity as shown in Table 4 (Tomar and Gupta, 1999).

Table 4: Suitability of tree spp. for saline soils

Tolerant (ECe 25-35 dS/m)*	*Tamari troupii, T. articulata, Prosopis juliflora, Pithecello biumdulce, Parkinsonia aculeata, Acacia farnesiana*
Moderately tolerant (ECe 15-25 dS/m)	*Callistemon lanceolatus, Acacia nilotica, A. pennatula, A. tortilis, Casuarina glauca, C. equisetifolia, Eucalyptus camaldulensis, Leucaena leucocephala*
Moderately sensitive (ECe 10-15 dS/m)	*Casuarina cunninghamiana, Eucalyptus tereticornis, Acacia auriculiformis, Guazum aulmifolia, Leucanea shannonii, Samanea saman, Albizzia caribea, Senna atomeria, Terminalia arjuna, Pongamia pinnata*
Sensitive (ECe 7-10 dS/m)	*Syzygium cumini, S. fruticosum, Tamarindus indica, Salix app., Acacia deanei, Albizia quachepela, Alelia herbertsmithi, Ceaselpimia eriostachya, C. velutina, Halmatoxylon brasiletto*

* ECe is the average rootzone salinity as measured in a saturation extract

Source: Tomar and Gupta, 1999

Case Studies

Biodrainage to control channel seepage in Indira Gandhi Nahar Project, Rajasthan, India

Large areas along the main canal in the Indira Gandhi Nahar Project (IGNP) became waterlogged mainly due to seepage from the canal and presence of impervious gypsum layer at shallow depth. Before IGNP, the depth of water table in the command area of Phase I generally ranged between 40 and 50 m below the surface water table and the quality of groundwater was highly saline and unfit for irrigation. With the introduction of irrigation, the groundwater table started to rise at the rate of 0.92 m year-1. In Phase II of the project, the groundwater table before the advent of irrigation generally ranged between 20 to 100 m below surface. With irrigation, it has been rising, though not at the same rate as Phase I. To protect the canal form sand drift and meet the timber, fuel and fodder need of the locals, plantations were raised in the area. The afforestation schemes included canal side plantation, block plantation, sand dune stabilization, pasture development, roadside plantation and environmental plantation. The main trees planted in irrigated areas were *Eucalyptus camaldulensis, Dalbergia sissoo* and *Acacia nilotica*, whereas *Prosopis cineraria, Tecomella undulata* and *Ziziphus* in unirrigated areas. *Lasiuruss indicus* grass was planted for pastures and in between mulch lines for stabilization of sand dunes. Along the canal, the width of plantation was 100m on the right side and 200 m on the left. Amongst different trees, growth of *Eucalyptus camaldulensis* was the fastest whereas Prosopis cineraria the slowest. The annual rate of transpiration was found to be 2971mm, about 1.2 class A pan evaporation (Heuperman et al., 2002; Kapoor and Denecke, 2001). Plantations made along the canal and around the submersed areas removed excess water through biodrainage and the groundwater table fell by about 15 m after six years. As a result of that inundation disappeared from most of the affected area. Considering the annual rate of transpiration of 3000 mm, for maintaining water balance roughly 5% of the area needs tree plantation.

Analysis of factors responsible for waterlogging and salinity in IGNP found were large percolation losses from the irrigated fields, seepage from channels, over use of water for irrigation, relatively low levels of groundwater development, subsurface barriers and absence of natural drainage. An optimal policy to control the problems of waterlogging and salinization require lower water allowance, efficient irrigation methods, conjunctive utilization of surface water and groundwater, planting trees and artificial drainage (Sharma, 2001).

Eucalyptus based agroforestry system for waterlogged soils at Puthi, Haryana, India

Two plantations 350 m apart comprising of 18 years old *Eucalyptus tereticornis* (Mysure gum) raised at a spacing of 3mx3m along the road and railway line on alluvial sandy loam soil at Dhob-Bhali, Rohtak (Haryana), lowered groundwater table by 0.91 m but no increase in salinity underneath the plantations than the ground water table underneath the adjacent fields without plantation Ram et al. (2007). The spatial extent of lowering of groundwater table in the adjacent fields was up to a distance of more than 730 m from the edge of a plantation.

But in developing countries like India, farmers have small holdings and not interested to put the land under sole forestry plantations which yield after a gap of five to six years. Under such situations, planting trees on farm boundaries in form of agro forestry can be a viable and remunerative option, which will provide regular income also. Parallel strip plantations of *Eucalyptus tereticornis* (Mysure gum) spaced at 66 m and each strip-plantation contained 2 rows of trees at a spacing of 1 m x 1 m resulting in a density of 300 plants ha-1 lowered the ground water table underneath the strip-plantations by 85 cm compared to adjacent unvegetated fields in 3 years (Ram et al., 2011). In this field study, four parallel strip-plantations of clonal *Eucalyptus tereticornis* were raised in December 2002 on four ridges constructed in north-south direction in 4.8 ha canal irrigated waterlogged fields of farmers at village Puthi, Hisar, Haryana. The shapes of draw down curves of ground water table in both transects were similar to the combined cone of depression of 4 pumping wells working simultaneously for a long period indicating that 4 strip plantations of clonal *E. tereticornis* were also working as bio-pumps. Water table was brought down mainly be due to the luxurious use of water by Eucalyptus plantation which transpired 268 mm per annum against the mean annual rainfall of 212 mm. Location of the research plot is shown as Figures 3(a), 3(b), 3(c) and 4.

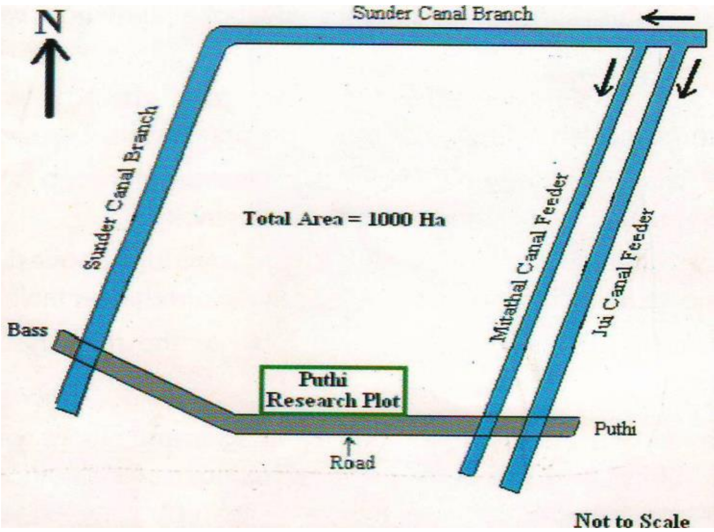

Figure 3(a) - Land locked area. Source: Jeet Ram et al., 2008

Figure 3(b) - Mithathal canal and Jui canal feeders. Source: Jeet Ram et al., 2008

Figure 3(c) - Sunder canal branch. Source: Jeet Ram et al., 2008

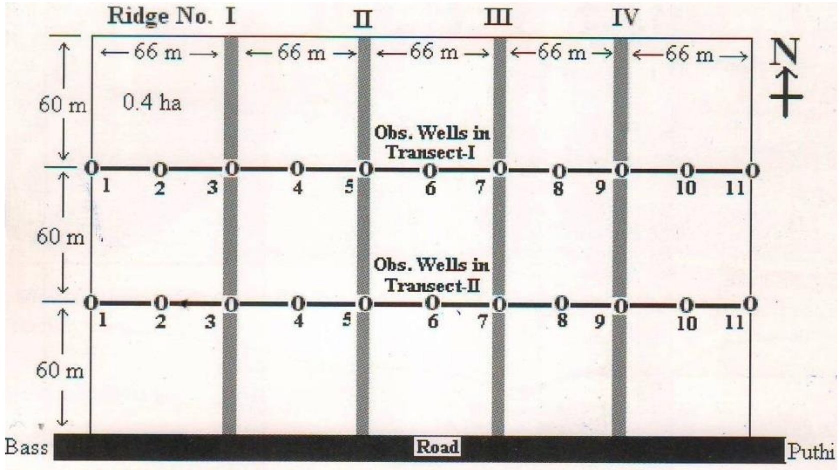

Figure 4 - Layout of experiment at Puthi showing position of observation wells and plantation strips. Source: Jeet Ram et al., 2008

Tree plantations harvested after 5 years and 4 months of growth produced 33 t ha-1 of root and shoot biomass and sequestered 15.5 t ha-1 carbon. Planting trees requires only initial investment and when established, the system provides economic returns by means of fodder, wood or fibre harvested. In this study, benefit-cost ratio was 3.5:1 for first rotation and would be many folds for next 3 to 4 rotations due to negligible cost of coppiced Eucalyptus. Lowering of water table allowed the farmers to advance sowing of wheat crop by more than two weeks. Due to timely sowing of crop and improvement in soil properties, wheat yield in the inter-space of strip-plantations was 3.4 times the yield in adjacent waterlogged areas without plantation. A view of agroforestry model of biodrainage at Puthi village is shown in Figure 5.

Figure 5 - Agroforestry model of biodrainage. Source: Jeet Ram et al., 2008

The question what should be the optimum spacing of Eucalyptus for strip plantation in agroforestry for achieving maximum benefits in terms of water table draw down, wood production and crop yields was still unanswered. Therefore, above study was continued in the same area by taking strip plantations of clonal *Eucalyptus tereticornis* in paired rows at spacing of 1m x 1m, 1m x 2m and 1 m x 3 m on farm acre boundaries (called killa-lines) spacing resulting in tree population of 300, 150 and 100 trees ha-1 (Dagar et al., 2015 personal communication). Considering wood biomass production, lowering of water table, carbon sequestration and crop productivity, agroforestry biodrainage model of six year rotation having strip plantation of Eucalyptus in paired rows on farm acre line in spacing of 1 m x1 m was found better compared to 1m x 2m and 1mx3m in waterlogged areas of north-east India. After effective results shown by the bio-drainage system in checking waterlogging in Haryana, the Punjab Government is replicating the biodrainage system in 3000 hectares of waterlogged area in Muktsar district (The Tribune, 19th April, 2013).

In Indira Gandhi Nahar Project (IGNP) Rajasthan (India) also tree plantations established along the canal lowered ground water table by 14 m in six years (Kapoor, 2001). The main reasons for the difference in drawdown of ground water table at the two sites (IGNP and Puthi research plot) were the design and density of plantations and the sources of recharge in ground water.

Biodrainage for reclamation of waterlogged deltaic lands of Orissa, India

Biodrainage potential of Casuarinas on land at two sites with groundwater table at 102 and 127 cm in coastal delta, Orissa suffering from waterlogging due to sea water intrusion and Eucalyptus at another two sites on waterlogged soils having groundwater at 150 and 167 cm, respectively caused due to topographical depression were compared by Roy Chowdhury et al (2011). At all the four sites, effects of biodrainage plantation on water table were clear and lowered it by 15 to 25 cm compared to non-vegetated area. As far as efficiency of drainage by plantation or tree water use per se is concerned, greater decline of water table underneath Eucalyptus compared to Casuarina indicated Eucalyptus was found more efficient than Casuarina. Therefore, Eucalyptus plantation was superior in providing drainage relief through intercepting water from deeper soil profile, compared to that under Casuarina plantation in topographically depressed area. This accelerated drainage has helped the farmer to advance rabi cultivation by a period of 15-20 days. Due to this, farmers were able to take watermelon in Casuarina and groundnut in Eucalyptus plantations and earned additional benefit. Yield of rice in Casuarina got improved but in Eucalyptus the crop yields were reduced after two years due to the shading effect and competition with intercrop for nutrients and other resources. Overall, the principle of bio-drainage to lower the rising water table with Eucalyptus and Casuarina vegetation appears promising. The successful intervention with pisciculture, integration of intercrops and crops like watermelon in reclaimed area is also feasible to enhance productivity of areas which otherwise remain sub-productive due to waterlogging. Therefore, high rate transpiring trees like Eucalyptus plantation may be grown for topographically depressed inlands and canal seepage interceptions and may be grown parallel to the field drainage options as an alternative. Similarly salt tolerant tree species like Casuarina may be a good option in coastal waterlogged areas. In Australia also, Casuarina performed better on shallow saline soils (Cramer et al. (1999) for lowering ground water table.

Control of shallow water table by block plantation of Eucalyptus at Kyabram, Australia

Large scale clearing of deep rooted forest trees with shallow-rooted annual crops and pastures followed by introduction of irrigation resulted in rise in water table from 30 m (before clearing) to 2 m or less and development of soil salinity at Kyabram, Australia (Heperman, 1999; Heuperman et al., 2002; Ferdowsian et al., 1996; George et al., 1999). Low returns from the agricultural production systems and the high costs of drainage engineering compelled to go again for planting deep-rooted permanent pastures, crops and trees for achieving a plant water use scenario that more closely approximates that of the pre-clearance situation. Trees lower water table through higher rates of transpiration than shallower rooted and often more salt sensitive crops and also provide timber wood, fuel, fodder to the farmers. During the study period, average rainfall in the region was 480 mm year-1 with an annual average of evaporation 1403 mm. The soils of the sites were loam Natrixeralf, a red brown duplex soil. The site was planted with Eucalyptus, irrigated with freshwater for initial six years and attained increments in height of up to 2.5 m year-1 measured during that period.

The average water table level at the plantation site in February 1977 (two years after tree establishment) was 1.94 m below the surface. Seven years after tree establishment, the trees significantly lowered down the water table underneath the plantation and its impact was observed up to 50 m into the irrigated pasture. As the trees exclude salts during water uptake, salinities in the upper part of the saturated zone (near the water table) underneath the plantation increased. At most of the points in plantation sites, water table salinities increased over the period (1982-1993) reflecting this salt concentration process. In 1993, water table salinities under the trees were clearly higher than outside the plantation. The salt accumulation was recorded between 2.5 and 5.5 m in the profile from the surface.

At another site in the same region decline of the water table was linearly correlated with tree spacing. The decline decreased with increasing tree spacing. The effects were conspicuous after four years of planting. For every 10 percent increase in planted area, the water table was lowered by about 0.4 m.

Integrated management of saline drainage effluent, USA

Disposal of drainage effluent in the San Joaquin Valley, caused selenium toxicity and bio-accumulated salts at high levels in plants and animals enough to cause mortality and to impair reproduction of fish and aquatic birds. Aquatic plants, invertebrates, fish, frogs, snakes, birds and mammals at Kesterson Reservoir contained elevated selenium levels, often averaging a 100-fold increase over samples collected for similar species at reference sites (Ohlendorf, 1989; Ohlendorf and Santolo, 1994). Therefore, combination of bio- and conventional drainage approach to drain water management was designed and demonstrated on a farm in the Central Valley in California (Cervinka et al., 1999).

Farm as a whole covers 620 acres and has 4 salinity zones. Out of these 3 zones each of 157 acres were planted with salt sensitive vegetables and provided with subsurface tile drainage. Similarly, independent drainage systems operated for salt tolerant crops/trees (130 acres) and salt-tolerant grasses (13 acres), whereas shared drainage system for the halophytes (5 acres) and the solar evaporator (2 acres). Vegetables were grown in non-saline zone and irrigated with canal or well water, whereas crops like cotton, alfalfa in low saline zone and received water from tile drainage, tail water (from vegetables), and of canal/well water vegetables. Salt tolerant trees and grasses were grown in moderate saline zone covering two per cent of the project area and irrigated with drainage water from salt tolerant crops. Similarly, saline water from salt tolerant trees and grasses was used in halophytes. This sequential water reuse process productively uses over 90 percent of the drainage water. The remaining drainage water goes into a solar evaporator where water was evaporated and salt crystallized. Sequential reuse of drainage water increased the overall efficiency of water use. The system also prevented on-farm drainage water from contributing to severe regional problems of poor groundwater quality and high water tables. Overall there was a net increase in crop yields and vegetable production grown in non-saline areas. Basically an integrated bio- and conventional drainage system managed irrigation water, drainage water, salt and selenium as resources within the boundaries of the farm and not discharged into rivers or lakes. It seems viable eco-friendly sustainable system for managing water logging and salinity at the farm level. This innovation has great potential for up-scaling in other parts of the world by incorporating location specific adjustments.

Biodrainage potential of Eucalyptus for wastewater disposal

Tree plantations are often expected to use water at higher rates than the shorter vegetation. This is because of greater aerodynamic roughness of tree plantations, clothesline effect in tree rows and deeper rooting system for accessing water down to several metres of soil. Therefore, biodrainage potential of trees having very high transpiration rates can also be exploited for recycling and reuse of wastewater and converting nutrient energy into wood biomass and improving environment. Very high rates of wastewater disposal (0.3–1.0 million litres day-1 ha-1) in *Eucalyptus tereticornis, Leucaena leucocephala* and *Populus deltoids* plantation were reported by Chhabra (1995). Morris and Wehner (1987) reported annual crop factors of 1.4–1.9 times the open pan evaporation (PAN-E) and the maximum daily water-use rates of 20 mm in summer (January) by 3-year-old Eucalyptus plantations irrigated with effluent in arid western Victoria, Australia. With the advancement in measurements of water use, transpiration rate by Eucalyptus plantations estimated by thermo-electric heat pulse method were found to be lower than the reported earlier. In Pakistan, water use to the tune of 0.86*PAN-E was reported from the saline sites (Khanzada et al., 1998; Mahmood et al., 2001). Some of the recent studies (Kallarackal and Somen, 2008; Forrester et al., 2010; Hubbard et al., 2010) show similar results but the overall water use by trees seems to vary a lot with the specific site conditions defining soil type, evaporative demands, stocking density and even the salinity determines the actual water use. In a ten year study conducted at CSSRI, Karnal by Minhas et al. (2015) Eucalyptus plantation irrigated with sewage performed better than the groundwater. Consumptive water coincided with tree growth rates and increased until sixth year of planting and stabilised thereafter. The annual sap flow values ranged between 418–473, 1373–1417 and 1567–1628 mm during 7–10 year of planting under low (163 stems ha−1), recommended (517 stems ha−1) and high (1993 stems ha−1) stocking density respectively. In the nutshell, Eucalyptus plantations can act as potential sites for year round and about 1.5 fold recycling of sewage than the annual crops. Layout set up of the experiment at Karnal farm is depicted in Figure 6.

Figure 6 - Measurement of transpiration rate with sap-flow meter. Source: Jeet Ram et al., 2008

Advantages

The merits of biodrainage technique over the conventional engineering based drainage systems are as given below:

- Farmers although realize benefits of drainage but are too poor to pay cost of drainage, whereas raising biodrainage plantations is relatively less costly and affordable.
- Biodrainage requires no maintenance after initial establishment
- No operational cost, as the plants use their bio-energy in draining out the excess ground water into atmosphere.
- Ecologically safe as drainage effluent is not produced.

- Increase in worth with age instead of depreciation
- Preventive as well as curative system for waterlogging and salinity
- Provides recreational areas and green open spaces, supporting beekeeping (Hadas 2001)
- Sequesters carbon and earn carbon credits
- Moderates the temperature of the surrounding by transpiration thereby proofing for heat and cold waves
- Mitigates greenhouse gases by absorbing CO2 and releasing O2
- Acts as wind break and protects crops in agroforestry system
- Provides higher income to the farmers due to the production of food, fodder, timber, fuel wood and other valuable products. Thinning, based on harvesting about 50% of the slower growing trees, could provide returns even in about five years. The felled trees might be used as a source of biomass for firewood, small poles for agriculture, and/or pulp production, if markets are available. Better performing trees, could be used to produce wood for household and garden furniture (Zohar et al., 2008).
- Biodrainage stabilizes soil on raised bed as highway avenue plantation
- Subsurface drainage in irrigated areas is a collective activity, thus needs appropriate institutional arrangements for farmers' participation (Ritzema et al., 2008). But in case of biodrainage, there is assured people's participation as the biodrainage plantations on farmer's field belong to the individual farmers.
- The improvement in soil salinity and waterlogging provides additional land for cultivation
- Increase in cropping intensity and soil organic carbon build-up
- More choice among arable crops including pulses and oilseed which otherwise are sensitive to waterlogging and salinity
- Timely sowing of crops thus facilitating better yield and profits
- Higher crop yields and nutrient use efficiency
- Increased employment generation and poverty reduction

Constraints

Apart from many advantages, the following limitations of biodrainage may be kept in mind:

- Requires land, may be 10 to 15 % of the total holding of the farmer.
- Requires irrigation for the survival of the trees
- There is a danger of damage in early stages of tree growth
- Tree plantations may not be effective in lowering down the water table in the early growth stages.

- Competition of foliage and roots between trees and crops for light, moisture, nutrient, etc and its effects on co-existing vegetation.
- There is increased activity of the wild animals like blue bull affecting general cultivation
- With age, there would be gradual decrease in capacities of trees for consuming and transpiring water thereby reducing extent of bio-drainage.
- In discharge sites, with evapotranspiration there can be salt accumulation in soil profile which will affect tree growth.
- Where farm holdings are small, obviously landholders are unable to set part of their farm aside for bio drainage activities. Therefore any application of this technique will have to focus on public land.

Future Research and Policy Issues

To further develop the technology of biodrainage, the following issues will need to be considered:

Research issues

- Improving consumptive use of water by trees: There is wide variation in tree water use values because of changes in climatic conditions, type and age of tree species, size of plantation, density of tree plantations (spacing), soil moisture regime, etc. This makes it difficult to select accurate design criteria for biodrainage tree plantings. What should be the optimum density of tree plantings for biodrainage for maximum evapotranspiration per unit area?
- Salt balance and salt tolerance: Further research is required on the mineral absorption by trees and salt-tolerance for estimating salt-balance. The growth of trees and salt-tolerant crops with increasing salt build up in soil profile and consequential impacts on transpiration capacity and excess water removal require further studies in detail.
- Tree species research: Biomass production and water use of desert trees like Prosopis which are high biomass producing and salt tolerant need to be investigated under conditions of abundant water supply.
- High potential biodrainage tree species and their clones/varieties may be identified for specific agro-ecological regions
- Role of highly transpiring Eucalyptus and other trees (bio- drainage) for control of waterlogging, particularly as a preventive seepage control measure in the vicinity of canals and as well as in appropriate agro- forestry models
- Impact of integrated conventional drainage approaches and biodrainage on controlling waterlogging and soil salinity for sustainability of agriculture and environment
- Process based models to predict salinity within the basin under the present and afforested conditions.
- The suitability of biodrainage plantation in shallow saline water table is still in debate.

Policy Issues

- Pilot level studies in waterlogged hotspots for better dissemination of biodrainage technology
- Superior planting stock of trees (clones of Eucalyptus, Casuarina, poplar, bamboos, etc.) which are both fast growing and high transpiring in waterlogged saline soils made available to the farmers
- Provide appropriate credit to the adjoining farmers for raising strip plantations along the canals, high ways and railway for interception of seepage and controlling rising water table.
- Minimum support price policy especially for wood and pulp producing biodrainage plantation to avoid distress sale
- Setting of plywood, paper and pulp industries in rural areas to encourage farmers to go for biodrainage
- Incentives for agencies responsible for undertaking biodrainage programmes
- Awareness and sensitization programs on biodrainage for stakeholders may be organized regularly.

Conclusion

To solve the twin problem of waterlogging and secondary salinization caused due to agricultural development and use of irrigation increasingly demands the biodrainage plantation of trees and salt-tolerant crops as an integrated part of the landscape and farming viewing the cost and environmental issues involved in using the conventional drainage technologies. Plantation of suitable salt tolerant deep rooted fast growing trees with high transpiration rates provides benefits in terms of reclamation of waterlogged area, controlling of water table, improving crop productivity, providing shelter belts, provide additional wood and forest products, and biodiversity. The problems associated with a rise in salinity in the root zone can be effectively delayed using biodrainage systems in semi-arid and arid areas. Biodrainage can be effectively used for water table management both in dry lands and irrigated areas. For better performance biodrainage plantation may also be raised on potentially waterlogged areas to prevent their conversion into waterlogged areas. In areas where the groundwater is sweet and is being subjected to over-exploitation for irrigation and other purposes, resulting in a steep fall in the water table plantation of high biodrainage potential trees might decline water-table further. For the proper planning of bio drainage activities assessment of water and salt balance in the landscape is a major requirement. Apart from advantages, biodrainage has its own limitations also as it requires large area of land, may not be very effective removing salts and performance of plantation is affected by increasing buildup of salinity in soil profile with time. Where bio drainage results in salt accumulation, engineering assistance is needed to make the system sustainable.

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SIMULATION OF WATER FLOW AND SALT TRANSPORT IN DRY DRAINAGE WITH HYDRUS-2D

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Abstract

Sustainable agriculture can help food security. It depends on water and salt balance in the root zone especially in arid and semi-arid regions of the world. Irrigation without drainage is not sustainable. Dry drainage (DD) is rather a new environmentally friendly concept in drainage of arid and semi-arid areas where the irrigation water is much less than the amount to satisfy the extent of the available land. DD was investigated at this study as an environmental and cost-effective alternative technique to the conventional systems. This study was carried out at University of Tehran, Iran, in July 2015 in Lysimetric scale. HYDRUS software was used for DD modeling. Parameters of water flow and salinity transport were optimized by inverse solution of HYDRUS. Results showed that DD could decrease and stabilize soil salinity of the root zone. The salinity at different soil layers of uncropped strips (evaporation strips) was higher than the salinity of cropped strips. Soil salinity at cropped strips was increased downwards while the soil salinity of uncropped strips was increasing upwards. Final soil surface salinity of cropped strips was 1.5 times of the irrigation water salinity while salinity of the soil surface at uncropped strips was reached to 4.5 times of its initial condition after one season. Standard Error and RMSE of observed and simulated volumetric soil water content were 0.26 and 0.104, respectively. Soil salinity of cropped area was predicted better that uncropped area. SE and RMSE of observed and simulated soil salinity were 0.29 and 2.26 (dS/m), respectively. Results of modeling showed that salinity of soil surface at uncropped area was decreased with the passage of time, while surface soil salinity of cropped area remains at its equilibrium.

KEY WORDS: Dry Drainage, Evaporation strip, Solute transport, Sustainable agriculture.

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Introduction

Irrigation sustainability is threatened by soil salinity which in itself is a major threat to food security. IPTRID (2006) estimated that between 10 to 15 percent of irrigated lands suffer from salinity problems with varying degrees throughout the world while a change between 0.5 to 1 percent occurs on nonproductive land each year, and nearly half of all irrigated areas are threatened in the long-term (CISEAU Project).

A report reviewing various estimates of the global extent of salinization on land and water resources concludes that of a total of 230 million ha of irrigated land around the world, some 45 million ha suffer from severe irrigation induced salinity problems (Ghassemi et al, 1995). The global cost of irrigation-induced salinity is estimated as much as US$11 billion per year (Vries et al, 2003).

There are some technical solutions to control soil salinity among which artificial drainage is considered as a major approach. There is a widespread belief that irrigation without drainage is not sustainable, but it is also necessary to consider whether conventional drainage systems are themselves sustainable. While this approach may be suitable for local circumstances, within large contiguous irrigation systems significant economic and environmental limitations may arise (van Schilfgaarde, 1994; Kijne et al., 1998; Ayars and Tanji, 1999; Smedema, 2000; Saysel et al., 2002; Sonuga et al., 2002). Conventional drainage systems have effective roles in the controlling of the water table and preventing soil salinization of irrigated lands; however, thecosts of maintenance and operations and the initial cost for the construction of such drainage systems are very high. In addition, the drainage water in these systems is often saline and sometimes contaminated, and their intrusion into surface water bodies (rivers, lakes, wetlands and so on) creates a number of environmental problems.

In recent years, there have been attempts to identify solutions, which are applicable within environmental constraints and are also economically viable (Hanson, 1989; Gowing and Wyseure, 1992; Asghar, 1996; Sharma and Tyagi, 2004). Currently, the application of alternative methods with due consideration to economical and environmentally friendly aspects instead of conventional ones is highly recommended,. DD is among such methods (Azari, 2004; Konukcu et al., 2006; Khouri et al, 1998; WARDA Annual Report 1997, Akram et al, 2008). DD, which causes parts of the land located adjacent to the cropped land to be retired forever, has been postulated as an alternative (Konukcu et al. 2006). Akram, et al. (2008) studied and modeled DD numerically using SAHYSMOD. They investigated some of the effective factors on DD such as soil hydraulic conductivity, depth to the impermeable layer, depth of the initial water table, the amount and salinity of irrigation water, different evaporation rates of the uncropped area and different ratios of cropped to uncropped widths. The results show that hydraulic conductivity had no effect on the soil salinity of the cropped area and the depth of the water table. The depth of the impermeable layer also had no effect on the water table drop, while it had a considerable effect on the soil salinity of the uncropped strips. They suggested that DD could be considered as a cost effective approach where water is scarce and the land is vast, They also concluded that the effectiveness of DD is higher when the neighboring strips are narrower i.e. 25 m parallel strips are more effective as compared to 50 m ones.

Dry drainage concept

In arid and semi-arid regions, the evaporative demand and the salinity of groundwater may be high and the upward evaporative flux from the saline water table may result in the accumulation of salt with a very high concentration at or near the soil surface. This can occur seasonally on fallow fields or continuously on unirrigated (abandoned) land. The benefits of using this process to control salinity by means of a well -managed evaporative sink area within a ''dry drainage'' scheme was first proposed by Gowing and Wyseure (1992).

In this method, a part of land in the irrigation scheme is permanently or seasonally fallowed and acts as a sink for excessive irrigation water and the salts transported with the groundwater. The groundwater system creates a pathway for the movement of the excessive irrigation water from the irrigated area to the fallow area. The groundwater table in the fallow area through evaporation declines, resulting in a hydraulic gradient and groundwater exchange between the two areas. Thus the excessive salt will eventually accumulate in the fallow area and the salt balance in the irrigated area can be maintained as depicted in Figure 1.

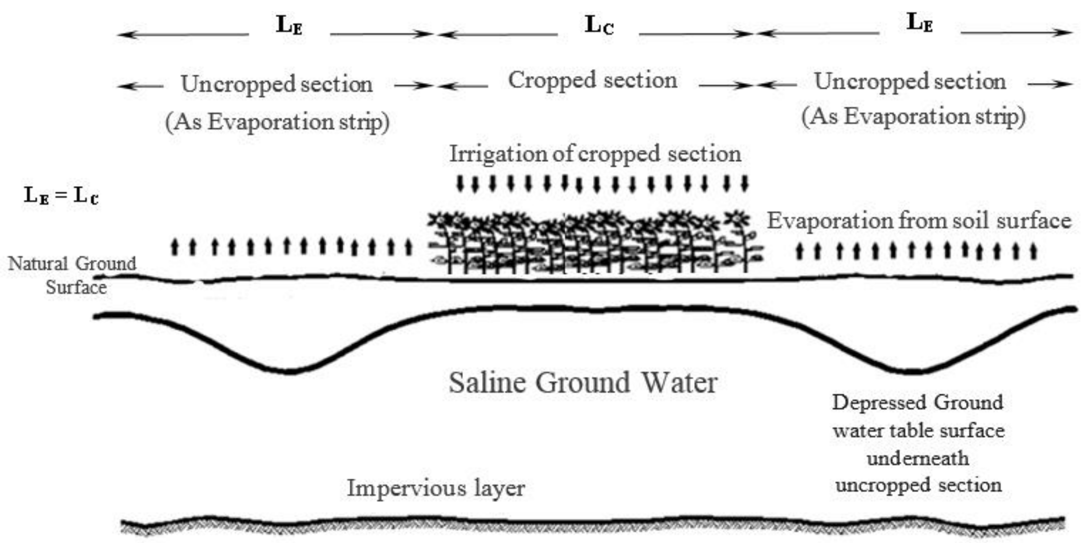

Figure 1: Schematic view of Dry Drainage process

The is the concept of DDis thus if the uncropped area is large enough and evaporation from this area is fast enough, then the necessary balance can be achieved without any artificial drainage.

There are evidences that DD aids in the controlling of soil salinity of the cropped area. In Fergana Valley where there was no outlet of groundwater, the farmers set aside 30-35 percent of the land as fallow land and successfully controll the soil salinity in the irrigated area (Kovda, 1971). In the oasis of Yerqiang River Basintheobservation of the salt balance n in a typical low-lying land over a two year period has shown that the low-lying land accepts 28-44 percent of the excessive salt from irrigation (Shimojima, 1996). DD is also recognized as a sound method by the West

Africa Rice Development Association (Gowing, 1992 and WARDA Annual Report, 1997). Numerical studies on hypothetical field-scale DD examples in the San Joaquin Valley of California, U.S.A were successfully carried out (Khouri, 1998).

There is evidence that some parts of the Indus Basin in Pakistan have already benefited from DD systems and the practical significance of this mechanism has been recognized for some time (Middleton et al., 1966). Doosti et al (2014) recommended an equal ratio of cropped section to uncropped section (50 to 50 percent) with the lowest risk.

Objective of the study

The major objective of this study was to investigate water and salt transport from a cropped to neighboring uncropped area in a research lysimetric scale. In addition, HYDRUS calibration and the optimization of the water flow and salt transport parameters were additional aims of this study. Another goal was to clarify whether a solute transport model (in this case HYDRUS 2D) is capable of simulating the dry drainage concept.

Materials and method

Study location

The study was carried out at research field of the Aburaihan College at the - University of Tehran, Iran (attitude: 35˚ 29' 1'', Longitude: 51˚ 40' 59"). Research open space lysimeters were used to collect the necessary data for interpreting and evaluating the effects of DD on the lowering of soil salinity in the root zone while keeping the water table at its desired depth.

Field experiment

The Lysimeter was made of black iron sheets (the surface of one square meter and a depth of one meter) with thickness of 2 mm. Stainless materials were used for preventing rusting and to ensure the entire inner surface of the lysimeter was stained using pool color (creating a special stainless steel surface with a blue color). At first, four rows of capped holes at one side of the lysimeter were used to collect and measure data during the experiment. However, due to the soil texture, measuring via installed holes was not possible, thus vertical measurements were done from the soil surface. A Schematic view of the research lysimeter is shown in Figure 2. According to previous studies, The cropped section (cropped area) and the uncropped section (evaporation area) were separated equally with an iron blade of 8 cm height.

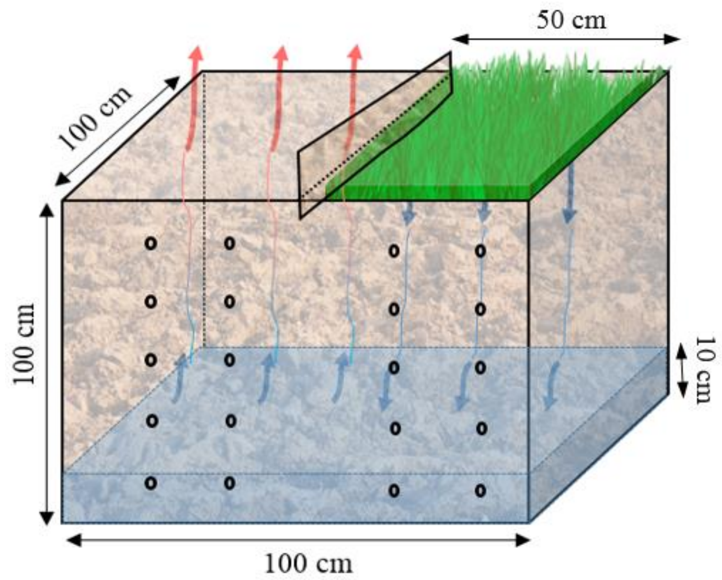

Figure 2: Schematic view of the research lysimeter

The Lysimeter was installed in the soil and a white foam board (2 cm thickness) was used for insulating and preventing direct contact of sunlight to the outside of the lysimeter's surface.

A large sifter (surface of 2m×2m and sieve size of 1 cm) was used to prepare the required 1.5 tons of soil to fill the lysimeter. Sufficient irrigation water was applied to keep the density of the soil at its natural condition. Then four soil samples were collected to measure the soil salinity at its initial condition. The Sieve analysis showed the soil was loam (Table1). The soil of the cropped zone was irrigated before the starting experiment to keep the water table at 90 cm depth from the soil surface. The Salinity of the shallow groundwater was 55 dS/m. Two observation wells were used, each to one side (cropped section and uncropped section) to measure the water table depth. Sport rolled lawn was planted in the cropped section as the reference crop.

Table1: Summery of soil physical and chemical parameters

Soil Texture	Bulk density (gr/cm^3)	Soil particles (%)			$EC_{e\ initial}$ (dS/m)
		Clay	Silt	Sand	
Loam	1.33	19	35.5	45.5	5.1

Measuring irrigation water requirement and preparing saline water

The amount of irrigation water was determined based on water table drawdown. Irrigation was done daily to compensate the drop of the water table and keep the water table nearly constant. Natural drainage water of Qazvin's marshland was used to prepare saline irrigation water. Every night, enough saline water was prepared for irrigation by diluting the marsh water in order to reach to an irrigation water with a salinity of 3 dS/m. A portable EC meter was used for measuring and recording water salinity. The Experiment started on July 26, 2015 and continued for 70 days. Total irrigation, Pan Evaporation and rainfall during these 70 days was 658, 587 and 17 mm, respectively (Figure 3).

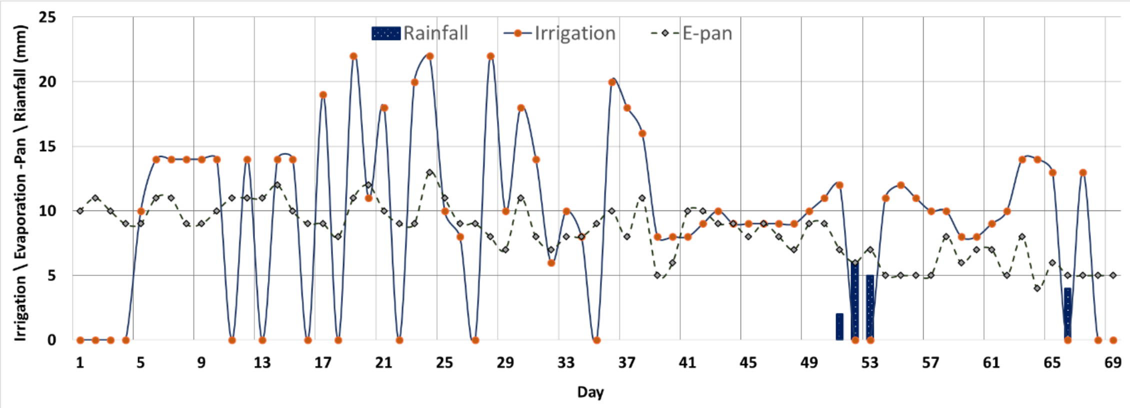

Figure 3: The amount of irrigation depths and evaporation from Pan during the experiment

Measuring soil moisture and salinity during experiment

Measurements included the gravimetric water content and salinity of the saturated paste extract (ECs) at four depths (0-20, 20-40, 40-60 and 60-80 cm from the soil surface). These measurements were done for both sides (cropped and uncropped section) and four times (days 1, 21, 35 and 68 after starting the experiment).

HYDRUS

HYDRUS is a general software package for simulating water, heat, and solute movement for a two/ three dimensional variably saturated porous media. HYDRUS numerically solves the Richard's equation for saturated-unsaturated water flow and the convection-dispersion equation for heat and solute transport. The HYDRUS-2D model (Šimůnek et al. 1999) uses the two dimensional form of Richards' equation incorporates a sink term to account for water uptake by plant roots as below:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[K\left(K_{ij}^{A}\frac{\partial h}{\partial x_j} + K_{iz}^{A}\right)\right] - S \qquad (1)$$

Where θ is the volumetric water content (dimensionless); h is the pressure head [L]; S is a sink term $[T^{-1}]$; x_i and x_j are spatial coordinates [L]; t is time [T]; K_{ij}^{A} are components of a dimensionless anisotropy tensor K^A; and K is unsaturated hydraulic conductivity function $[LT^{-1}]$.

The HYDRUS-2D model implements the soil-hydraulic functions proposed by van Genuchten (1980) and Mualem (1976) to describe the soil water retention curve, θ(h), and the unsaturated hydraulic conductivity function, K(h), respectively:

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{(1 + |\alpha h|^{n})^{m}} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \qquad (2)$$

$$K(h) = K_s\, S_e^{l}\left(1 - \left(1 - S_e^{1/m}\right)^{m}\right)^{2} \qquad (3)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}, \quad m = 1 - \frac{1}{n}, \quad n > 1 \tag{4}$$

where θ_r and θ_s denote the residual and saturated water content, respectively (dimensionless); α is inverse of the air-entry value [L^{-1}]; K_s is the saturated hydraulic conductivity [LT^{-1}]; n is the pore-size distribution index (dimensionless); S_e is effective water content (dimensionless); and *l* is pore-connectivity parameter (dimensionless), with an estimated value of 0.5, resulting from averaging conditions in a range of soils (Mualem 1976).

HYDRUS-2D numerically solves the convection-diffusion equation with zero- and first-order reaction and sink terms. The Galerkin finite-element method is used in this model to solve the governing equation subjected to appropriate initial and boundary conditions. In this study, the general form of the equation was used to simulate salinity movement in soil by solving the following equation:

$$\frac{\partial \theta c}{\partial t} = \frac{\partial}{\partial x_i}\left(\theta D_{ij}^{w} \frac{\partial c}{\partial x_i}\right) - \frac{\partial q_i c}{\partial x_i} \tag{5}$$

Where c is the salinity concentration in the soil [$M\ L^{-3}$]; q_i is i^{th} component of the volumetric flux [LT^{-1}]; D_{ij} is the dispersion coefficient tensor [L^2T^{-1}]. D_{ij} can be defined as follows:

$$\theta D_{ij}^{w} = D_T\,|q|\,\delta_{ij} + (D_L - D_T)\,\frac{q_j q_i}{|q|} + \theta D_w\,\tau_w\,\delta_{ij} \tag{6}$$

Where D_w is the molecular diffusion coefficient in free water [L^2T^{-1}]; τ_w is the tortuosity factor (dimensionless); δ_{ij} is the Kronecker delta function ($\delta_{ij} = 1$ if $i = j$, and $\delta_{ij} = 0$ if $i \neq j$); D_L and D_T are the longitudinal and transversal dispersivities [L].

Appropriate spatial discretization is crucial to avoid numerical oscillations and achieve acceptable mass balance error (Šimůnek et al. 1999; Valiantzas et al. 2011). At the soil surface (with sharp gradients), the discretization decreased to approximately 1 cm and in the other parts it was approximately 3–4 cm. As suggested in the manual of the HYDRUS-2D model for minimizing or eliminating numerical oscillations, the criterion "$P.Cr \leq 2$" was used, in which P and Cr are the Peclet and Courant (Cr) numbers, respectively.

The simulation geometry and boundary conditions for DD at lysimeter are presented in Figure 4.

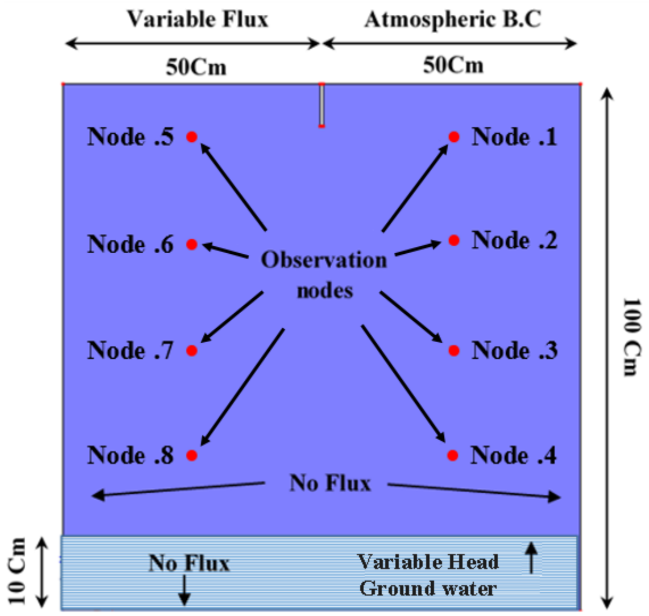

Figure 4: Geometry and boundary conditions of dry drainage used in HYDRUS

Bare soil evaporation from the uncropped area was estimated by multiplying the Ep (evaporation from pan) and Kp (empirical coefficient). Kp was defined as the result of water balance during simulation. A number of water flow and salinity transport parameters were estimated using an inverse solution procedure implementing the Levenberg-Marquardt optimization module built-in HYDRUS- 2D (Šimůnek et al. 1999). The inverse method is based on minimizing a suitable objective function, which expresses the discrepancy between the observed and predicted model values.

Results and discussion

Field experiment results

In general, soil salinity in the uncropped section was more than the soil salinity of the cropped section in all soil layers. In the cropped section, soil salinity increased downwards. However, over time, the salinity of different layers of the cropped section increased and reached to equilibrium after about 35 days; in as such that the soil salinity of the top soil (0-20 cm) at the beginning of the experiment was 2 dS/m and after 35 days this amount increased to about twice that of the irrigation water salinity (about 6 dS/m) and remained constant until the end of the experiment.

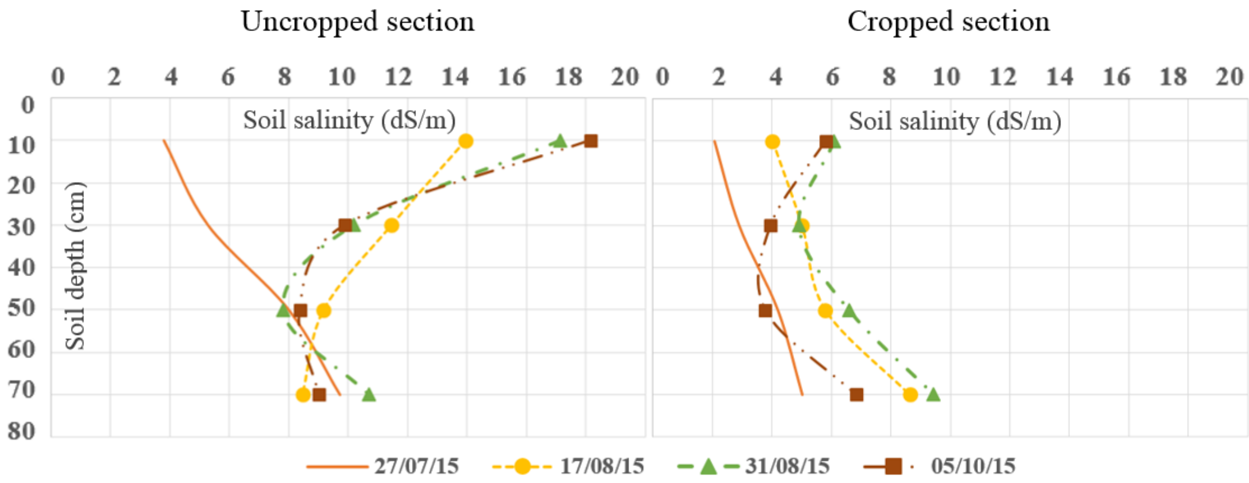

Figure 5: Soil salinity changes with time in cropped and uncropped sections

Initial soil salinity of the uncropped section was increasing downwards which conversed (decreased from up to down) after starting irrigation with saline water. The results showed that during the experiment, top soil salinity was higher than the deep soil in the uncropped section. Changes in salinity at different depths of this section indicate that salinity movement is upward (inreverse tothe downward movement of salinity in the cropped section). Over time, the soil salinity of each layer increases but the rate of this increase drops, which indicates salinity has reached its equilibrium. Most changes to the soil salinity is related to the top soil of the uncropped section. It has increased four times, from 4 dS/m at the beginning to about 18 dS/m at the end of the experiment.

Figure. 6 shows the soil salinity differences (SSD) at equal depths of the cropped and uncropped sections over time. It can be concluded, however, that SSD of the top layer is lower than other layers at the beginning of the experiment and it is higher than the other layers at the end of the test. Over time, the slope of SSD is reduced in bothsections and the soil salinity reaches its equilibrium. SSD of the lower layers are reduced during the experiment and at the end of the test, the least amount of SSD in the 60-80 cm layer was recorded.

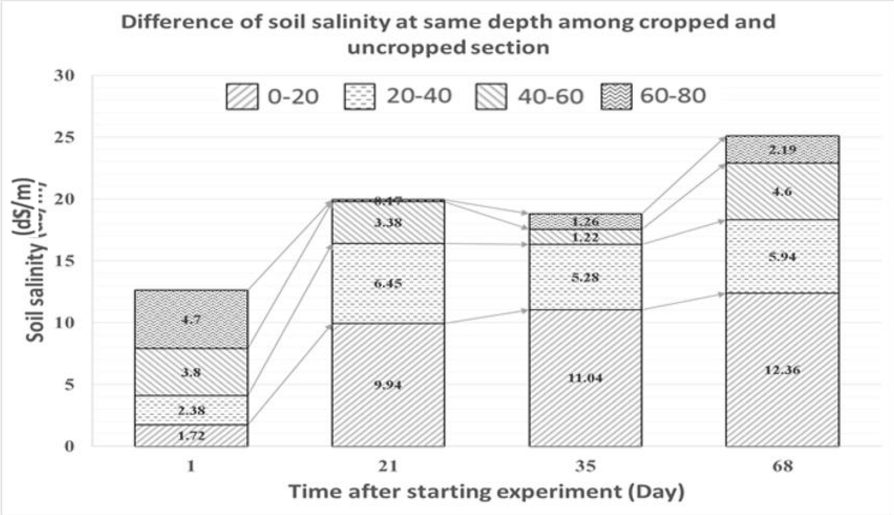

Figure 6: Soil salinity difference (SSD) at the same depths in cropped and uncropped section

Modeling results

The optimized soil water flow and the salinity transport parameters were shown in Table 2. HYDRUS was rerun with an optimized parameters. The results of the comparing of measured and modeled soil water content and soil salinity are shown in Figures 7, 8 and 9.

Table 2: HYDRUS outputs of optimized and statistical parameters

Parameters	hydraulic parameters					Solute transport parameters				
	θr (m^3/m^3)	θs (m^3/m^3)	α (mm^{-1})	n (-)	Ks (mmh^{-1})	D_L (mm)	D_T (mm)	D_w (mm^2h^{-1})	R^2 (-)	NRMSE (-)
Value	0.011	0.498	0.0017	1.53	5.05	317.9	1.42	2.55	0.987	0.34

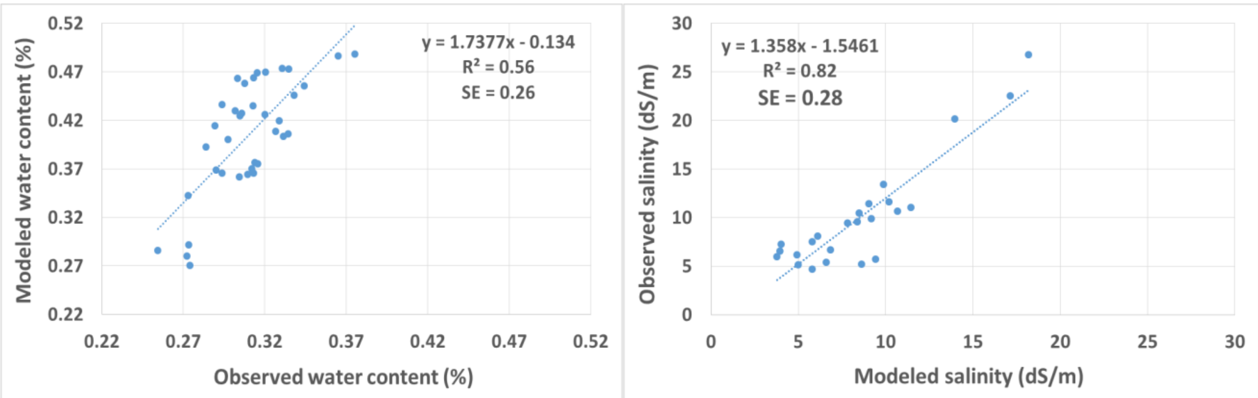

Figure 7: Comparison observed and modeled soil water content and soil salinity

The results show that the modeling of soil water content for both cropped and uncropped areas was good. The Existence of a shallow water table leads to high soil moisture content for both sides and results into a low range of observed soil water content. However, HYDRUS finds the best parameters of water flow and salinity transport using an inverse solution method. The SE and RMSE of observed and modeled soil water content were 0.26 and 0.104 (m3/m3) respectively. The soil salinity of cropped area was simulated better than that of the uncropped area. The SE and RMSE of the observed and modeled soil salinity were 0.29 and 2.26(dS/m), respectively.

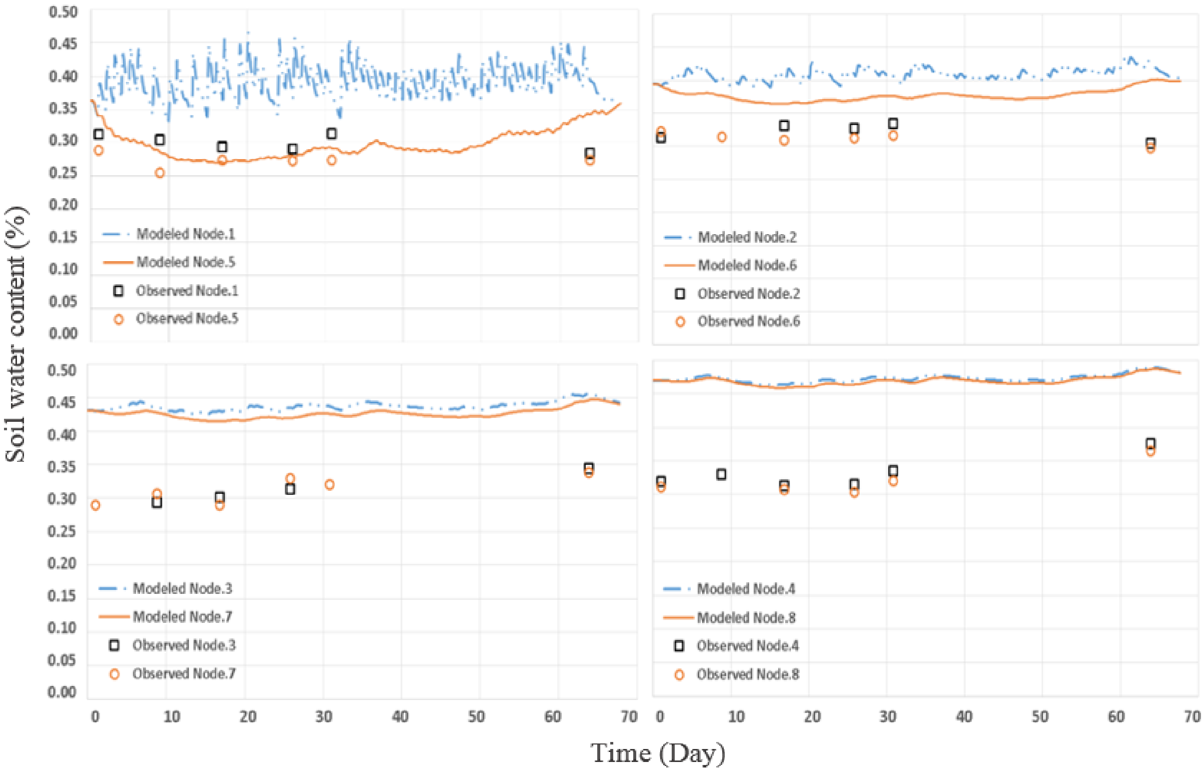

Figure 8: Measured and simulated water content of different layers

The results of the model show that the salinity of the soil surface in the uncropped area increases with time, while the surface soil salinity of the cropped area reached equilibrium. In other words, DD can stabilize soil salinity of the root zone by transporting salt from the irrigation area to an evaporation area (from cropped to uncropped area).

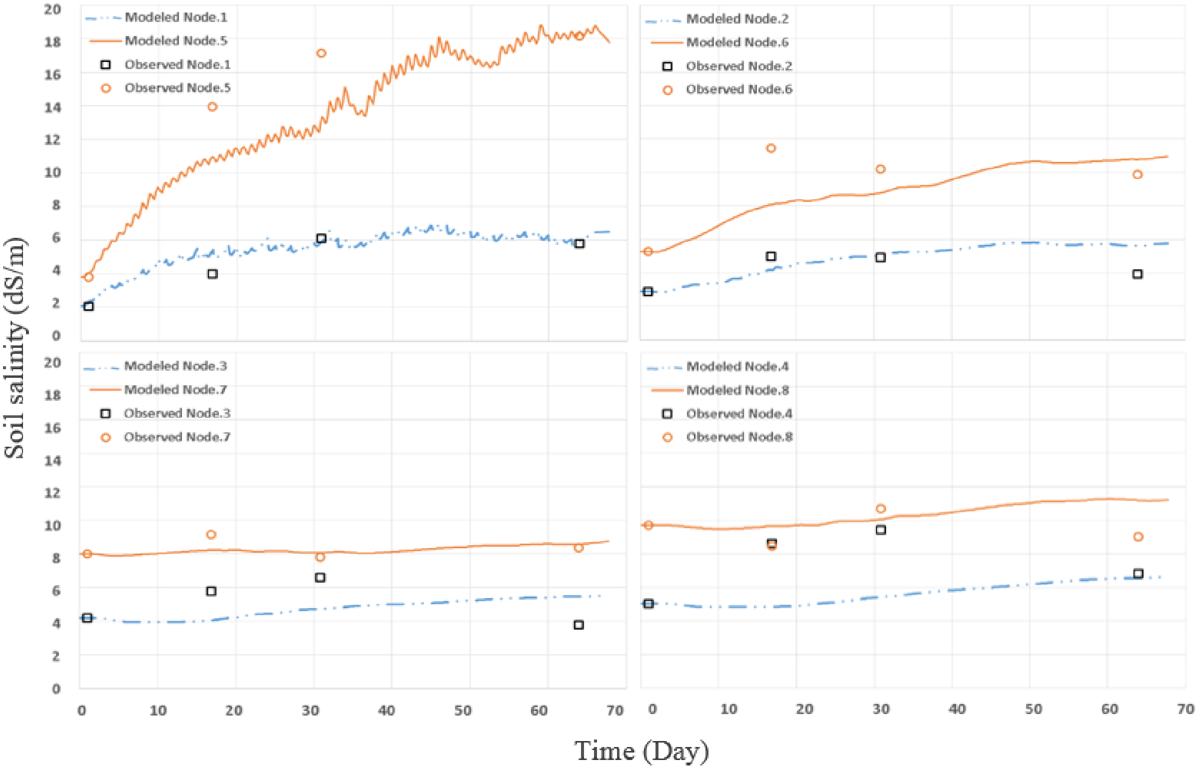

Figure 9: Measured and simulated soil salinity of different layers

Conclusion

There is no clear physiological analysis for Sport rolled lawn ; hence, it was not possible to discuss plant conditions scientifically. However, it appeared to be with no water stress. The salinity of the root depth was low without any sign of soil salinity. DD is able to decrease and stablize the soil salinity of the root zone by transporting salt from an irrigation area to an evaporation area. Salinity variation and water flow direction in this study was matched with the fundamentals of DD (Gowing and Wyseure, 1992). DD can be modeled well using HYDRUS. Although at Lysimetric scale, the low range of the observed soil water content exists as a result of a shallow water table, this limitation does not exist on a large scale and the modeling of DD can be done with more confidence.

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5

Topic 5: Irrigation and Drainage Management

DRAINAGE SYSTEM IN IRRIGATED SECTOR KEY FOR BETTER WATER MANAGEMENT GEZIRA SCHEME – SUDAN

Mufadal E. M. Ahmed[1,*], Abu Obieda B. Ahmed[2]

Abstract

Agriculture remains a key element and pillar of Sudanese life, and represents the main driving force for its economy and as an income generating sector for more than 50% of households. This sector accounts for about 31% of GDP (Central Bank of Sudan CBOS-report, 2015); The irrigated subsector as part of the agricultural sector is responsible for the production of cash crops (cotton and sugar cane,..) and cereals. In mega irrigation schemes such as the Gezira Irrigation Scheme (GIS)- the forerunner of all major schemes in Sudan with an area of about 0.882 million ha-the drainage (surface) system plays a significant role in tandem with the irrigation system. Water logging and hence the significant reduction in crop production, coupled with negative environmental impacts are considered as strong obstacles against harnessing the available water resources for better livelihoods.

This paper is a contribution to the Sudaese governmen's effort towards upgrading GIS. The drainage system within the scheme did not receive enough attention and witnessed severe deterioration due to several reasons that occurred over the operational lifetime of the scheme, which in itself accelerated the spread of silt and weeds in the network system of the scheme.

The paper discusses and attempts to diagnose, and analyze the performance of the GIS drainage system by identifying its arrangement, design, capacities, and adequacy to contribute a solution to water management and constraints to sustainable development. In addition it provides a set of amendments and improvements to the existing system including a revision of its design criteria and how that improvement, if implemented properly, can result in better water management and providing an environment for production.

KEY WORDS: Surface drainage, Water logging, Design criteria, Gezira Irrigation Scheme, Water management

Introduction

Sudan, with an area of 1,882,000 square kilometers, and a population of about 40 million is an agricultural-based economy; that agriculture remains a key sector and the core of Sudan life, is representing the main driving force for its economy and as an income generating sector for more than 50% of households. The sector accounts for about 31% of GDP (Central Bank of Sudan

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CBOS-report, 2015). *The irrigated agriculture sub-sector* is also a key factor in agriculture, which contributes to the stability of the country agricultural production, and includes 100% production of sugar cane and more than 80% of cotton.

The GIS is huge in size and dominates the entire irrigated subsector in Sudan, approximately 47% of the entire total irrigated area in Sudan (Plusquellec, 1990).

The Gezira scheme was designed in the 1920s after prolonged experiments had been carried out on a prototype scale. It was designed with the main objective of producing cotton, as a single cash crop. The irrigation and drainage of the scheme *was* laid out to suit the size of tenancy and crop rotation. The flat and featureless topography was favorable to the adoption of regular gridiron layout. The basic unit is a group of four adjacent fields of 90 fed (1 feddans=0.38 ha) each called a Number. One crop is grown on each number following the four rotation system. Each number is divided into 18 tenant fields of 5 fed (called hawasha),(Farmers do not own their lands; they are tenants and arrangements for endorsement of land ownership is a very complicated problem since the 1921 Gezira Land Ordinance). The tenants fields are divided by a network of cross-bunds for irrigation by basins (now it transferred to furrow), (Plusquellec, 1990). (fig. 1& 2 shows the scheme location and the standard field layout).

The irrigation system comprises twin main canals running from head-works at Sennar dam with a design combined capacity of 354m^3/s, and a network of irrigation and drainage canals. The main, branch and major canals are designed as regime conveyance channels. The minor canals are designed for distributing water continuously flowing from the major canals. According to the design principle the field outlet gates serving the "numbers" are open 12 hours per day at a nominal flow of 116 1/s (5,000 m^3/12 hour). The irrigation and drainage system main features include (Plusquellec 1990):

- 2 main canals of total length of 261 km with conveyance capacity ranging from 168 and 186 m^3/s at headwork to 10 m^3/s at the tail; 11 branch canals of total length of 651 km with conveyance capacity ranging from 25 to 120 m^3/s.
- 107 major canals of total length 1,652 km with carrying capacity ranging from 1.5 to 15 m^3/s; and 1,498 minor canals of total length of 8,119 km, a delivery capacity ranging from 0.5 to 1.5 m^3/s; 29,000 water courses called “Abu Ashreens” Abu XX of total length of 40,000 km with 116 L/s capacity; and 350,000 field channel called “Abu Sitta” (Abu VI) of total length of 100,000 km with 50 L/s capacity.
- All canals have headwork and cross-regulators (types are: sluice gates, well head regulator and pipe regulators, and Butcher weirs).
- The drainage system comprises:
  - ❖ The present surface runoff drainage system consists of minor surface drains of total length of about 6,000 km and major drains totaling about 1,500 km in length
  - ❖ Escape drains in the Gezira Main Canal with total escape capacity of 67m^3/s; and Protective drain of 130 km.

Background

Since its establishment, the GIS have experienced many changes. The Sudan Gezira Board (SGB) replaced the former managing Sudan Plantation Syndicate in 1950. Production relations have undergone several modifications. The Joint Account System (JAS) was modified in 1946, 1950 and in 1970, and was replaced by the Individual Account System (IAS) in 1980/81 up to date. (A.M.Eldaw, 2004).

The Cropping System

Based on the tenancy agreement, decisions on crop choice, crop mix and crop rotation are the domain of the Gezira Board. The Agricultural Committee (a sub-committee of the Board of Directors) is the body that makes decisions on crop rotation, though with technical support include all agricultural activities. The initial crop mix in the Gezira Scheme included, besides cotton as a major crop, sorghum and lubia (dolichos lablab). These crops were grown in a three-course rotation: cotton–sorghum/lubia–fallow. The crop mix and crop rotation were subjected to various changes for technical and economic reasons in the course of time between the early 1930s and the early 2000s. Following the intensification policy in 1975/76, a unified four-course rotation was adopted all over the irrigated area. This rotation was expanded in the early 1980s to a five-course rotation to introduce fodder cultivation as a basis for the integration of livestock production into the scheme's cropping system but not adopted. All these developments lead to many changes of the cropping rotation adopted (A. M. Eldaw, 2004). (Table1). Crop Rotation in the Gezira Scheme after 2005 Act adoption is not defined as liberization of cropping system allow farmers to cultivate freely(not obliged), and SGB is just planning and supervising.

Table 1. Development of Planned Crop Rotation in the Gezira Scheme

Season	Crop rotation	Land use %	Remarks
Gezira: 1925/26– 1930/31	C – S/L – F	66.30	
1931/32– 1974/75	1931/32 First change crop rotation in crop rotation to combat cotton infestation, followed by many changes affected by diversification policy	33.30, 44.75, and 69.75	eight course rotation was established
1975/76– 1980/81	C – W – G/S – F	75.00	
1981/82– 2005/06	C – W – G/S – F – Fo	75.00	Fo-Not adopted
Managil extension: 1975/76 - 1980/81	C – W – G/S – F	100.00	
1981/82 – 2005/06	C – W – G/S – F – Fo	75.00	Fo-Not adopted

C = cotton; F = fallow; Fo = fodder; G = groundnuts; L = lubia;; S = sorghum; W = wheat
Source: Galal, M. Y. (1997), remarks are added to the table, and recent seasons are amended

Scheme Operation

Before the adoption of 2005 Gezira Act the operation of the scheme is centrally controlled: The management is divided between the Ministry of Irrigation (MOI) which is responsible for the irrigation network (23 subdivisions) and the Sudan Gezira Board ((SGB), 106 blocks), which is responsible for agricultural operation. The water orders (or indents) are passed to the MOI engineers, summed out throughout the system up to head-works at Sennar dam..

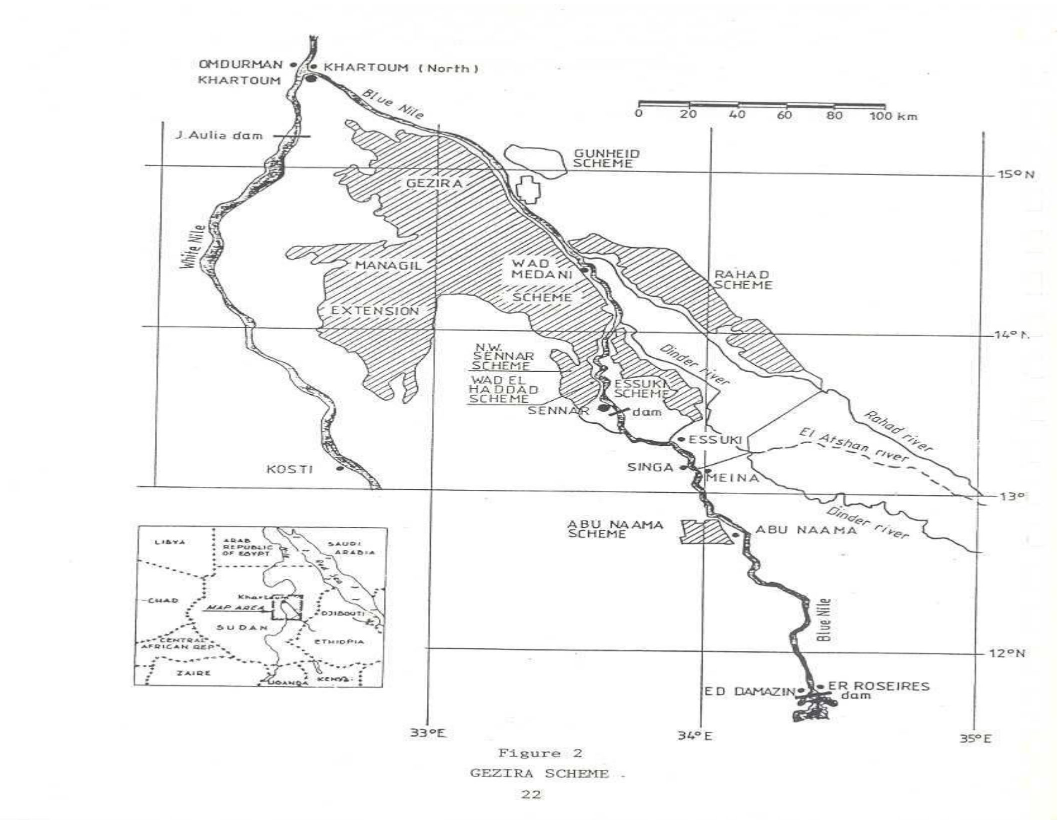

Figure 1. Gezira irrigation scheme location map (source: david t. Williams, 1988,)

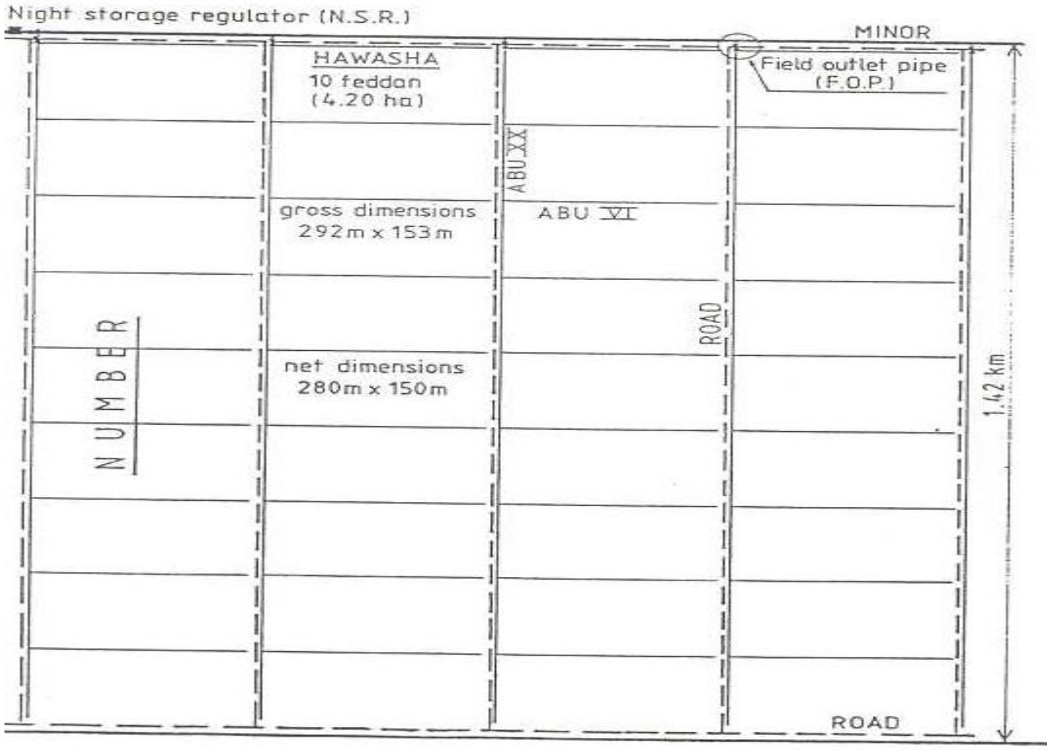

Figure 2. Gis standard typical field layout (source: david t. Williams, 1988,)

MOI(Ministry of Irrigation) delivers the required discharge up to the head of the minor canals, and SGB is responsible for the delivery of water to the tenants.

The Gezira scheme is not a sophisticated one by present day standards. The design, however, took the best advantage of some favorable and unique features of Gezira: (1) The flat topography; and (2) the adopted tenancy system. The adoption of the night storage system resolved the issue of night irrigation found in many schemes, and provide a remarkable solution to the complex problem of adjusting water releases at the head-works. A negative characteristic of the minor canal, which was probably overlooked, is its ability to trap the silt released into the system. For about 40 years, the Gezira scheme was operated satisfactorily on the basis of the original design and operational concept. The management of GIS ran into problems in the early 1970's shortly after the scheme reached its present extension and application of intensification. (Plusquellec,1990). Because of the lack of financial resources, MOI was not able to cope with removal of silt and weed clearance. Poor maintenance led to a reduction in the transit capacity of canals, wear out of regulatory system.

The Drainage System in the Scheme

Basically, the scheme design surface runoff drainage system consists of minor surface drains of about 7,800 km length, collective or major drains of about 2900 km length, escape drains, in Gezira Scheme main canals; it is characterized by a very limited capacity for runoff of surplus water tables 2 &3 shows drainage capacities.

Table 2. Scheme Escape Drains (sources: Gezira Regulation Handbook)

Item	Escape	Authorized Capacity (Mm^3/day)	Remarks
1	K.57 Escape	1.80	closed
2	K.77- Wad El Nau	0.40	closed
3	K. 108 –Beika Escape	0.90	Feed University of Gezira farm
4	K.169-Abu Usher	1.20	
5	Managil escape (k65)	1.5	closed
	Total	5.80	

Table3. Scheme Collective, Protective, and Minor Drains

Description	Scheme Administrative Divisions				Scheme Total
	North Gezira	South Gezira	East Managil	West Managil	
Total Irrigated Areas(fed)	834,000	435,274	445,726	485,000	2,200,000*
T. length of minor drains(km)	1,825	2,710	1,465	1,865	7,865
No of collective Drains	20	35	16	17	88
T. length of collective (km)	602	843	471	957	2,873
Shawal protective drain-in km					130

* This total includes pump station schemes within Gezira, like Hurga & Nur el Din,. etc),
Source: Ministry of Water Resources, Irrigation and Electricity (MOWRIE).

The original design of the Gezira Irrigation System recognized that because of the nature of the soil and absence of a high water table, there was no need for, and indeed no means of providing sub-surface drainage of the fields. The only need for drainage, therefore, was for dealing with surface runoff from rainfall or excess irrigation. The system of drains which exists in various areas in the Gezira has been provided with the object of carrying off rainwater from the land as soon as possible after it has fallen. Although there are no field drains parallel to the Abu XX to take runoff from the fields; Minor drains settings (figure2), are run parallel to minor canals discharging into collector drains which generally follow the lines of natural drainage and lead the runoff water to outfalls. The collective drains ideally outfall beyond the cultivation boundaries to natural drainage lines (depressions) or thence to the Blue or White Nile. However, several drains terminate in large local depressions usually on land which is unsuitable for agriculture; after that the runoff water is allowed to pond up and then evaporate.

The drainage system design capacities were originally based on empirical formulae derived from experience of basin irrigation according to the relationship: (MOI -Design Sheet File DSF)

$\mathbf{Q = CA^{2/3}}$, Where:

Q = discharge in m^3/day

A = Catchment area in fed (Feddan)

C = runoff factor, a constant depending on intensity of rain, soil permeability, geographical zone and other climatic factors (=150 for North of the Scheme and 270 for far South of the Scheme) (according to DSF specification). This relationship is developed for the cultivated area under basin irrigation and assumes considerable storage of potential runoff on the field and some storage in fallow area.

The drainage channel system was set as complementary to the canal system. Minor drains and collective drains channel sections are designed based upon the Manning equation (principally based on 0.20 m free board from ground level for various slopes of minor drains and side slope 1:1 –DSF and other parameters are set accordingly).

The Problem and Constrains

Changes in agricultural field practices from basin irrigation to furrow system intensify the flow of surface water (rain or excess of irrigation) to the limited capacity drainage system, and the relationship (formula) used for design is no longer valid for application. Also the existing irrigation and drainage system is suffering since the late 1970's, when the Sudan Government was very much concerned about the general decline of the irrigated agriculture production particularly in the GIS. It was agreed to initiate a rehabilitation program (with the World Bank). The rehabilitation project initiated in 1984 concentrated on the restoration of the irrigation system and a package for rehabilitation of the drainage system were included within other components as:

"*To restore the drainage systems to original design standards the project includes removal of an estimated 3.0 million* m^3 *of silt from major(collective) drains, construction of 190 km of new drain and rehabilitation of 4,000 km of silted up minor drains to their design sections. Five new drainage pumping station will replace the old ones which are out of operation. Two new siphons and six hundred road crossings along the major drains are also to be installed*", (World Bank, report 1994)

Unfortunately the two important items namely: Silt clearance of minor drains, and excavation of new minor drains were not executed, and other items are not fully implemented (no records). Accordingly the present drainage running without field and minor drains (the minor drains are completely buried and not exist).

The working drainage system inside the Scheme is only collective drains with very limited capacities. Also depressions where most of the collector drains outfall have been silted up, covered with grass and partially with forest do no longer receive the drainage water effectively even part of the them are used as township for labors (Kanabi). Eventually, the drainage water from collective drains inundates the nearby cultivated fields (water logging). This is also coupled with excess water from irrigation (as wear out of regulatory system), and in the absence minor drains the areas along & around collective drains are infested with weeds. Leading to a wide spread of water covering other fields & field roads. It is also very common that farmers and villagers are suffering a lot during the rainy season even to reach their farms. The results are a very bad environment for production. Table 4 below shows the main impacts in the last rainy season (2016), and Malaria infection as recorded by health authorities.

Table 4. Areas of main crops affected in the last rainy season (Jul – Sep 2016), and Health Impacts*

Item	Crop**	Damaged Crop Area(fed)	Inundated Crop Area(fed)	Total Crop Area Affected(fed)
1	Cotton	2,449	3,240	5,689
2	Groundnut	12,022	4,537	16,559
3	Sorghum	29,141	14,460	43,601
4	G . Total	43,612	22,237	65,849

* Average Malaria infection inside Gezira during rainy season increases by about 2.7%(source- Malaria Treatment Department – Gezira State Ministry of Health, Wad-Medani)

**Other crops no records, Source of data is SGB.

Also the Gezira Scheme has experienced many administration changes in the early 2000s, especially after adoption of 2005 Act (2009-2015), where the irrigation sector transferred from MOI to Ministry of Agriculture and liberation of cropping in the GIS without a comprehensive look to the consequences as

- A non defined cropping rotation(many crops per one block or Number)

- Interruption of indent-supply procedure(high indent for long periods almost full season), and water logging (very poor water management)

The results are an improper use of the system, and inefficient water management.

Effect of crop liberization: Before adoption of 2005 Act, the working crop rotation is 4 courses, which indicate that during rainy season 50% of the area will be not under cultivation (25% of cultivable area is fallow + 25% is for winter crops), and so 50% of the area is receiving ponding or storage of drainage water (especially rain cut irrigation water). Changing to 5 course rotation, theoretically 60% of the area will be under cultivation(10% excess); but in reality (and after adoption of 2005 Act) is 75% will be under cultivation(no fallow, only winter crop area or not yet planted is remained) leading to reduction of ponding(storage capacity) areas by 25%.

Methodology and Material

Approaches

The problems related to the drainage system in the GIS have many dimensions such as technical, managerial (agricultural policy), and institutional complications. The approach proposed in this paper is based on the investigation, revision & check, and analysis for the real causes of the problem taking into consideration the following:

- The scheme network is huge and it is not possible to cover a wider range for such a system in this part of the study.
- The approach concept of investigation and survey will select an area of study, collect basic data, information and carry out all checks and analysis for the selected area.
- The approach will deals with the application of developed techniques or formula following the design of the system and proved to be suitable to the system.
- Problems related to the system and not existing within the selected area, there will be a reference to that; and analysis results and solution proposed will be drawn with recommendations for the whole drainage system in the scheme.

In the essence, this approach returns to the original objectives of the study and attempts to ensure that the results and recommendations can be viable in practice.

Investigation and Revision

This investigation and revision for drainage design flow rate in the Gezira Scheme is carried out concurrently with a reference to a report of a comprehensive study conducted to MOI by Sir M. MacDonald & Partners Consulting Engineer for Rahad Project under design review of irrigation canal and drainage system in 1977. Also the above report (*design review Report)* was referred to two reports as follows:

(i) An earlier report: (Roseires pre-investment survey, Report No.5 “The Hawata Extension to the Rahad Project, Part III- Engineering” Sir M. Mac Donald & Partners, Hunting Technical Services Limited, October 1966)

(ii) Tambul Pilot Study for Long Furrow to Rahad Project in 1971.

The three reports will be named and mention in this study as: design review Report, Report No.5 Hawata Extension, and Tambul Report; respectively.

The Rationale to revise and use this study of Rahad to be applied in GIS is as follows:

- The two schemes are located within the Sudan Central Clay Plain, almost extended to same latitude, separated by the Blue Nile (Fig3), with comparable climatic conditions, similar topography (gentle slope), and identical soil properties.
- Climatic Data used in Review report is mainly for Wad-Medani data
- The Gezira scheme principles and basics for design is used in the design of Rahad scheme(forerunner scheme)

Basically the used relationship ($Q=CA^{2/3}$) is for the cultivated area under basin irrigation and assumes considerable storage of potential runoff on the fields and some storage in fallow areas. The capacity of the designed drainage system for the north area can drain 10% runoff from a 100 mm storm on 10,000 fed in six days. In the south of the area the channels will drain 18% of a similar storm in six days (Sir M. MacDonald *design review Report*, 1977). However, the potential runoff from furrow irrigation is likely to be greater since the furrows will facilitate runoff from the fields. It is necessary and essential therefore to revise the design formula mentioned above; several alternative approaches are introduced by the *design review Report* as:

(1) The drainage capacity may be designed to remove the potential runoff for a design frequency (say 1 in 5 years) thus reducing ponding on the fields to a minimum. However, this is likely to prove uneconomic both in terms of the drainage capacity required and capacity of downstream structures (bridges, culverts etc.)
(2) Alternatives could be made to accept a certain amount of ponding in the fields that would not affect the crop or damage properties, and would reduce the drains size.
(3) The *design review Report* is referred to a report produced for Tambul Pilot Study for long furrow irrigation for Rahad Project (Tambul is a town in North Rahad Scheme – within the Gezira State) attempted to adopt the drainage design formula, $Q = CA^{2/3}$, to allow for increased runoff from irrigation areas using straight furrow system. A number of changes were introduced. Firstly, ponding within the cultivated area was reduced to 48 hours. Secondly, the surface runoff from a small area was assumed to be about 88 mm from a design point rainfall value of 100 mm. Thirdly, the area rainfall reduction factor was increased from 0.667 to 0.9 for areas between 500 and 5000 fed, and 0.8 for Northern Area and 0.86 for the Southern Area for areas between 5000 and 20000 fed. (Sir M. Mac Donald, *design review Report* 1977).

Comparison between the drainage rates derived from *Tambul Report* and Report No.5 Hawata Extension to Rahad Project is shown in table 5 below.

Table 5. Drainage Rates Obtained from Previous Reports (in m^3/sec.)

Item	Drainage Area (fed)	Tambul Report		Report No.5 – Hawata Extension	
		North of Jebel el Fau	South of Jebel el Fau	North of Jebel el Fau	South of Jebel el Fau
1	1	0.002	0.002	0.0017	0.003
2	100	0.20	0.20	0.04	0.067
3	1000	1.00	1.00	0.17	0.31
4	5000	4.30	4.30	0.52	0.94
5	10000	3.20	5.50	0.81	1.46
6	50000	11.50	22.0	2.31	4.17
7	100000	20.0	40.0	3.83	6.67

Source: (Rahad Project Design Review Report, Sir Mac Donald, 1977).

The design Review Report carry out a series of revision, checks, and comparison to the findings of the two reports to obtain a revised drainage rates and that includes:

a) *Point Rainfall Analysis* for rainfall in the Rahad Project Area using average monthly distribution for Wad Medani and Gedaref (1941-1970).

b) *Area Rainfall* to reduce the design point rainfall values (area reduction curves) it was concluded that a fair estimate to use and select W.M.O 30 minutes duration curve.

c) *Design Flow with Field Storage*

The design flow may be calculated using a simple water balance equation

Q_o = RF – SMD – ET (mm), where: Q_o = design flow in mm, RF = rainfall, SMD = Soil moisture deficit, ET = evapotranspiration

The calculated design flow was carried with assumption of 24 hours and 48 hours duration under the following estimates:

Open water evaporation of the order 6mm/day for the month of August (would be applicable because surplus water would be ponded on the surface as the low infiltration capacity of the clay soils once they had been wetted.

- 10 mm soil moisture deficit (only small SMD is to be expected because August is generally the wettest month.; and the results of calculations are incorporated for comparison (results are not included in this paper).

d) *Design Flows with no Filed Storage*

This is made if no allowance for surface ponding using Unit Hydrograph (peaked hydrograph), the report uses the triangular hydrograph following the procedure laid down by the Soil Conservation Services, and design peak flows.

Eventually the design review report for Rahad made a comparison of results and plot curves relating design peak flows to catchment area based on the followings:

(i) Report No. 5 Hawata Extension; **(ii)** Tambul Pilot Study;
(iii) Field Storage of 24 hours duration;
(iv) Field Storage of 48 hours duration; and **(v)** Discharge hydrograph estimates.

The plotted curves relating design peak flows to catchment area are shown in fig4

A recent Comparison from Rahad irrigation scheme rehabilitation program showed that the drainage system of the Rahad scheme is the best in the irrigated subsector.(YAM-CDC,2015)

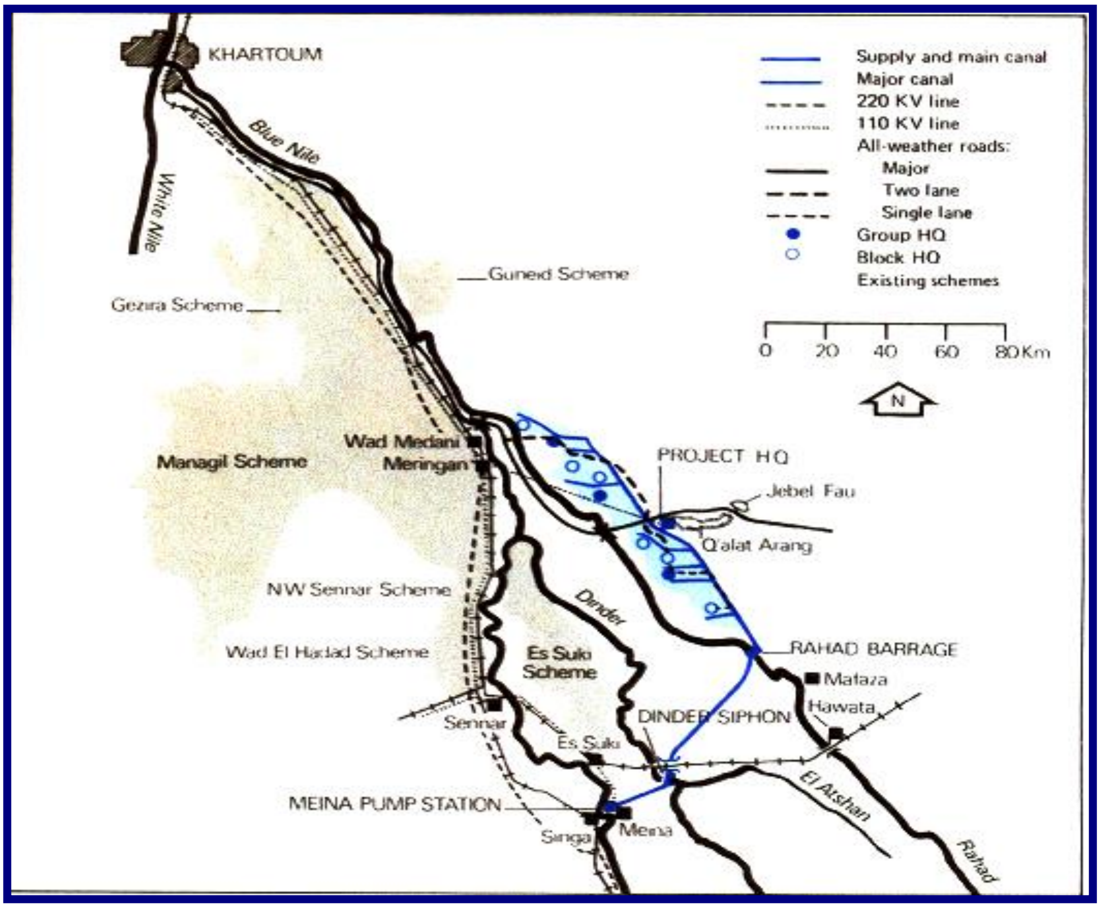

Figure3. Rahad scheme location map- source: moi annual report 1981

Experimental Site layout (Study Area)

Study Area

The selected area of the study is Bashkar collective drain, located in Tayba Block in the centre of the Gezira Scheme and starting at the end of Ibrahim canal opposite to K 110 Gezira Main Canal (nearby Beika group of regulators k108) (Messelamia Sub-division North-west Wad-Medani by about 15km), refer to figure3.

Basic data of the collective drain is as follows:

- The drain was constructed with the Scheme in 1920's
- Remodeled in 1932; length 12.1 Km, and outfall in Gezira main canal k121(*drawing Longitudinal section No.G.C.S. 32 -9076- Project directorate- MOI*).
- The drain has three reaches with parameters as follows:

1st reach, drainage area: 1800 F, Q=0.27 m^3/s, Bed width 2.0 m, slope20 cm/k
2nd reach " " : 3120 F, Q=0.40 m^3/s, " " 3.0 m, slope 11 cm/k
3rd reach " " : 5880 F, Q=0.55 m^3/s, " " 4.0 m, slope 11 cm/k.

Technical Checks

Applying the formula used for design of the system (MOI- Design Sheet File (DSF), & technical notes: we get the followings:

$Q = CA^{2/3}$ $m^{3/}$day, C= runoff factor, is 150 for north, and270 for south Gezira (DSF)

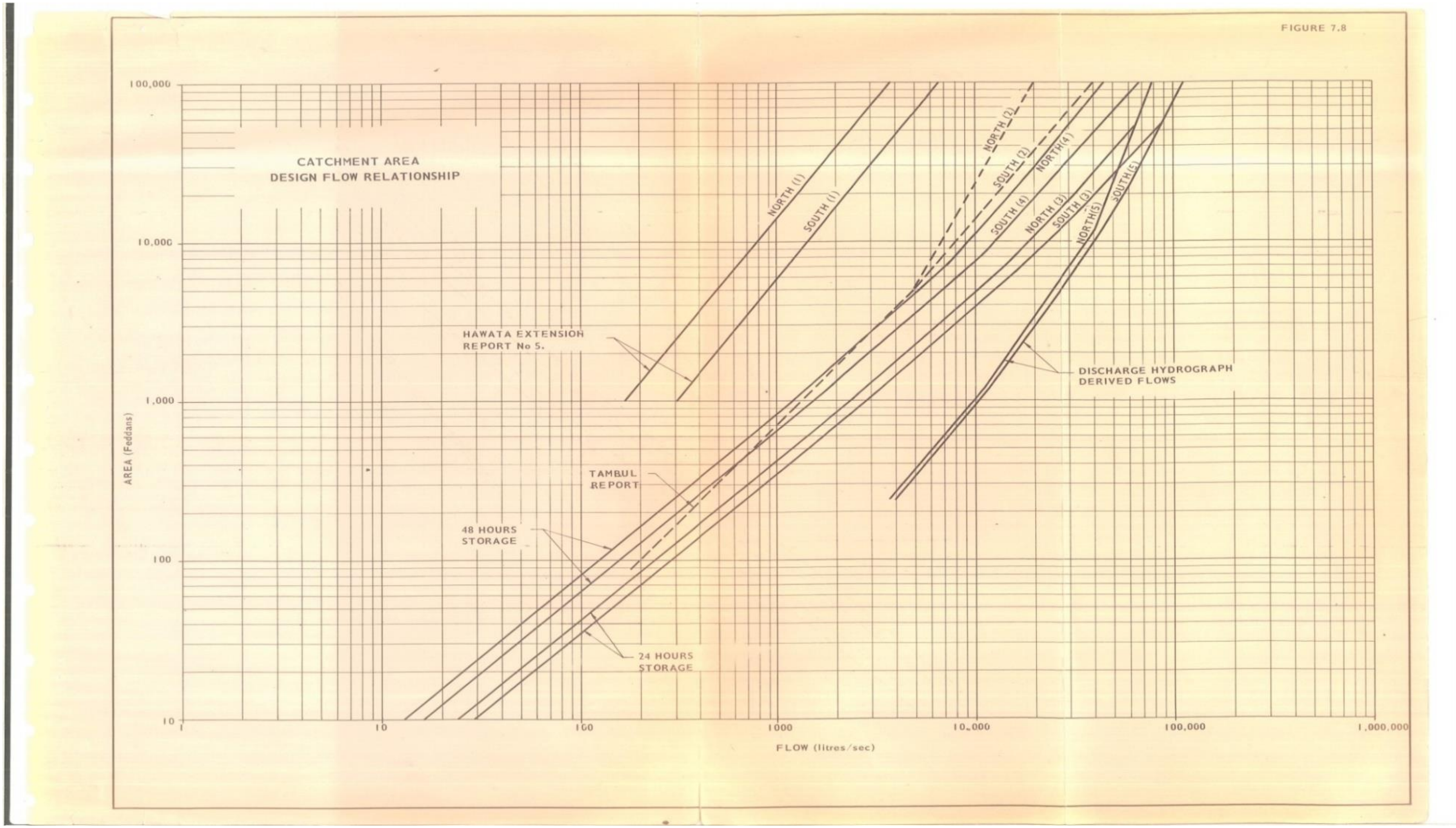

Figure 4. Curves relating design peak flows to catchment area (source: design review report,1977)

Then $Q = 150\ A^{2/3}$, A = catchment area in fed
Reach 1 → $Q_1 = 150x(1800)^{2/3} = 22{,}251\ m^3/day = 0.26\ m^3/s$.
Reach 2 → $Q_2 = 150x(3120)^{2/3} = 32{,}114\ m^3/day = 0.37\ m^3/s$.
Reach 3 → $Q_3 = 150x(5880)^{2/3} = 49{,}007\ m^3/day = 0.57\ m^3/s$.,
The check shows that discharges are compatible with the design in accordance to the formula. From the preliminary investigation the drain is infested with sediment and weeds. Bashkar collective drain outfall structure (siphon 2lines with 0.76 m size) was constructed in1932, and still in good condition, but the gates spindles are removed. Also it was noticed that the operation level during the past periods was changed.

Results and Discussion

From the investigated & revised relationship and curves relating design peak flows (Figure 4), to use and apply these relationships to Gezira drainage system, the following could be raised:

- The area of study is in the mid part of Gezira and compatible with the classification (latitude and climatic condition) of the review report study, to be in North of Jebel El Fau (refer to Figure3).
- Hawata extension report No.5 findings are based on the DSF formula under which the GIS was designed (it is identical to the original design of our area of study) and so it will not be used in our analysis.
- The criteria of no storage (hydrograph flow) have been considered in the analysis.

The result of new setting for Bashkar collective drain using the derived capacities relationships is as shown in Figugre.5, and table.6, below

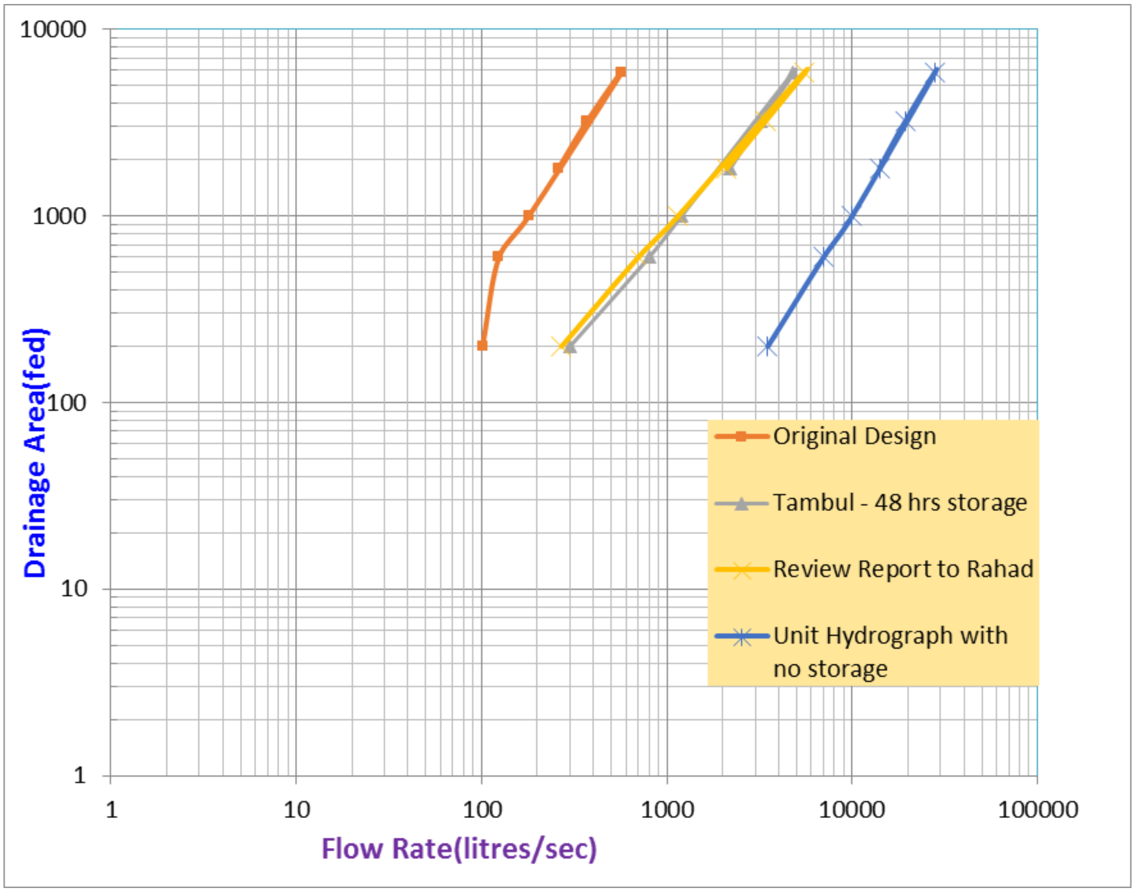

Figure. 5. Derived Drainage Capacities for Bashkar Collective Drain

Table 6. Capacities Derived for Bashkar collective drain

Item	collective drain reach	Drainage area (fed)	Drainage Capacity (m^3/s)			
			Existing Original design	Tambul Report(48 hrs storage	Review Report to Rahad	Hydrograph flow(with no storage)
1	Reach 1	200	0.101	0.30	0.27	3.50
2		600	0.124	0.80	0.70	7.0
3		1000	0.18	1.20	1.15	10.0
4		1800	0.26	2.2	2.1	14.0
5	Reach 2	3120	0.37	3.2	3.4	19.3
6	Reach 3	5880	0.57	4.8	5.5	28.0

Using the derived capacities from table6 above the design section parameters of Bashkar collective drain new setting are shown in table7, below (using Manning Formula with parameters as stated in the DSF).

Table 7. Bashkar Collective Drain New Setting Design Parameters

Description	First Reach				2nd reach				3rd reach			
	Q	Bed width	water depth	Velocity	Q	Bed width	water depth	Velocity	Q	Bed width	water depth	Velocity
	m^3/s	m	m	m/s	m^3/s	m	m	m/s	m^3/s	m	m	m/s
Drainage Area(fed)	1800 fed				3120 fed				5880 fed			
Drain Bed Slope	20 cm/km				11 cm/km				11 cm/km			
Existing Design Parameter	0.26	2	0.38	0.28	0.37	3	0.46	0.24	0.57	4	0.49	0.26
Tambal Report- 48 hrs Storage	2.2	3	1.06	0.51	3.2	4	1.34	0.45	4.7	4	1.67	0.5
Design Review Report- 48-hrs Storage	2.1	3	1.03	0.5	3.4	4	1.39	0.45	5.5	4	1.82	0.52
Hydrograph Derive Flows	14.0	6	2.13	0.81	19.4	10	2.32	0.68	27.5	12	2.57	0.73

Conclusion

- ✓ From the results of application of derived capacities for the selected study area, the following have been revealed:
  - a) The Hydrograph derived flow(with no storage), is unsuitable to be used for its high values of flow rate, which implies higher design parameters(bed widths - reaches 12m); and difficulties to be implemented for an existing system(no enough room or space, difficulties with existing structures to pass these discharges), and the high cost expected from such a change.

b) Despite some discrepancies mentioned in the Review Report about the flow rates derived from Tambul Pilot Study, we propose to use the Tambul Report with 48 hours storage derived values as it is:
   i. Higher discharges are less than those derived by the Design Review Report.
   ii. More suitable applied study to the existing Gezira drainage system which facing difficulties with spacing in its route for widening its sections, amending its structures.
   iii. Valuable 48 hours storage is of high import to the existing drainage system and can be linked with the scheme cropping pattern

- ✓ For minor drains the setting will be as originally designed with the old formula for the following reasons:
  - It's difficult to apply the new derived relationship as the minor drains now are not exist, and the space left between the end A/XX and the street and the next adjacent minor canal is short and the spoil sediment cover part of that space.
  - The cost will be high, it will be a new excavation, removing of spoil in(i) (if any) is an extra tedious and costly job.
  - Intension in this stage to recover the design system.
- ✓ For depressions where collective drains are outfalls; need to be cleaned from debris, silt, weeds, and equipped with new pumps. And where township are exist a new outfall system to be investigated (some collective drains are outfall in the main canals, e.g. Bashkar drain)

Recommendations

The applicability of the recommended revised and derived drain capacity from the Tambul Pilot Study is *not* an easy job, and after weighting up all the assumptions, revisions, and calculations which have been made, that the collective drain capacities should be calculated based on field storage of 48 hours and a constant surface runoff, and the following will be workable guidance for implementation of the study:

- Remodeling of drainage system using the new flow rates (changing as far as possible only for water depths, and minor changes to bed widths in accordance to collective drains routes).
- Changing of cropping pattern system to the 4 course rotation as it will be compatible to the design characteristic of the scheme and suitable to storage system during rainy seasons.
- The design criteria for minor drains will be as specified in the DSF, with extra amendments as follows
  - For minor drains with length less than 2 km the drain will be excavated with A/XX ditcher as small ditch with one bank, and one crossing at outfall to the collective drain.
  - For minor drains with length more than 2 km the drain will be excavated with A/XX ditcher to first 2.0 km and the remaining as parameter provided from the design, and with one bank., crossing should be in accordance to actual needs(farmers access).
  - In both above cases where the space is covered by the spoil from de-silting, it should be removed to the original ground surface and continue accordingly.
- A further study is needed for amending the outfalls of collective drains (depressions), outfalls to main canals, and rivers (Blue or White Niles) in accordance to the existing situation of each case and changes happened during the past periods.

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OPERATION AND MANAGEMENT PRACTICES OF DRAINAGE AGRICULTURE UNDER THE LOWLAND AREAS IN INDONESIA

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Abstract

Drainage agricultural development and management in Indonesia has recently been conducted by the government since 1960s. This was implemented by means of reclaiming the lowland areas with open drainage facilities for achieving several objectives among others such as the increasing of the national production of rice as a staple diet of the people, with some scattered coconut and palm oil plantation interspaced. Initially this effort was geared toward supporting the achievement and sustaining food self sufficiency, apart from providing agricultural land for involuntary transmigration population resettlement in order to support the Government Program, as well as resolving the vast decreasing of conventional irrigated agricultural lands due to the fast population explosion followed by the rapid land conversion from well developed irrigation areas to urban, industrial and other purposes.

Out of the total 162.4 million ha of potential agricultural land in the f Indonesian Archipelago, about 20.56% consists of lowland areas (tidal and inland areas) and are extended along the eastern coast of Sumatra, West, South and Central Kalimantan, Sulawesi and Papua are major islands with a total area of about 33.393 million ha of which 60% consists of tidal lowlands (about 20.096 million ha) and about 40% are the inland non tidal area (about 13.6 million ha), most of which are lowland schemes that are currently in the second development stage. The subsequently developed open drainage schemes are therefore currently demanding for sustainable operation and maintenance techniques.

This paper intends to discuss the problems, constraints and future prospects of agricultural drainage development and management with a special focus on operations and maintenance practices under the lowland conditions in Indonesia towards a sustainable future development and management. Special attention has been given to underlying experiences considering the lessons learnt from field practices for effective utilization of lowland development and management. Finally, the analysis also reviews the technical, institutional, organizational, and other nontechnical impacts as well as the impacts of climate change on low land development.

KEY WORDS: Operation and maintenance practices, Agricultural drainage, Inland lowland areas, Food crops, Soil and water management, Climate change.

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Introduction

Development and management of agricultural drainage in Indonesia has only been implemented jn the lowland areas by the government since 1960s, of which are mostly under the open drainage system. These efforts were conducted with special concentration on several objectives among others are to increase the national food production for food security program, which are mainly rice as the staple diet of the people, in order to achieve self sufficiency; to provide agricultural lands for involuntary transmigration settlement for achieving homogeneous population density of the densely populated areas on Java and the leased densely populated Outer Islands by means of agricultural drainage Government for Supporting the livelihood of the people under the involuntary Transmigration Program; to support regional development program; to increase the income per capita; and in particular to back up the increasing limited capacity of conventional irrigation development and management that has been increasingly competing with the rapid acceleration of increase of the country's population and demands for supporting the livelihood on the people in particular and the country's economy in general.

During the initial period, the development of agricultural drainage has been carried out as a gradually long term process with low cost technology under the open drainage sistem, known as the step wise development strategy. This strategy was based on the country's condition that has been facing number of problems and constraints, (Soesanto Soedibyo, 1977). These among others are: (1) Limited availability of budget for infrastructural development, and the underlying demand for developing the large areas on the Outer Island; (2) Lacking of knowledge, skill and experiences in drainage land development and management especially in the form of appropriate technical design and implementation criteria; (3) The underlying social cultural problems and constraints of the involuntary transmigration people where most of them are coming from 'dry' upland areas that are mostly unfamiliar with drainage agriculture under the lowland conditions.

At present, out of 162.4 million ha of potential agricultural land in Indonesia, about 20.56% consisted of lowland areas, and the rest of 79.44% consisted of upland. The lowland areas are extended along the eastern coast of Sumatra, Kalimantan, Sulawesi and Papua at the total area of about 33.393 million ha of which 60% consisted of tidal lowlands at about 20.096 million ha and about 40% of inland non tidal area at about 13.26 million ha, most of which lowland schemes are in the second development stage (see Table 1. List of present lowland development in Indonesia, and Figure 1., General map of the distribution area of lowland in Indonesia).

On the one hand, the majority of lowland schemes are not yet well developed, where on the other hand their potentials might be considered as an important alternative means to increase food production, to realize crop diversification and the development of the lowland area perse'. Now, the question remains on the anticipation for future lowland development, and therefore by considering the field experiences in lowland development and underlying economic conditions of Indonesia in general, it is apparent that a better utilization of the lowland resources would be highly possible, for example through application of appropriate water management system, instead of a simple open drainage systems by means of trial and error or to skip some preliminary steps of the development, with special scrutiny on the environmental impacts of the development and management in terms of technical and non-technical aspects.

Table 1. List of lowland distribution and development status in Indonesia

Location	Total lowlands potential areas			Total developed lowlands		
	Tidal lowland (ha)	Inland lowland (ha)	Total lowland area (ha)	Tidal lowland (ha)	Inland lowland (ha)	Total lowland area (ha)
Sumatra	6,604,000	2,766,000	9,370,000	615,250	279,480	849,730
Kalimantan	8,226,900	3,580,500	11,707,400	219,950	192,190	412,140
Sulawesi	1,148,950	644,500	1,793,450	85,320	36,280	121,600
Papua	4,216,950	6,305,770	10,522,720	-	25,200	25,200
Total	20,096,800	13,296,770	33,393,570	920,520	533,150	1,453,670

Source: Research Institute for Water Resources, Bandung, 2013

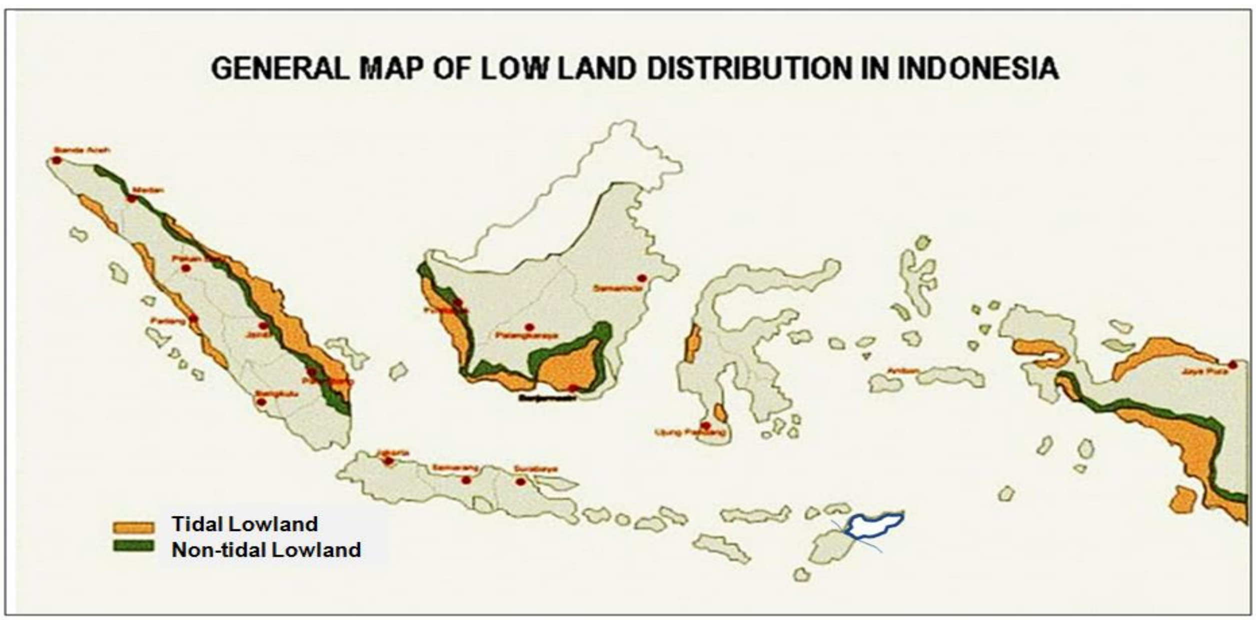

Figure 1. General map of the lowland distribution areas in Indonesia

Despite the difficulty for initial development process, lowland in Indonesia, including inland and tidal lowlands are considered to be very high potential natural resources which are scattered over the archipelago such as illustrated in Figure 1. The overall figure of the lowlands areas are currently estimated at about 33.4 million ha which is consisted of tidal lowlands at about 20 million ha and the rest are inland lowland and swamps. Most of the potential areas are located on Sumatra, Kalimantan and West Papua Islands. With the escalating demands for food as well as land demands for human settlement and industries, it is quite obvious that the appropriate lowlands development would contribute significantly to meet the increasing food demands.

Status of lowland development

Lowland Areas: From Table 1 we can see the lowland figures as previously stated above, that the total land areas in Indonesia is currently recorded at ±33.4 million ha, consisted of tidal lowlands at about ±20.1 million ha and inland lowlands at about ±13.3 million ha, scattered over the islands of: (1) Sumatra at about 10.87 million ha; (2) Kalimantan at about 10.56 million ha; (3) Sulawesi at about 1.45 million ha; and (4) Papua at about 10.52 million ha. This figure can be seen in the following schematic diagram stated in Figure 2 as follows.

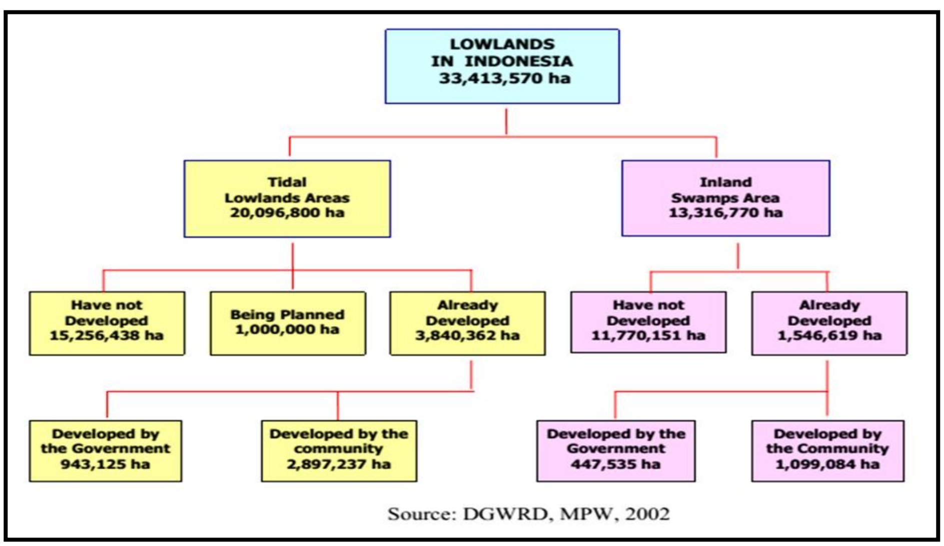

Figure 2. Schematic diagram of lowland development and potential in Indonesia, including tidal lowlands and inland lowland areas

Tidal lowland areas

Tidal lowlands are the lowland area near the coastal vicinity that is affected by tidal movement of the river level as the result of tidal fluctuation of the sea. According to hydro-topography the tidal lowlands are divided into four categories (see Figure 3 below):

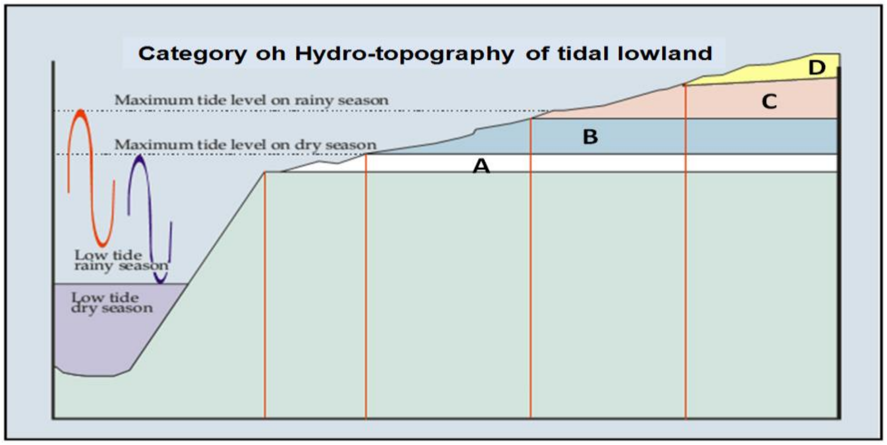

Figure 3. Category of hydro-topoghraphy of tidal lowland

Category A: The lowlands areas that are frequently inundated by high tide due to fluctuations of water level at the river. This type of land is highly suitable for cultivating lowland paddies.

Category B: The lowland area that are occasionally inundated by high tide due to fluctuations of water at the river. This type of land is suitable for mono-crop lowland paddy cultivation during the rainy season and second crops during the dry season.

Category C: The lowland areas that have never been inundated by the highest tide due to fluctuations of surface water of the river, however, the tides are still having effects on the fluctuations of ground water up to 50 cm below top soil surface. This type of land is suitable for annual paddy crop during the rainy season and second (upland) crops during the dry season.

Category D: The lowland areas that have never been inundated by the highest tide due to fluctuations of surface water of the river and having ground water surface deeper than 50 cm from top soil surface. This type of land is suitable for upland crops and perennial plantations.

Inland lowland area

Inland lowland also known as swamp land is the type of lowland that is not affected by tidal fluctuations. This type of low land is divided into three hydro-topographical zones namely: (1) The *“lebak pematang”* zone, which is the shallow dyke with short term inundating period; (2)

The *"lebak pertengahan"* zone, which is relatively deep and with longer period of inundation; (3) The *"lebak dalam"* zone, which is deeper than the other categories, yet with longer inundation period or permanently inundated.

In general, the inland swamp developments are prioritized on the *"lebak pematang"* and "*lebak tengahan"* zones, while the *"lebak dalam"* zone is kept preserved under its natural condition. Please see the inland lowland category as illustrated in the following figure.

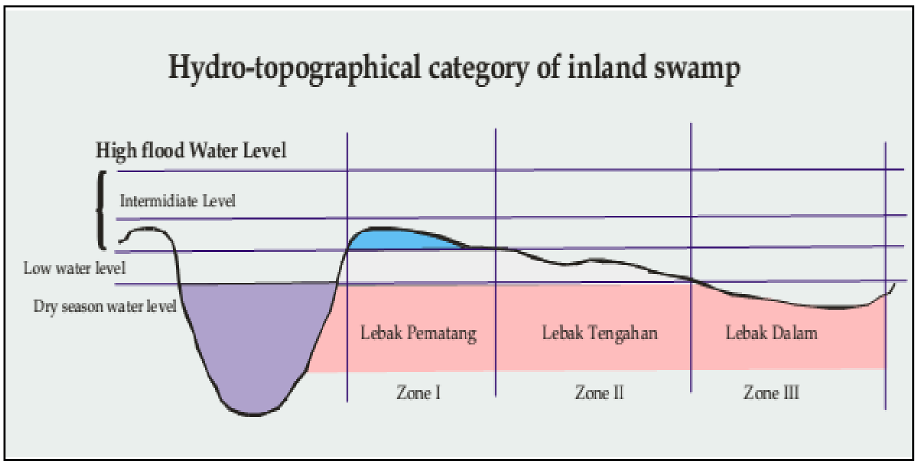

Figure 4. Hydro-topographical category of inland lowland

Based on the empirical practices, one of the determinant factors for a successful lowland development is the appropriateness of land preparation technique together with effective water management in such a way to be able to maintain the optimum plant growth. Given the vulnerability nature of the lowlands, the development must be conducted judiciously and gradually by carefully considering both technical and non-technical aspects such as socio-economic as well as environment. Based on long terms practices the lowland development phase is mostly consisted of three stages of development process. These stages should therefore be considered carefully for post construction operation, maintenance and management.

Stage I: Initial land reclamation process which is conducted by constructing a series of simple hydraulic infrastructures, such as open channel drainages with regulatory structures. At this stage, the water management is merely dependent upon the natural condition.

Stage II: Follow-up development as the continuation of Stage I which was conducted by means of improvement and upgrading of the existing drainage infrastructures. The existing water channels usually equipped with regulatory structures and levees for flood control and flood prevention. In this stage, it is important to guarantee the reasonable level of fresh water circulation by separating the conveyance water supply and drainage conveyance.

Stage III: Efficient utilization of the available lowland and water resources by means of fully operating and maintaining the developed infrastructures. Under this development stage, the water and land management are already stabilized with independent and sustainable operation.

Low-cost development approach

Since the underlying condition of agricultural development is still dominated by gravity irrigation, then at the initial stage the lowland development is still put at the second priority by adapting the low-cost development approach by which the newly reclaimed land can only be developed marginally and the marketable production surpluses will be expected to be materialized at the subsequent stage later on. Therefore the lower return per ha will require larger land holding to generate reasonable incomes, for which the land holdings allotted to new settlers, should not be less than 2.00 ha per household.

Besides budgetary advantages, low-cost development also offers some attractive advantages in future absorption capacity of the projects, while the soil productivity can still be increased in the future whenever funds are available for further investment. With this in mind, the area to be developed still have the capacity to absorb the livelihood improvement of the future generation of famers in the particular area.

Operation of canal and hydraulic infrastructures

Objectives of appropriate water management at lowland area: Implementation of water management at the drainage agricultural under the lowland area should consider the following objectives: (a) Achievement of proper soil condition for agricultural implementation (proper land maturity, acidity and elimination of hazardous materials) and water quality that could support agricultural practices; (b) Fulfillment of water supply and drainage to meet proper plant growth; (c) Elusion of over drainage that could entail formation of acidity, toxic materials and excessive land subsidence, particularly for peat soil; (d) Fulfillment of proper balance on water demand for plant growth and daily life water consumption; (e) Elusion of saline water from disruption to plant growth and other water use beneficiaries; (f) Achievement of navigation control (if required); and/or (g) Protection of canal embankment from soil erosion and land sliding.

Water management zoning: Determination of planning and canal operation must be based upon Water Management Zoning (WMZ) which is unit of land use that combined with quality of physical characteristic of land and type of the proposed utilization of land. Determination of this WMZ is very important because it would bring about consequences on the types or form of water management that must be planned including selection of type of water management infrastructure and operation procedure. WMZ is highly related with land use planning and arrangement of water infrastructures. Some particular areas have the similar demand for water management based on the physical characteristic of the land in terms of hydro-topographical type, drain ability and type of soil. Factors that are affecting similarity of land for WMZ are among others are: depth of tidal irrigation, drainage capacity of land, depth of pyrite layer, depth of peat soil, salt intrusion, and types of land units. Consideration of WMZ in water management planning would result in the proper management system.

Traditional system (Type 1): This is the oldest system, applied by *Banjarese*, *Buginese* and *Malays* traditional farmers they reclaimed the lowland areas by connecting them with a tidal river. During low tides, they are connecting canal drains the (toxic) water to the river, while during high tides fresh water enters the canal system and can be conveyed to the fields. Under this system, each canal serves about 40 ha agricultural land, so only a fringe of few km along the river can be developed by this system. The distance between two canals is about 400 m. This scheme has been widely implemented in Sumatra and Kalimantan Islands.

Anjir **system (Type 2):** In South and Central Kalimantan, main canals were constructed within the period of 1950 to 1970s. These canals were constructed between two tidal rivers, to allow for inland navigation. These navigation canals were incorporated with other lowland reclamation projects and also serve as transportation for the neighboring drainage lowland areas. Operation and management for this type of system should pay special attention on sedimentation problems due to the tides at both ends have more or less the same phase. In most cases, sedimentations are coming from the canal bank erosion due to navigation activities.

Rib system (Type 3): This system is mainly applied in Sumatra and it can be characterized by its right-angled layout (Sugandar, 1976). The principle of this system is that areas are made suitable for agriculture at low costs by making maximum use of tidal fluctuations in the canals. The system mostly composes of main canals which are used for navigation, secondary canals and tertiary canals. These water management systems are more flexible for adaptation.

Fork system (Type 4): This open drainage system was introduced to overcome acidity problems, in Southern Kalimantan for reclamation of potential acid sulphate soils (Soenarjo, 1977 and Harjosopangarso, 1986). The system consists of a primary canal of approximately 2,000 m in length and it branches into two or three secondary canals with length in the range of 3,000 to 10,000 m. Tertiary canals are constructed perpendicular to the secondary canals with the lengths of 2,000 m. The primary and secondary canals have also navigation functions. Most of the systems have a large pond (a so called *kolam*) at the end of each secondary canal with the dimension of 200 x 200 m. In fact the dimension of the *kolam* is too small in order to have the jet flow effect for flushing the systems.

Combined system (Type 5): In addition to the above four systems, a combination of the rib and fork system has been applied as well.

For more details the general elaboration of the types canal layout of hydraulic infrastructures can be seen at Figure 5., below.

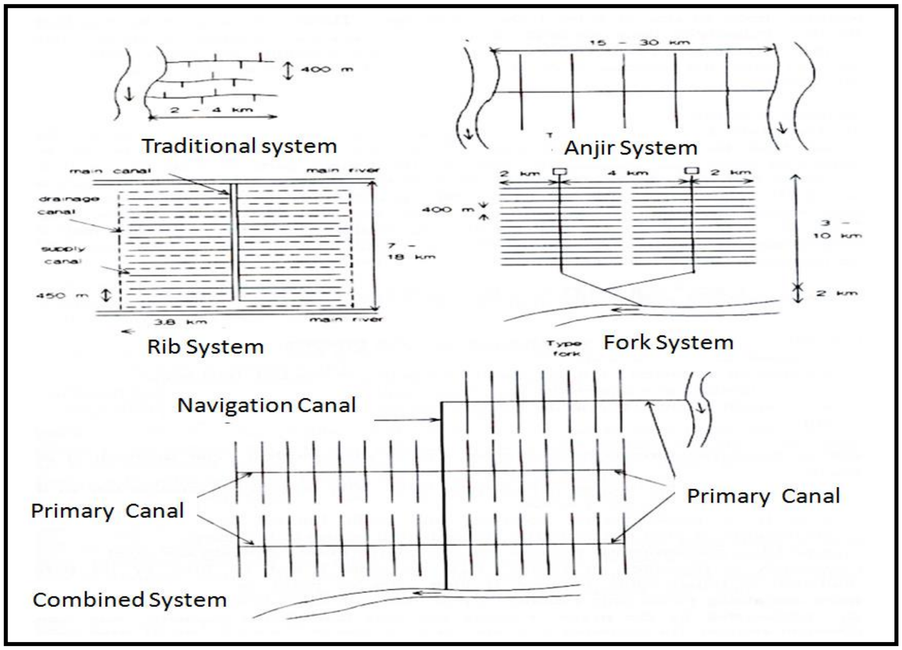

Figure 5. General layout of canal system and hydraulic infrastructures of tidal drainage agriculture (traditional, *anjir*, rib, fork, and combined systems)

Land suitability and water management practice

As the starting point of land suitability analysis, hydro-topographical conditions in the tidal lowlands are defined as the field elevation in comparison to river, or canal water levels in the nearest open water system (Suryadi, 1996). In this context, four hydro-topographic classes are generally distinguished: (1) Category A (tidal drainage agricultural areas). The fields can be flooded by the tides at least 4 or 5 times during a 14-day neap-spring tidal cycle in both the wet and the dry season. These areas are situated mostly close to river mouths; (2) Category B (periodically tidal drainage agricultural areas). The fields can be flooded by the tides at least 4 or 5 times during a 14-day neap-spring tidal cycle in the wet season only; (3) Category C (areas just above tidal high water). The fields cannot be regularly flooded during high tide. The groundwater table may still be influenced by the tides – than it requires drainage agricultural system. Cropping is mainly dependent on rainfall, although some additional water supply by infiltration might be possible with an intensive field ditch system. Many category C areas in the wet season are planted with rice crop. For the dry season dry food crop is the most likely alternative. With a sufficiently large tidal range the cultivation of tree crops is an option for these areas; (4) Category D (upland areas). The fields are entirely above tidal influence. Dry food crops and tree crops are best suited to these areas when they do not receive extra water from adjoining higher areas.

In the relatively low tidal lowland areas (category A and B) the main purpose of the water management system is to control drainage by operating the water control structures based on the water requirement in each cropping stage. If required water can be supplied during dry periods. From time to time flushing may be required in areas where acidity still can develop. In the relatively high tidal lowland areas rice crop is completely depending on rainfall, but subsurface flow of groundwater to the adjoining secondary canals may cause relatively high water losses. Therefore the main purpose of the water management system could be to control relative high water levels in secondary canals to prevent too low groundwater tables. For water management at the drainage agriculture, the implementations are based on a number of information with spatial distribution characteristics which have to be taken into account. These among others are topography, soil, hydraulic, hydrology, cropping systems and local practices. These series of information are very important to minimize the negative impacts to sustainable development of drainage agricultural development.

Flap gates for controlling incoming and outgoing water flow

The existing hydraulic infrastructure in the already reclaimed schemes which were based on the low-cost development approach, have typical features in common. In principle, the tidal flow that affect the drainage agricultural practices are utilizing flap gates, with the function of controlling incoming and outgoing flow of tide through the dual function of the channel (some time refers to as "*irrinage"* (irrigation and drainage) canal. Thus during the ebb flow, the incoming water from downstream is protected by maintaining the stable level that maintain the moisture content at the root zone. Similarly, during the tidal flow, the outgoing flow of the water must be released to a certain extend that the moisture content of the soil will not drop below the optimum moisture content for supporting the optimum plant growth (See Figure 6. and Figure 7., Example prototype flap gates model system and the dual functioned flap gates made of hollow fiber glass – filled with water for maintaining proper balance -- installed at the outlet and inlet structures of the drainage agricultural canal that are in operation).

Water Gates for controlling outgoing water flow: For the non tidal lowland, the control gates are not dual function, in the sense that drainage water management for drainage agriculture is designed for allowing the excess water to leave the land till the moisture content is at the stable condition for supporting the underlying plant growth. Thus, the water gates are continuously operated to maintain the optimum water level set up for maintaining the underlying water use, including the excess water resulted from time to time from rainfall in each particular location of drainage agriculture.

Gate operation for water control at the macro level: For water management at the macro level, which is water control at the drainage infrastructure at scheme level prior to distribution to the micro level (farm level), water management is very crucial because it determines the availability before distribution to the micro level. The objective of water control at this macro level among others are: (a) To release the excess water at the surface as well as at the ground water level; (b) For protection and flood mitigation; (c) For protecting salt intrusion; (d) For provision, allocation and distribution of raw water for drinking water; (e) Bulk water allocation for agricultural and industrial demands; (f) Control of water elevation at the main drainage canal; (g) Water quality control at the main canal level; and (h) Controlling the water transportation.

Gate operation for water control at the micro level: Especially for the water management at the micro level which is water control at the farm level related with the daily condition and environment of plant growth, the gate operation must be properly managed in such a way to be able to meet the water management at the micro level for supporting optimum crop water evapo-transpiration, these among others are: (a) Water requirement for optimum nutrient absorption; (b) Avoidance of germination, growth and spread of plant pests and diseases; (c) Control of plant pest and diseases; (d) Avoidance of negative impacts of toxic soils; (e) Leaching of component of toxic materials; (f) Controlling of soil moisture content and ground water level at the farm block; and (g) Controlling of water quality for plant growth at the farm level.


Figure 6. Prototype model and operation principle of double functioned fiber glass flap gate (left); Figure 7. Flap gates installed at hydraulic structure for operation (right)

Problems and constraints

General problems and constraints: In general, there are a number of problems encountering operation and management of agricultural drainage in lowlands areas, these are among others: (a)

Implementation performance cannot be conducted in accordance with the main tasks and function of the responsible institution because of integrated nature; (b) Since the implementation of Local Government autonomy in 2003 the field operation and management personnel (water master, ditch tenders and gate keepers) are directly under the control of local district government, and most of them are retired, others are assigned to other local government agencies; (c) The actual trend of local farmers of transforming the agricultural practice from food crops to palm oil plantation; (d) Severely lacking of O&M as well as management budget (mostly only available between 30 to 60% of the requires budget); (e) Lacking of appropriate understanding on the principle and implementation of maintenance and rehabilitation activities; (f) The Implementation standard of implementation of O&M budget support from central government are differed from one implementing agency to others; (g) Lacking of O&M facilities for field staff; (h) Poor coordination amongst central and local government authorities on implementation of O&M activities; (i) Ineffective working condition, coordination and participation of water user association in O&M of drainage agricultural infrastructures at the farm level; (j) Poor O&M budget allocation in terms of adequacy and utilization schedule by the local government, so performance of operation and services are hardly synchronized; (k) O&M activities of drainage infrastructures between agriculture and fishery sector are hardly adjusted in terms of transplanting and fishery breeding; (l) Inappropriate role and responsibilities of the farmers for farming O&M of drainage infrastructures at the farm level.

Land resources potentials are among others: (a) Soils are mainly clays, which make them productive only after reclamation, unless they are covered by peat; (b) Rainfall amount and distribution in the wet season are adequate for one rain-fed crop; (c) If additional irrigation is introduced (low lift pumping), wetland rice will provide a high yield under the proper water management. This alternative may in future proved to be a feasible development option; (d) If drainage measures are taken, upland crop cultivation, such as cassava, maize and soybeans, will be possible. Perennial crops like coconut and oil palm may also be grown well.

Constraints of tidal lowlands are among others: (a) Tidal lowlands are located in remote areas, hindering supply of inputs and marketing of products; (b) Close to river mouth, salinity may create problems for agriculture and drinking water, especially during the dry season; (c) A substantial part of the tidal lowlands are covered by (potential) acid sulphate soils and/or peat soils. So the water management infrastructure has to be adjusted to the changing conditions; (d) Inadequate soil and water management systems in most places; (e) In many tidal lowlands, lack of supporting data, mainly related to the soil, hydro topographical and land suitability conditions. Labor shortages that favor farming technology systems without land preparation based on low yielding traditional rice varieties; (f) Lack of O&M of the water management systems at tertiary and secondary levels and almost non on-farm water management; (g) Inadequate infrastructure and post harvesting management facilities; (h) Lack of good credit facilities and agricultural inputs and limited market facilities; (i) existence of pest and diseases; and so on.

Constraint on water allocation and management: (1) The implementation of gradual approach on lowland development is mostly associated with low land reclamation technology, which is relatively new for Indonesian engineers. Therefore, and hence much experience and empirical works are needed on the basis of trial and errors; (2) Implementation of large-scale land reclamation is highly susceptible to environment; (3) Inappropriate water allocation and management would bring about significant reduction of agricultural productivity due to soil salinity; (4) The effort to separate conveyance and drainage channels usually encountered by a number of constraints among others the farmers attitudes; irregular water requirements for individual farmer; constraint of gates operation on water channels that are utilized for water transportation are regarded by the farmers as obstacle rather than solution; lacking of O&M endeavors would result in a number of problems.

Constraints on socio-economic and agro-economic aspects: Based upon experience in the past low land development implementation, much attention had been given to the technical as well as civil engineering aspects and less attention were addressed to the non technical aspects, including the lack of continuous monitoring and concern on land development, gradual process of the maturity of land consolidation. Irregular condition of soil fertility, the magnitude of soil acidity and application of fertilizer; irregular physical characteristic of lowland swamp in relation with the depth of pit soil and acid soils as the accumulation of soil acidity; the need of regular fresh water circulation for maintaining consistence soil leaching.

Environental impacts and climate change

Environmental Aspects: One of the most vulnerable aspects of lowland development to take into consideration is the impact of physical intervention on the sustainable balance of aquatic ecosystem. This is partly due to the nature of the swamp area as the marginal land for agricultural development. Therefore, any abrupt change due to development intervention such as land reclamation, would encounter the natural balance of aquatic habitat, including the natural equilibrium of pests, aquatic weed, and other such bio-environment.

Other crucial environment aspects of lowland development is about the impacts of escalating degradation of upper watershed of the river basin due to uncontrollable human activities such as traditional shifting cultivation, logging and other such activities. This aspect, therefore, needs to be scrutinized through appropriate integrated watershed management. Further to this, the lowland development must be addressed by virtue of environmentally-friendly approach, should the drainage agricultural practices in such an area to be environmentally sustainable.

Anticipation of impact of Climate Change: One of the most important aspects of O&M and management of drainage agriculture at the lowland area is anticipation and hence adaptation as well as mitigation of the impacts of climate change, which is relationship with the emission of CO_2. The facts of CO_2 emission at the lowland area in Indonesia that must be properly scrutinized are among others: (a) Based on the report of Wetland International and Alterra Wageningen 2006, the total lowland area in Indonesia is about 33.4 million ha, of which 22.5 million ha (67%) consisted of peat soil area, at the average of about 32% out of 22.5 million ha associated with "occupied land"; (b) Till present about 1.8 million ha has already reclaimed by the government, and about 350,000 in the form of inland lowlands and hence about 464,000 ha consisted of peat soil area (at an average assumption of 32%); (c) In this regard, there two major factors affecting the significant emission of CO_2 at the peat land area which are over drained and forest fire; (d) With an estimate of surface water draw down at 10 cm due the impact of climate change and/or over drained would resulting CO_2 emission at about 13 ton/ha/year (Wetland International and Alterra Wageningen 2006); (e) With an assumption of 464,000 ha of peat land that that had been suffered from drawdown of surface water at 10 cm, means that about 6 million ton of CO_2 per hectare per year has been ejected to the atmosphere with the subsequent impact to human life on earth.

Lessons learnt

Based upon the long term implementation of lowland drainage agriculture in Indonesia there a number of lessons learned for future development and improvement of the reclaimed areas, new reclamations and the conservation of areas, among others are: (1) Improvements in reclaimed areas, the first priority would have to be to make better use of the developed infrastructure by a better O&M, both at the on-farm and at main system levels, using the past experiences as a guidance; (2) For new tidal drainage agriculture the areas that have a potential for reclamation have been identified, may be expected that sooner, or later the remaining potential tidal lowland areas will be reclaimed. This is still a very substantial area compared to the present total cultivated area with paddy rice in the country of about 8.5 million ha; (3) Environmental considerations and sustainability. Decision on lowland development projects for drainage agriculture has to be tightly related with the use of ecological data for all decisions on future lowland development projects. The deep peat soil areas are basically unsuitable for development on a sustainable basis and mostly are demanding for preservation; (4) First generation problems. At the initial stage there should be a strong commitment of the involved organizations. Farm sizes and layout pattern, that initially have been implemented, may become inadequate to cope with developments in society, and hence, farming may become uneconomic; Insufficient institutional arrangements and organization to properly operate and maintain the flood protection; Insufficient skill of farmers to cultivate crops under the conditions as prevailing in the newly reclaimed land; and other such lessons leant.

Based on these lessons learnt it is highly important to develop proper action plan for the medium and long term lowland drainage agriculture taking into consideration the following components: (1) Data base development, including inventory activities and seminar of lowland development in Indonesia in order to know the actual stage of development which cover physical and human resources; (2) Integration of lowland development with the regional spatial planning; (3) Effect of climate changes in lowland development in Indonesia; (4) Capacity building and human resources development related to lowland drainage agricultural development in Indonesia.

Most important lesson learnt is that the future potential of lowland drainage agriculture become more and more important for Indonesia and will be the future for agricultural development. This is particularly the case that there currently a continuous loss of agricultural lands on Java Island for urbanization, industry and other non agricultural infrastructures – the loss of agricultural land is about 30,000 to 40,000 ha/year. With the underlying trend decrease of rice production on Java Island due to continues land conversion to non-agricultural utilization; and the increasing land and water competition with the requirements for rice cultivation, the only alternative in the future for compensating the above trend is on intensifying the future potential of drainage agriculture. Next to that, a monitoring program for climate change, especially sea level rise should be done soon in order to analyze and to evaluate the possible impact of sea level rise to lowland development in Indonesia and must immediately anticipated by means of adaptation or mitigation of Climate Change as early as possible.

Future Challenges: For obtaining the maximum advantages, the future use of lowland developments for drainage agriculture are encountered by a number challenges and constraints including among others: (1) Lowland drainage agricultural development involves cross-sectoral activities, therefore it requires intensive inter-agency coordination among the relevant institutions; (2) Lowland drainage agricultural development takes relatively a long time process, which demands for long-term commitment on financial investment; (3) The facts that lowland drainage agricultural development possesses good prospect a large spectrum, therefore, development planning would be increasingly become more complex in line with the demands for sustainable and environmentally sound development; (4) The follow up stages of lowland drainage agricultural development requires adequate economic and social infrastructure supports for increasing demand of sosio-economic development; (5) The complexities associated with the prospective lowland agricultural drainage development would require more than just capable human resources but also demanding for highly qualified personnel as well as reliable R&D support; (6) In order to gain a maximum advantage of the developed lowland drainage infrastructures, effective O&M of the water resources facilities must be undertaken and improved on sustainable basis; (7) Climate change and particularly the sea level rise which is predicted as 0.65 m per century (BAPPENAS, 2004) will have an impact to the lowland conditions especially related to it hydro-topographical condition. The impact will be more areas will change from B hydro-topographical category to A and from C to B (Rahmadi, 2009). Therefore water management systems would have to be adapted to these conditions in addition to the proper monitoring system, in order to evaluate the sea level rise as early as possible.

Concluding remarks

Based upon experiences it can be concluded that lowland drainage agricultural development is a long term and dynamic process of land and water relationship. Most of the lowland drainage agricultural development schemes in Indonesia are in the second stage and for immediate future development a careful and environmentally sound scenario should be carefully taken into account. It is evident that lowland drainage agricultural development in Indonesia has already been undertaken for more than 25 years. During which, the Central Government, especially the Ministry of Public Works, D.G. of Water Resources and the Ministry of Agriculture have been involved, both in research, planning as well as implementation.

Lowland drainage agriculture in Indonesia has a future potential to become the rice granary of Indonesia. For that purpose, the first priority is to make better use of the developed infrastructures by conducting a better O&M at on-farm and at system levels. Subsequently, the farmers have to be supported consistently along the improvement of irrigation and drainage agricultural practices, crop diversification and post harvest activities. In addition it is highly important in this case, also to protect the ecological valuable areas as well and conservation of the areas that are having potential land subsidence and other hazards in the near future.

A nationwide study for lowland drainage agricultural development and management as well as conservation in Indonesia should be carried out soon in order to identify the prospects of lowlands as well as the related conservation toward sustainable environmental conditions, development stage, human resources development, potentials and also constraints for the future use for other land utilization such as for agriculture, conservation, urban, as well as adaptation and mitigation effect of climate changes.

Based on these activities, an action plan for lowland development in Indonesia for medium and long term can be derived. A monitoring program for climate change, especially sea level rise should be done soon in order to analyze and to evaluate the possible impact of sea level rise to lowland development and hence sound measures can be proposed as early as possible.

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SHALLOW GROUNDWATER DRAINAGE AND ITS WATER QUALITY FROM PROTECTED FARMING IN KOREA

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Abstract

In the agricultural watershed in Korea, nutrients are discharged through various means such as soil erosion, runoff, infiltration, or drainage. Protected farming has expanded by increasing the demand for value-added agricultural products in Korea. In some agricultural areas, particularly in protected farming, due to excessive fertilization and irrigation, the nutrient excess phenomenon is becoming increasingly serious. The drainage of water and non-point source pollution (NPS) management under the protected farming method needs to be devised to manage water quality of shallow groundwater and reduce NPS pollution loads from protected farming practices. This study was conducted to investigate shallow ground water infiltration and drainage from protected farming cultivation in comparison with conventional farming practices. In the protected farming field, tomato and cucumber crop were cultivated twice a year using a drip irrigation system and nutrients were applied by fertigation. Irrigation, soil moisture content, shallow ground water level and flow, and weather conditions were monitored and soil water and soil on protected farming sites and shallow groundwater samples at 8 different sites on the watershed were also collected during the crop growth season to investigate water drainage and nutrient leaching characteristics in protected farming. Key NPS such as electronic conductivity (EC), total phosphorus (TP), total nitrogen (TN), and nitrate-nitrogen (NO_3-N) were analyzed. The results show that NO_3-N concentration and EC of soil water is high in the total soil layer, and some nutrient concentration in the sub-soil layer is higher than those in the upper soil layer. In addition, the nutrient concentrations in shallow groundwater is generally higher as compared to conventional farming. Eventhough fertilization and irrigation were applied regularly for crop production, there is a possibility of over fertilization and it may affect nutrient accumulation due to poor drainage of subsoil whereas in case switching

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the land use from paddy fields is to protect farming or nutrient leaching when over irrigated. In addition, in areas having high shallow groundwater level, a direct impact of excessive irrigation and fertilization increased in accordance to drainage and water flow. This results will serve as the platform not only for long-term shallow groundwater water drainage and nutrient monitoring and management under the protected farming cultivation approach but also for the derivation of guidelines on farming practices enhancement to reduce NPS loads from protected cultivation.

KEY WORDS: Non-point source pollution, Protected farming, Shallow groundwater, Water drainage.

Introduction

Protected farming has been expanded due to the increasing demand for value-added agricultural products and the decreasing area of available agricultural land in Korea. Approximately 60 % of the new protected farming area has been installed in paddy fields (Lee et al., 1998). In protected framing cultivation, unlike the paddy field cultivation, precipitation is blocked and water for crops is only obtained through irrigation.

Nutrients for plant growth are supplied by fertigation which involves supplying nutrients in irrigation water for increasing nutrient uptake by plants (Mahajan and Singh, 2006; Liang et al., 2013). In addition, protected farming in Korea occurs year-round more than two rotations a year. Due to the misconception that the application of large amounts of nutrient results in high crop yields, excess nutrients are a potential source of nonpoint pollution accumulate in the soil and leach downward with the application of irrigation water, possibly causing soil and groundwater contamination (Thompson et al., 2007; Shi et al., 2009; Min et al., 2012; Hong et al., 2014).

Because of yearly increases in protected farming cultivation, nitrate-nitrogen (NO_3-N) concentrations in the shallow groundwater near the protected farming area had increased and in some cases the concentrations exceeded the groundwater quality standard for agricultural water 20 mg L^{-1} (Ha et al, 1997). If contaminated or salinized groundwater is used for irrigation water, it can cause a cycle in which nutrients reaccumulate in the soil and leach to shallow groundwater (Lee et al., 2008).

According to Hong et al. (2014), the total NO_3-N losses in protected farming practice through leaching to deeper soil were 54.7-758.6 Kg N ha^{-1} in one rotation. A significant amount of nutrients were not utilized for crop growth but instead leached in accordance with the movement of the soil water. To minimize leaching of nutrients into shallow groundwater, it is necessary to investigate the processes of shallow groundwater fluctuation and leaching. In particular, nitrogen is a mobile nutrient that is rapidly leached (Hong et al., 2014). Irrigation with high nitrogen use in protected farming results in the substantial loss of nitrogen through leaching and the consequent contamination of the shallow groundwater, especially, NO_3-N (Li et al., 2003; Thompson et al., 2007, Wan et al., 2010).

In this study, to investigate shallow groundwater drainage and its water quality from protected farming, soil moisture content, fluctuation of shallow groundwater and water quality were collected and analyzed.

Materials and methods

Study area

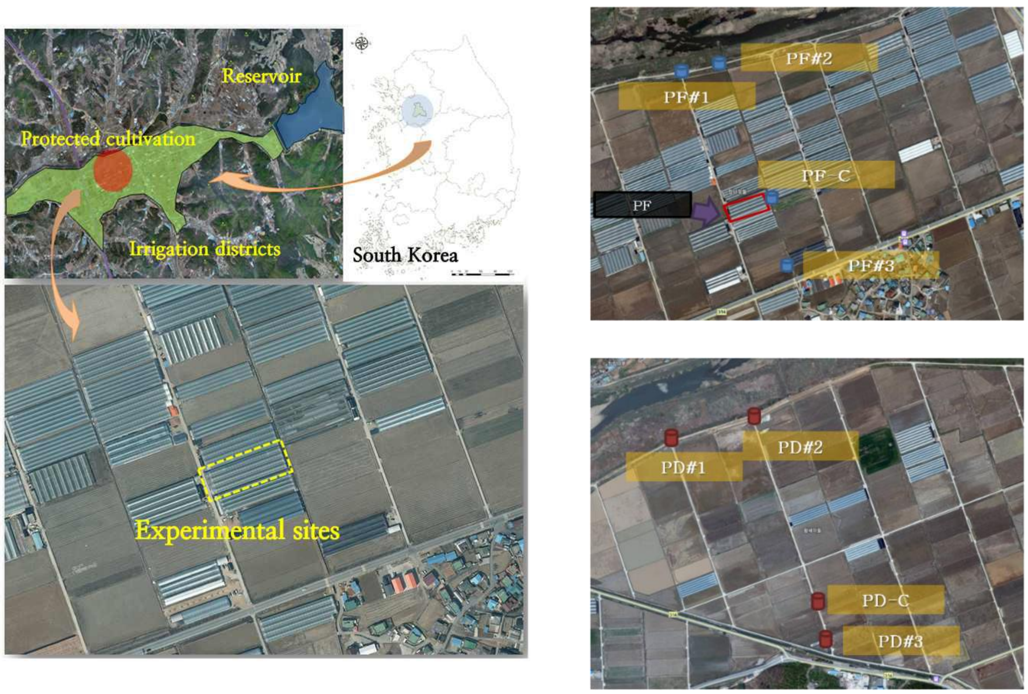


Figure1. Location map of the experimental sites: protected farming and paddy fields

This study was conducted in protected farming cultivated area located in Namsa-Myeon, Cheoin-Gu, Yongin-Si, and Gyeonggi-Do, South Korea (E 37°06′04″, N 127°08′08″) as shown in Fig. 1. This area was a traditionally rural area mainly cultivated rice paddies, but recently the land use has changed to protected farming cultivation for vegetables and flowers. The 30-year average annual temperature in the study area is 11.4˚C and annual precipitation is approximately 1312.2 mm and rainfall is mainly concentrated in the summer season from June to September. The soil type in the study area (RDA SIS, http://soil.rda.go.kr) is classified as the Seogcheon (SE) series (*coarse loamy, mixed, nonacid, mesic Fluvaquentic Endoaquept*). According to the farmer's interview, irrigation/fertigation in protected farming fields occurred every 2 or 3 days for 2 or 3 hours and crops are cultivated two rotations a year

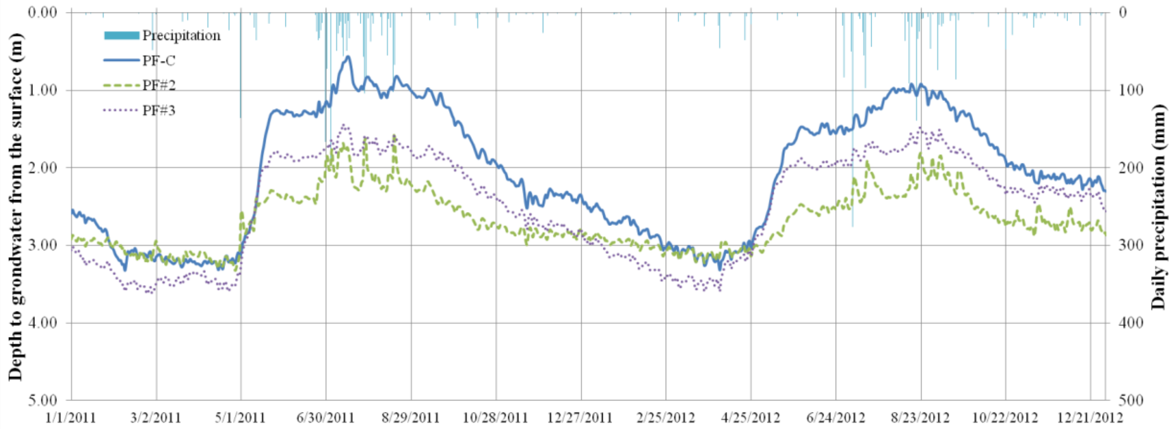
Monitoring system layout

To monitor shallow groundwater drainage and its water quality, soil moisture content on protected farming experimental site, and shallow groundwater level and quality were monitored and analyzed as shown in figure 1. Volumetric soil moisture content (%) was measured using a Frequency Domain Reflection (FDR) probe (EnviroSMART soil moisture probe, Sentek Pty. Ltd., Adelaide, Australia) at 60 and 90 cm soil depth in every 15 minutes. Shallow groundwater level at 8 different sites (4 points near protected farming area and 4 points on paddy fields) were monitored every 1 hour and water samples were collected biweekly. The samples were analyzed at the Seoul National University National Instrumentation Center for Environmental Management (NICEM). The EC (ECw, electrical conductivity of the soil solution) and the concentrations of NO_3-N, T-N, and T-P were determined for the shallow groundwater samples.

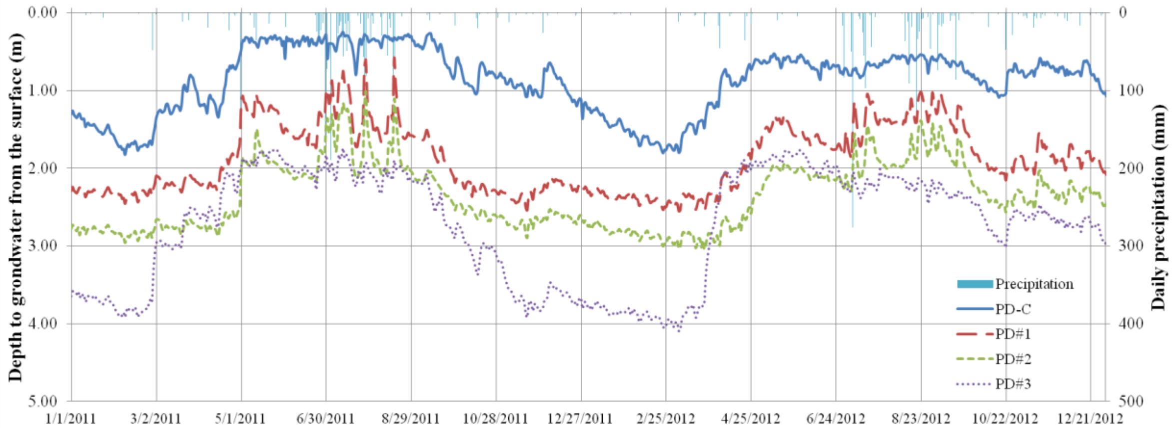
Results and discussion

Shallow groundwater drainage

The elevation of shallow groundwater in protected farming fields were 14.9 m in PF-C, 14.2 m in PF#1 and PF#2 and 15.5 m in PF#3. The elevation of shallow groundwater in paddy field area were 16.7 m in PD-C, 14.1 m in PF#1, 14.9 m in PF#3 and 17.7 m in PF#3. Figure 2 is the temporal variation of depth from surface to shallow groundwater in protected farming and paddy field area. The depth and pattern of fluctuation of shallow groundwater are similar between protected farming and paddy field area. It has increased during the wet season accordance with precipitation event and decreased on the dry season. In particular, on the monitoring points of PF-C located behind of site, shallow groundwater has increased and the depth was less than 1.0 m during the wet season. As shown in figure 3, when the depth to shallow groundwater was less than or near 1.0 m (on June-August), the soil moisture content tends to be almost saturated even rainfall is intercepted due to frequent irrigation/fertigation and high groundwater level. There is the possibility of nutrient accumulation and subsequent leaching into the shallow groundwater.



(a) Protected farming



(b) Paddy field

Figure2. Temporal variation of depth to shallow groundwater table from surface in protected cultivation and paddy field area

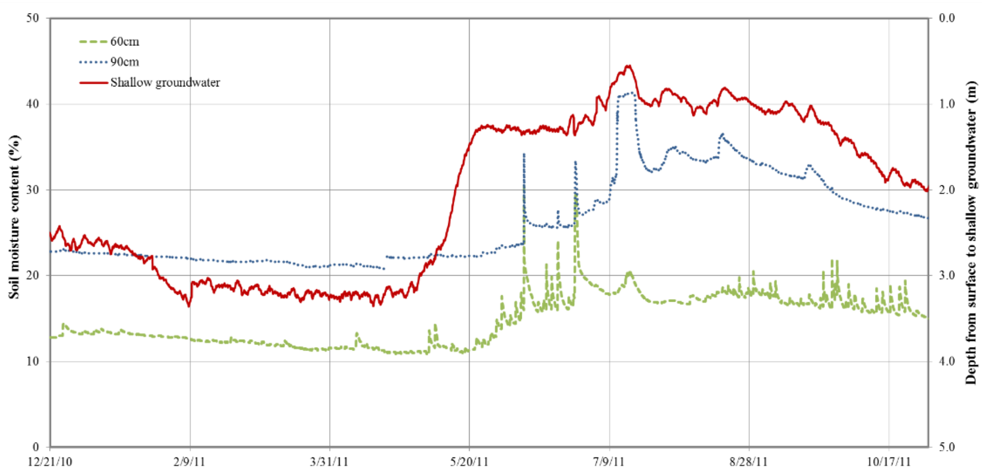


Figure3. The comparison between soil moisture content at 60 and 90 cm soil layer and depth from surface to shallow groundwater at PF-C

Shallow groundwater quality

Table 1 shows the average and standard deviation nutrient concentrations of shallow groundwater at 8 different sites. TP concentration on paddy field was higher than on protected farming sites. However, EC and other nutrients (NO_3-N, TN, etc.) on protected farming were higher than on paddy field, even though the depth and level of shallow groundwater were similar between two sites. The EC and NO_3-N levels are the main factors that influence shallow groundwater contamination through leaching in protected cultivation (Kim et al., 2008; Hong et al., 2014). In particular, excess NO_3-N leaching into groundwater can cause many problems including cyanosis (Kurunc et al., 2011).

EC is correlated with salinity. Excessive salinity can cause nutrient absorption and inhibiting plant growth when utilized as irrigation water. According to the USDA, irrigation water with an EC greater than 2.25 dS m^{-1} is difficult to use for agricultural purposes (US Salinity Laboratory Staff, 1954). According to the FAO, an EC greater than 3.0 dS m^{-1}has adverse effects on crop growth (Ayers and Wescot, 1995). The EC in protected farming fields has similar pattern and no fluctuations or trends and the average EC was less than 1.0 dS m^{-1} and regulation for irrigation from USDA and FAO.

Protected farming cultivation tends to apply high volume of irrigation and high frequency and nutrient levels in fertigation (Hong et al., 2014). As a result, nitrate leaching and nutrient concentrations are much greater in protected farming cultivation than in paddy fields (Sun et al., 2012). The average NO_3-N concentration of shallow groundwater in protected farming fields are 0.24-3.39 mg l^{-1}which are higher than in paddy fields (0.05-0.67 mg l^{-1}). As shown in figure 4 and 5, the NO_3-N concentration at PF-C behind the protected farming cultivation site has been increased during the summer season with high precipitation and groundwater level. According to Hong et al., (2014), excess nutrients with excess fertigation have accumulated in the root zone and the NO_3-N concentration below 90 cm soil layer has increased during the summer season. The NO_3-N concentration in these season was also increased with the increasing of shallow groundwater level. It may have been affected by the nutrients accumulation and drainage from the soil water to shallow groundwater as the elevation of the shallow groundwater level is increased.

Table 1. Average and standard deviation EC and nutrient concentrations (TN, NO_3-N, and TP) in the shallow groundwater

Location	EC (dS m^{-1})		TN (mg L^{-1})		NO3-N (mg L^{-1})		TP (mg L^{-1})	
	avg	std	avg	std	avg	std	avg	std
PF-C	0.37	0.12	3.01	2.23	2.82	2.12	0.02	0.03
PF#1	0.55	0.07	0.32	1.18	0.24	1.09	0.02	0.01
PF#2	0.35	0.10	1.01	3.16	0.94	3.14	0.02	0.03
PF#3	0.51	0.10	3.80	1.81	3.39	1.62	0.03	0.02
PD-C	0.16	0.04	0.28	0.39	0.17	0.36	0.22	0.31
PD#1	0.33	0.08	0.28	0.58	0.13	0.29	0.04	0.03
PD#2	0.47	0.08	0.25	0.90	0.05	0.13	0.08	0.09
PD#3	0.22	0.09	0.82	1.02	0.67	0.97	0.04	0.05

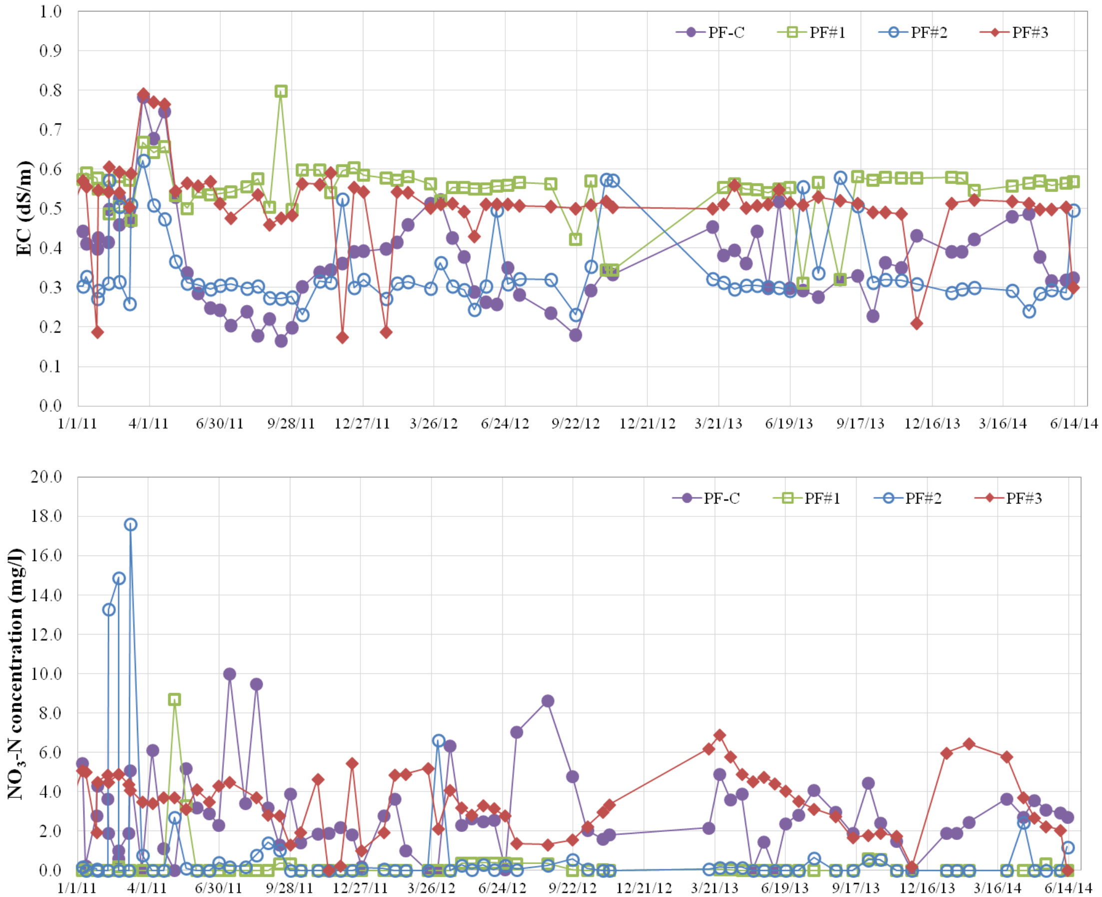
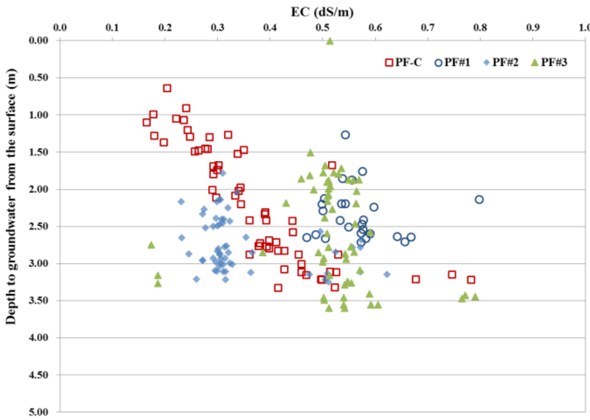
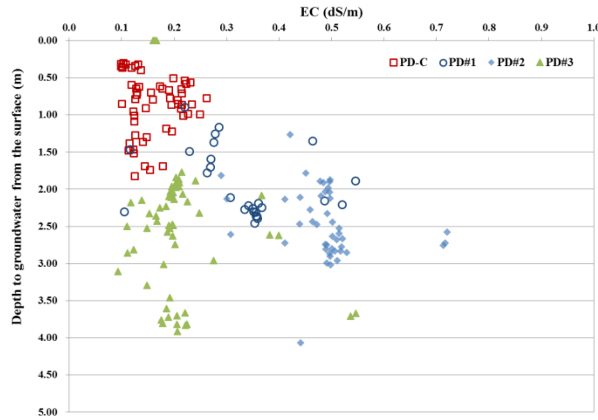


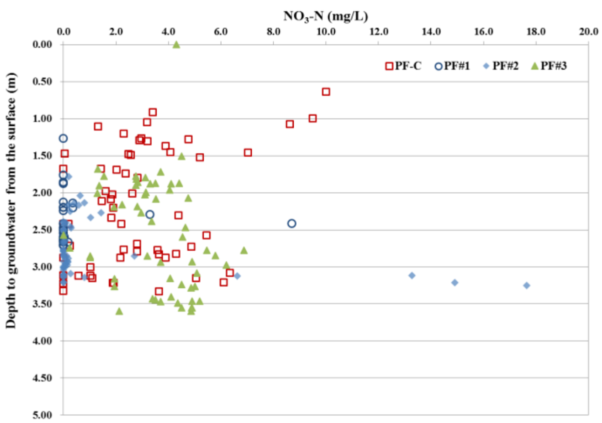
Figure 4. EC and NO_3-N temporal changes of shallow groundwater



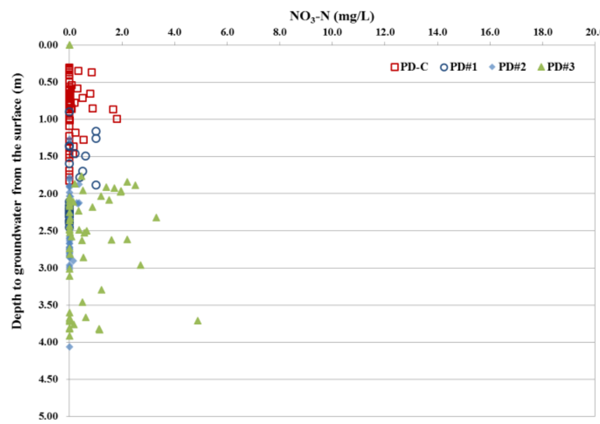
(a) EC (PF)



(b) EC (PD)



(c) NO_3-N (PF)



(d) NO_3-N (PD)

Figure 5. Comparison between EC and NO_3-N and depth to groundwater from the surface

Most environmental factors, weather conditions, irrigation, and fertilization, can be controlled in protected cultivation. However, NO_3-N, which is one of the most important factors controlling crop growth, is difficult to retain in a soil layer because its movement depends on the mobility of soil water (Hong et al., 2014). Therefore nutrients such as NO_3-N can leach into the lower soil layers and enter shallow groundwater, which has a higher elevation than confined groundwater (Tan et al., 2012).

Conclusion

In protected farming cultivation in Korea, the excess of nutrients is becoming increasingly serious. The purpose of this study was to monitor and analyze shallow groundwater drainage and water quality at protected cultivation fields. This study found that even NO_3-N and other nutrient concentration in protected farming fields were less than the groundwater regulation for irrigation, however, it and its standard deviation and variations were higher than in paddy fields.

In particular, the NO_3-N concentration on PF-C behind the protected cultivation site during the summer wet season has been increased with increasing of groundwater lever. It is considered that the nutrient concentration on shallow groundwater may be influenced by nutrient accumulation by over fertilization or drainage according to the irrigation or fertigation.

There is a possibility of shallow groundwater pollution if conventional management of protected farming practices continued. This study can inform guidelines to reduce the agricultural non-point pollution load, manage shallow groundwater and aid in the development of a model for analyzing agricultural non-point pollution from protected farming cultivation.

Acknowledgments

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THE STUDY OF WATERMELON CROP RESPONSE UNDER SHALLOW WATER TABLE AT INITIAL GROWTH FOR DEVELOPING DRAINAGE PLANING AT TIDAL LOWLAND AGRICULTURE

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Abstract

Water melon cultivation is one of the suitable alternatives applied in order to increase farmers income in tidal lowland agriculture zones. The research of crop adaptation to wet soil conditions is required so that farmers will be able to decide the best planting time based on the existing land typology conditions .. The research focuses on the determining of crop physiology response during its initial growth period within a greenhouse. The treatments consisted of water table depths at 15, 10 and 5 cm below soil surface, respectively. The observation of water table surface was carried out in the field. Analysis of crop potential based on water status condition in the root zones was conducted using secondary and primary data. The results of crop adaptation at a shallow water table depth showed that treatments of water table at depths of 10 cm and 5 cm were not signficantly different in terms of crop height with a magnitude of 12.6 cm and 12.3 cm having respectively 3 leaves. However, it had a significant effect on root length with a magnitude of 11.9 cm and 3.1 cm, respectively. The Maximum crop height of 15.2 cm and 4 leaves was found upon the treatment at 15 cm water table depth. It can be concluded that farmers are advised to plant on the basis of the water table conditions of 10 cm below the soil surface. The objective of accelerated planting is that crops do not need irrigation water at a generative phase. This condition is especially recommended for C land typology which had a high porosity and low capillary flow.

KEY WORDS: Tidal lowland, Watermelon, Water table, Drainage.

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Introduction

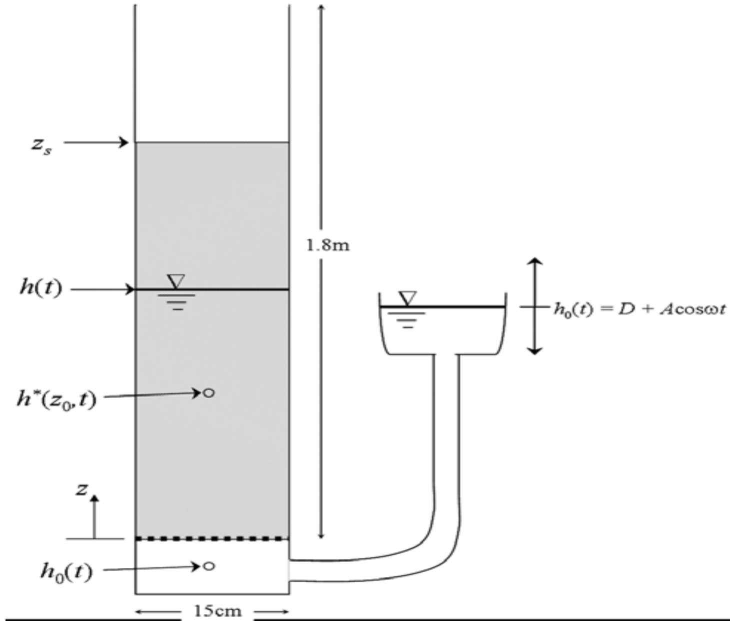
Agriculture enterprise in tidal lowland area had faced the main constraint in form of land use conversion from food crops to plantation crops. One effort of controlling land use conversion in tidal lowland agriculture is to increase the planting intensity. The study by Imanudin *et al.* (2010; 2011) at tidal lowland of Delta Telang II showed that land had high potential for two or even three times planting. The change of planting pattern into two times planting could produced equal income compared to income from oil palm crop. The change of planting pattern from *rice-fallow* into *rice-corn* and *rice-corn-corn* was more profitable (Imanudin and Bakri, 2014). Crop diversification with watermelon provided new prospect for farmers because it could produced higher income than that of oil palm plantation. The profit gained from watermelon cultivation can be as high as 30 million rupiahs/ha with duration of 70 to 90 days. According to Gunawan (2014), if watermelon production is 11 tons and its price is 3000 rupiahs/kg, then the net profit received by farmers was about 18.5 million rupiahs. Therefore, watermelon cultivation effort at wet land is necessary as an alternative of farm enterprise diversification.

Tidal lowland area with shalow water table has high potential for watermelon cultivation. Soil water contribution through capilary flow is sufficient to provide crop water requirement (Imanudin and Bakri, 2014). This condition has advantage because irrigation for land is not needed resulting in cost saving. However, if delay planting is occurred during flowering phase at dry season in which water table has exceed the critical level (150 cm), then irrigation pump should be provided (Singh *et al.*, 2006). However, long period of flooded condition results in abiotic stress for crop, affects sprout growth rate, seed development and subsequently affect crop growth and development, especially at initial growth period (Dat *el al.* 2006). Crop is capable to tolerate water content level which exceed 25% higher than field capacity (Prawoto *et al.*, 2005). Information related to water melon tolerance level to water content condition higher than that of field capacity is not yet available up to nowadays.

Based on the above discussion, basic research is required to determine watermelon crop response at initial phase to shallow water table condition. Information related to minimum depth of water table for crop planting is very important for farmers to determine the planting date.

Materials and methods

Materials and equipments used in this study were soil media having sandy loam texture, water melon seeds, water and aqua bottles. Equipment design for water table level control was produced by using continous flow system (Figure 1) in which soil water level within soil media is made in equilibrium with soil water level in reservoir using the principle of connected vessel. Analysis of soil water contribution through capillary movement (Figure 2).



Source: Udom *et al*. (2013)

Figure 1. Exprimental set up of soil water contribution to supply crop water requirement.

Figure 2. Exprimental application of soil water depth to supply irrigation for crop

Treatments of soil water depth were consisted of 5, 10 and 15 cm below soil surface. Soil water depth in the range of 5 to10 cm is frequently found in the field at land condition after rice harvesting which is usually occurred in March-April.

In order to maintain constant value of soil water treatments, then water height in column should be kept constant which require daily observation. Crop growth is observed and height as well as leave numbers will be measured at two weeks after planting. Root length and leave numbers of crop for each treatment will be observed at the end of expriment. Data analysis of daily water table level was done to determine planting potential in the field. Data of daily water table level was obtained from secondary data (Imanudin, 2010) and direct observation of daily water table level at Telang II area in 2015. Data of daily water table level would also be compared with rainfall data in 2015. Rainfall data was obtained from Kenten Climatology Station of Palembang.

Experimental site

Research was conducted in the greenhouse at Agroecotechnology Department, Faculty of Agriculture, Sriwijaya University from March to April 2016. Data of daily water level from secondary data and direct observation was used to analyze planting time. Direct observation was done at tertiary plot of Delta Telang II, Mulya Sari Village, Banyuasin District.

Results and discussion

Study of Planting Potential in Tidal Lowland Area

Water melon cultivation in tidal lowland area so far is highly depend on season. Planting in wet season can not be implemented due to very high soil water level as a results of rainfall effect although high tidal water was blocked to prevent water from entering the land. High rainfall intensity couple with insufficient duration of low tidal water for water discharging results in full water within channel and difficulty of water table drawdown. Figure 3 showed data of water table fluctuation in February to March at B land typology in 2015 which was highly affected by rainfall. Observation area was at Delta Telang II. The drastic upward flow of water table was due to rainfall. Water table would continously drop in case of no rainfall. This condition showed that micro water management system was relatively effective in lowering of water table level. Micro water management system was developed by constructing small channel (called *micro channel*) for every 8 m distance having depth of 20 cm. Tertiary channel has function to collect rainfall water and water gate in tertiary channel has function to discharge water. However, farmers could not capable to do planting in early March because average depth of water table was less than 10 cm below soil surface. Figure 3 also showed that water was flooded for 10 to 12 days. Direct planting of water melon seeds could not be done in this condition. Planting can be done at 14th day or in middle of March.

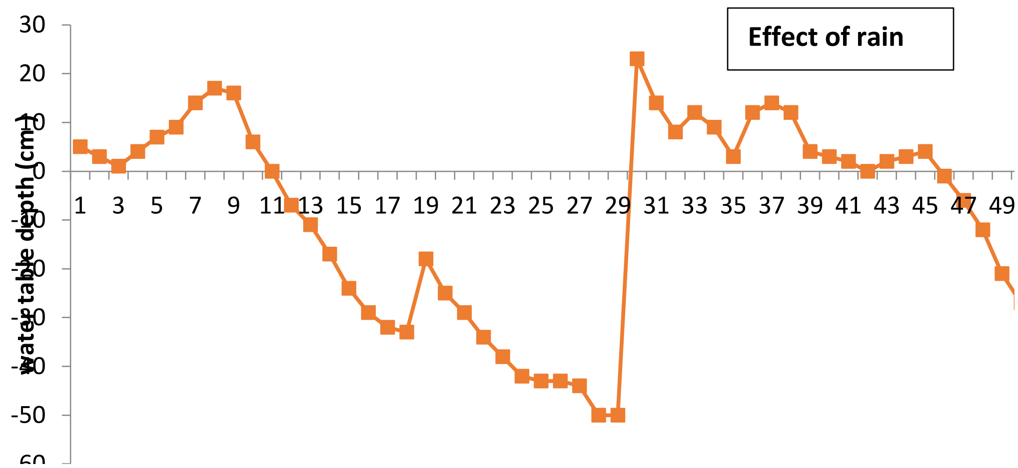


Figure 3. Water table condition in March 2015 at dry climate condition.

Figure 4 showed water table level observation at Telang I area in 2009 which indicate that water table was extremely saturate up to May for crops cultivation, except for rice cultivation. Planting can be done in last of May or early of June so that crop frequently experienced dryness during generative phase in August. According to Bakri *et al.*(2015), water management objective was as water retention within tertiary channel for crop cultivation at tidal lowland area in period of June-September. If high tidal water still capable to enter tertiary channel, then proper water gate is stoplog system with retention level of 50 cm depth. Stoplog height is regulated so that high tidal water can enter the channel and water was held at minimum of 50 cm depth during low tidal water period. If automatic fibre flap gate is available, then gate position is located in rear side facing the land at dry season so that high tidal water can enter the channel and gate will automatically closed during low tidal water. However, this gate is easily damage and it can not be repaired by farmers (Imanudin *et al.*, 2015b).

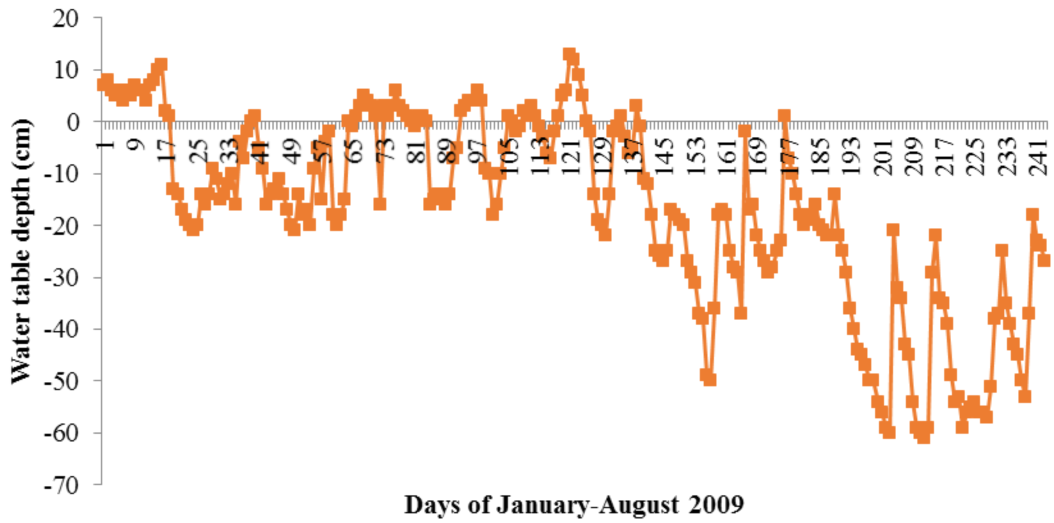


Figure 4. Water table condition during January-August period at normal climate condition (Imanudin et al, 2010).

Planting should be done at the end of wet season in April or even in March due to dry season as a results of El Nino effect in 2015. Crop adaptation in early growth period to wet condition should be conducted. The effort to move foward this planting time is done to prevent water deficiency at generative growth phase. Dry climate condition in August-September cause soil water content in root zone was close to permanent wilting point condition due to the decrease of capillary potential because water table position was dropped to more than 150 cm (Figure 5). Rainfall was start decreasing entering July and the maximum decrease was occurred in August-September-Okrtober (Figure 6). Wang *et al.* (2004) reported that irrigation effort is needed for crop cultivation if rainfall is less than 120 mm. Irrigation water with magnitude of 68 mm will capable to increase production by 46%. Irrigation water couple with mulch can increase production with magnitude of 11.4 ton/ha than that of without mulch addition.

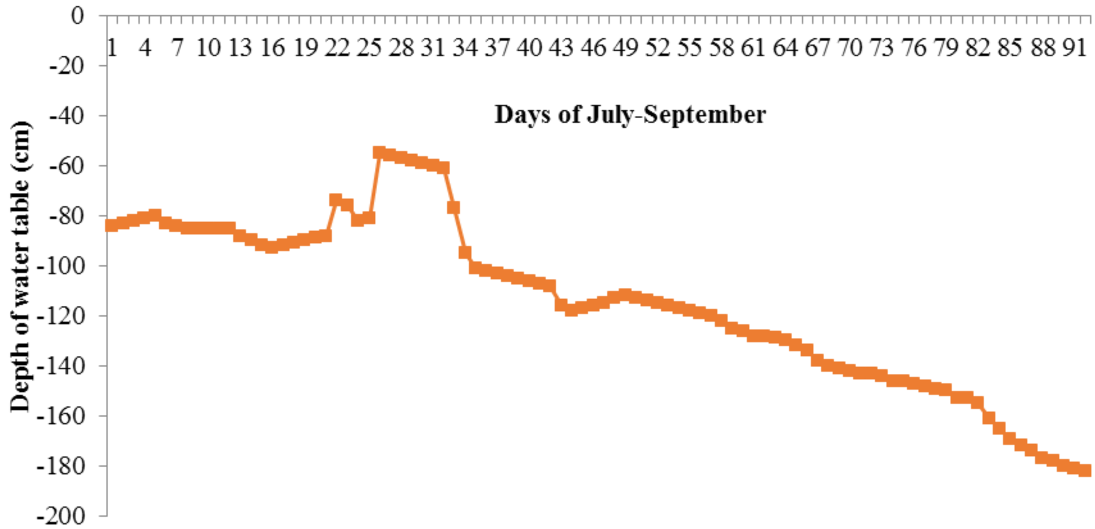


Figure 5. Water table condition at dry season in 2015 in land typology B

Relationship between soil water existence and evapotranspiration rate showed that the closer soil water to soil surface, the higher was the crop evapotranspiration rate. Karimova *at al*. (2014) had reported for the case of loamy clay soil that soil water position at 1.5 m below soil surface had evapotranspiration value of 47% and at position 3 m below soil surface had evapotranspiration value of only 23%. This finding showed that crop requires addition of irrigation for maximum evapotranspiration at those positions.

Results of study by Singh *et al*. (2006) on Typic Haplustalf soil with clay content of 45% showed capillary water movement with magnitude of 18.7 mm/day at soil water depth of 90 cm below soil surface and soil water contribution was decreased to 10.7 mm/day at soil water depth of 120 cm below soil surface. Soil water contribution on sandy clay soil at soil water depth of 0.74 m below soil surface was 4.76 mm/day and its contribution was 2.45 mm/day at soil water depth of 1 m below soil surface (Udom *et al.*, 2013). These data showed that soil water movement at condition of 100-120 cm below soil surface is sufficient to fulfill crop evapotranspiration requirement. However, crop will require addition of irrigation water if soil water condition was located more than 200 cm below soil surface. Therefore, water retention function to keep soil water located at 100-130 cm below soil surface is very important if farmers conduct crop cultivation during dry season. Planting intensity can be done two or even three times as an impact of this land and water management. Intensive farm enterprise can decrease forest and land fire indirectly if land is properly managed and utilized (Imanudin and Susanto, 2015).

Experimental Study of Water melon planting test at shallow water table condition

The basic consideration for the test is earlier planting of water melon during wet season period in March or early April (see the Figure 6). It is hoped that acceleration of this planting time can prevent dryness during the plant flowering and harvesting phases. The third planting times for watermelon or corn can be done in case of normal climate condition. Testing of crop response was conducted within greenhouse. Two treatments of soil water depth were implemented consisting of 5 cm and 10 cm below soil surface.

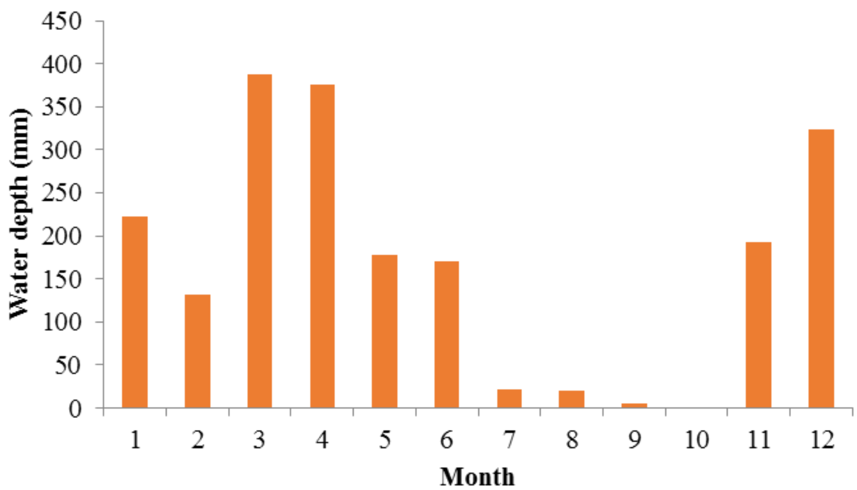


Figure 6. Rainfall condition at the study area (source: Kenten Climatology Station, 2016)

Crop testing results for two soil water status mentioned above showed that crop can still grow at soil water depth of 5 cm below soil surface with under optimum growth level. Watermelon crop had already growth at the 4th day for soil water depth of 10 cm below soil surface, but it did not grow for soil water depth of 5 cm below soil surface. Crop height was 5.6 cm and its leave was still cringe (closed) with uplifted seed skin at the 6th day for soil water depth of 10 cm below soil surface, but stem prospective was just emerging for soil water depth of 10 cm below soil surface. Crop height was 12.1 cm with 3 leaves at the 17th day for soil water depth of 10 cm below soil surface, whereas crop height was 8.2 cm with 3 leaves addition at the 17th day for soil water depth of 5 cm below soil surface. Average growth rate of crop until the 17th day for soil water depth of 10 cm below soil surface was 0.71 cm/day and its value was 0.48 cm/day for soil water depth of 5 cm below soil surface. Crop growth description can be seen in Figure 7.

-5 cm -10 cm -15 cm

Figure 7. Visualization of watermelon respond to shallow water table condition (15th day)

Laboratory expriment was stopped after 20 days of planting time because it is estimated that water table drawdown was dropped more than 20 cm below soil surface at field condition. This period was entered the end of wet season (April) if farmers did planting at the end of March. Plant can be more adaptive to environment condition at this period. Observation at 20th day was conducted on watermelon crop treated with water table depth of 15 cm below soil surface. Crop height was 15.2 cm and had 4 leaves at 20th day observation. The crop had more leave numbers at this treatment than that of 10 cm and 5 cm below soil surface treatments. Humphries *et al.,* in Gardner *et al.,* (1991) had stated that leave numbers and size were affected by genotype and environment. The leave position on crop which is primarily controlled by genotype also has effect on leave growth rate, final size of leave and better response capacity to environment such as water availability. Crop which capable to produce higher photosynthates will produce more leave numbers because photosynthates will be used to develop crop organs such as leave and trunk in accordance to the increase of crop dry matter weight (Hasanuddin *et al. in* Firda, 2009).
Average growth rate of crop height was 0.76 cm/day for 15 cm below soil surface treatment. This value was relatively similar to the result obtained from 10 cm below soil surface. Therefore, watermelon cultivation can be started if field condition showed water table depth of 10 cm below soil surface. The contrast condition was found on 5 cm below soil surface treatment which showed the stopping growth of root elongation. The root crop length was only 3.1 cm at 20 days after planting which indicated that root growth avoids water table level.

The ideal condition for crop growth is at available water condition which located between field capacity and permanent wilting point. Crop growth at initial phase will be disturbed if soil humidity status is at 75% level of exhausted available water condition, whereas optimun crop growth is at 50% level of exhausted available water condition (Modi and Zulu, 2012). It was reported that soil with continous high water content had potential to experience deficiency in macro nutrients such as N, P, K, Ca and Mg as well as toxicities of Fe and Al (Hairunsyah, 1987). Some of these macro nutrients had structural role, for instance Mg as porfirin core composer within chlorophyl, N as the main element of amino acid, protein and enzyme composers, whereas Ca as the main composer of crop cell wall. The subsequent effect of this soil condition will characterized by decrease of chlorophyl content, yellowing, drying and falling leaves as well stopping of plant's prospective growth.

Crop which flooded within short time will experience hypoxia condition (lack of O_2). Hypoxia is usually occurred if part of crop roots is flooded (crown part is not flooded) or crop is fllоded for long time but crop roots are located near soil surface. If all part of crop is flooded, then crop roots is located further deep in soil and experience flooded for longer time so that crop was at anoxia condition (without O_2 environment). Anoxia condition is occurred 6 to 8 hours after flooded because O_2 is suppressed by water and the rest of O_2 is utilized by microorganisms. The left over O_2 content within soil at flooded condition with availability of crop is used up faster because O_2 diffusion rate within wet soil is 10,000 times slower than O_2 diffusion rate in air (Amstrong 1979 *in* Dennis et al., 2000). Condition of hypoxia or anoxia not only prevent N fixation, but also distribution of N and other minerals which in turn impede root growth and nodulation. Leave will experience yellowing followed by leave falling due to insufficient transportation of N and minerals into crown part. Scott *et al*. (1989) had reported that flooded effects were indicated by leave yellowing, leave falling at the lowest joint, dwarf and decrease of dry matter weight and crop yield. According to Hapsari and Adie (2010), results study for soybean crop showed that yield losses in general at vegetative phase was lower than that of reproductive phase having respective values of 17 to 43% and 50 to 56%. The magnitude of yield losses was depended on crop variety, crop growth phase, flooded period, soil texture and the existence of crop weeds and diseases.

Potential time planting at land thypology C

Results from greenhose experiment showed that watermelon can be planted at condition of shallow water table within 10 to 15 cm below soil surface. If watermelon cultivation will be conducted at C land typology in tidal lowland area, then planting time can be accelerated in the end of February or planting was directly conducted after rice harvesting at first planting period. Planting can be done by using hole system in which rice straw was cleared and micro channel was developed for every 6 to 8 m using single plow equipment. Planting time should be quick in order to prevent dryness. Harvesting is estimated in the end of May if planting is done in the end of February or early of March. Generative phase would be in May. Observation results of water table level fluctuation (LWMTL, 2006) showed that planting time could be done in early of March in which water table level was located 20 to 30 cm below soil surface. Planting actually can be done in February based on water table data, but it is better to be done in early of March because farmers were busy in activity of first season rice harvesting in February. Land area with C land typology is highly depend on rainfall. Water supply from high tidal water could not be provided because average height of high tidal water could not flooded into the land. Water retention in channel should be provided in order to maintain water table position close to roots zone.

Flowering phase in May had pose high risk because water table is frequently dropped into 90 to 100 cm below soil surface (Figure 8). Therefore, irrigation was needed in this phase for at least two times application. Irrigation by using pump (or pump irrigation) would be very helpful in this condition in which water was pumped from tertiary channel using furrow irrigation system application. High soil porosity in this C land typology at tidal lowland caused capillary water was not sufficiently available to fulfill crop evapotranspiration requirement if the depth of water table was 100 cm below soil surface.

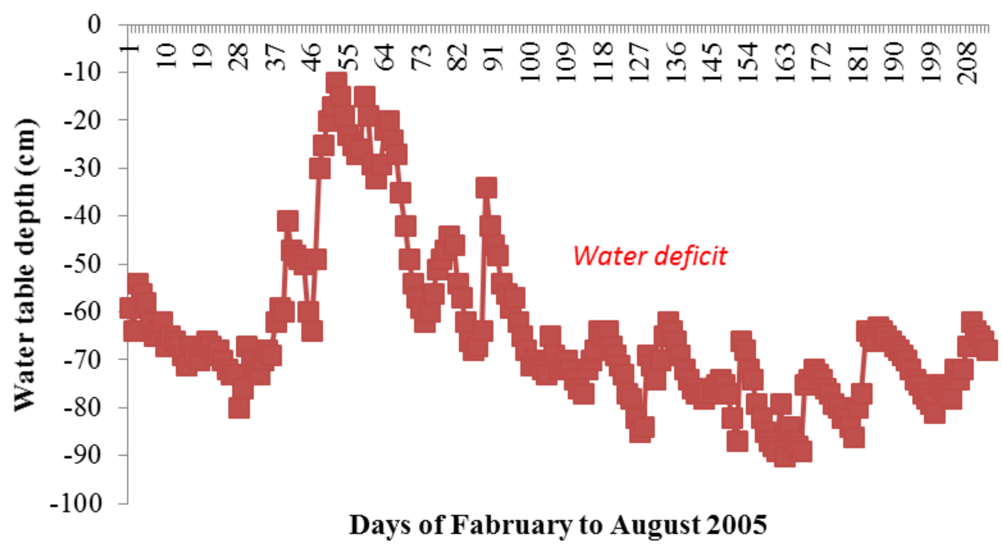


Figure 8. Water table fluctuation at C typology of tidal lowland area (LWMTL, 2006).

According to Pasribu *et al.* (2013), crop water requirement (Etc) for watermelon is 2.80 mm/day for initial growth phase, 6.23 mm/day for middle growth phase and 4.36 mm/day for final growth phase, respectively. Results of study by Singh *et al*. (2006) showed that soil water contribution was 10.7 mm/day if water table depth was 120 cm below soil surface for dominated clay textural soil. On the other hand, capillary water contribution was 4.76 mm/day if water table depth was 74 cm below soil surface and 2.45 mm/day if water table depth was 100 cm below soil surface for sandy loam soil (Udom et al., 2013). This condition showed that critical level of water table depth for crop was 100 cm below soil surface for C land typology, whereas critical level of water table depth for crop was 150 cm below soil surface for B land typology which was dominated by clay soil. Analysisi results of water table fluctuation showed that crop (watermelon) cultivation can be done without irrigation water addition at B land typology (Figure 9).

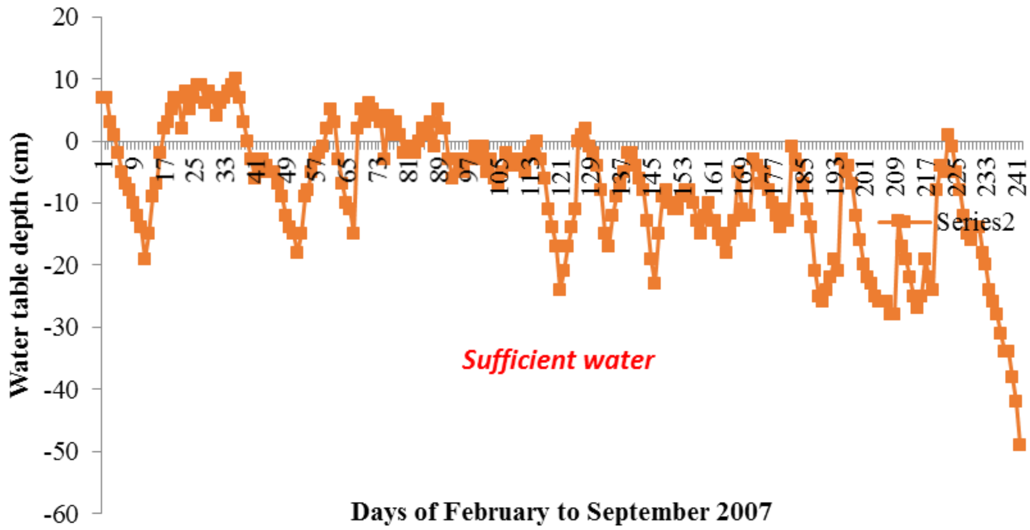


Figure 9. Water table fluctuation at B land typology (Imanudin *et al,* 2010)

Conclusion

- Watermelon crop had potential to be developed in tidal lowland area because it was relatively tolerant to shallow water table depth at initial growth phase. This crop was capable to grow at water table depth of 5 cm below soil surface. The optimum growth was achieved at water table depth of 15 cm below soil surface. However, field application showed that watermelon could be planted at water table depth of 10 cm below soil surface. Results of field study showed that water table depth for B-C land typlogies had achieved 15 cm below soil surface in March-April. Accelerated planting in the end of March was very important in order to prevent dryness occurrence for crop at generative phase because gravitational irrigation system could not be applied to most of tidal lowland areas.
- Crop adaptation to water table is vary depending on planting time and land typology. Crop could be planted in June and was harvested in September without irrigation water provision for A and B land typologies. Capillary water at these land typologies was sufficient to fulfill evapotranspiration requirement. However, earlier planting time in March and harvesting in May-June should be conducted at C land typology because this land had high soil prosity. Capillary water during dry season in this soil could not fulfill evapotranspiration requirement. Water table level in June-September could achieved more than 120 cm below soil surface.

- The tertiary channel should be equipped with water gate to control the proposed water table depth. The main option for A and B land typologies was drainage, whereas for C land typology was water retention.

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IMPORTANT ROLE OF THERMAL REMOTE SENSING (TRS) IN IRRIGATION AND DRAINAGE PROJECTS (CASE STUDY: MINOO ISLAND)

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Abstract

Temperature as one of the most important thermodynamic factors effect on some environmental parameters like rate of physical and chemical reactions, dissolution of minerals and evapotranspiration by soils and vegetation strongly. In design of irrigation and drainage systems, estimation of water requirement for cultivation of crops based on cultivation pattern, in order to avoid of water logging, water shortage and excessive consumption of water and produce run-off more than capacity of drainage system is essential, therefore accurate estimation of evapotranspiration is necessary, especially in arid and semiarid climate like Khuzestan province to manage water resources intelligently. As usual in irrigation and drainage projects, temperature data recorded by meteorological stations is used to estimate evapotranspiration by Penman-Monteith equation, these stations recorded temperature as spot in a small spatial scale and land cover variety does not consider in large spatial scale. Exactly because that, engineers and designers should be careful in using of data obtained by meteorological stations in big scale especially when distance between meteorological stations is away. One of the most effective and newest tools to investigation about land surface temperature (LST) is thermal remote sensing, this technology is related to remote sensing science that process and interpret data obtained in the thermal infrared region of the electromagnetic spectrum is used and can be applied as an alternative or at least complementary selection. This study is done aimed to mapping and classification of land surface temperature pattern in lands scope of Minoo Island. In order to evaluation of land surface

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temperature in Minoo Island, Landsat satellite images (OLI sensor) was used. We compared two recent thermal images acquired in 07/11/2015 and 07/13/2016 before and after logging operation respectively to show dynamic of temperature pattern in spatial and temporal scales. Results of this research demonstrated there was an important different between these two patterns before and after logging operation, as different period of time, pattern of LST changed with regards to land use too, in other words we observed for same places before and after logging operation (variability of time) and according to land use (variability of location) a difference between 8 to 10 C^{o}. These results show importance of spatial and temporal changes of temperature and its role to effect on water requirement, especially in Iran plateau. Finally, authors recommend strongly application of TRS technology as an alternative for or at least a complementary method beside of traditional methods to estimation evapotranspiration by databases like NETWAT that is based on meteorological stations data provided as spot small scale.

KEY WORDS: TRS, Irrigation, Drainage, Water Management, Temperature.

Introduction

Temperature as one of the most important thermodynamic factors effect on some environmental parameters like rate of physical and chemical reactions, dissolution of minerals and evapotranspiration by soils and vegetation strongly. In recent decease application of thermal remote sensing (TRS) has been developed to study and research about environmental changes. Land surface temperature (LST) mapping by remote sensing technology have been used frequently to determine spatial pattern of temperature, developing models of LST exchange, and analyzing the relationships between temperature, land use and land cover in agricultural areas. Recent researches have demonstrated relationships between spatial pattern of temperature and surface features such as vegetation indices and moisture content of soils. Recent researches inquired the effect of biophysical parameters on spatial pattern of temperature by application of essential surface factors such as vegetation index instead of postural land use classes (Amiri et al, 2009). The vegetation index–LST relationship has been used by some scientists (by Carlson et al. (1994) to recover and regain surface biophysical factors, by Kustas et al. (2003) to adapt sub-pixel thermal variations, and by Lambin and Ehrlich (1996) to survey land cover dynamics). Many researchers have reported a reverse relationship between vegetation and LST, this results motivated other researches into two major fields: statistical analysis of the relationship and the temperature/vegetation index (TVX) approach. TVX by definition is a multi-spectral method of combining LST and a vegetation index (VI) in a scatterplot to observe their associations (Quattrochi and Luvall, 2004).

According to World Bank report (World Bank, 2014), global temperatures are 0.8 °C above pre-industrial temperatures. Based on past greenhouse gas emissions and current trends, a further atmospheric warming to 1.5 °C above pre-industrial levels is expected in the short term. In absence of concerted action to reduce emissions, global warming is expected to be around 2 °C by 2050 and 4 °C by 2100. No region will be spared from this change and the adverse effects of this phenomenon will be felt on agriculture, water resources, ecosystems, and human health, especially in regions that are already the most vulnerable, such as semi-arid areas. Proper water resources management is important in reducing vulnerability to drought and other extreme events that may occur with increasing frequency as a consequence of climate change. Arid and semi-arid regions of the Middle East area are already significantly affected by climate change according to the fifth report of the Intergovernmental Panel on Climate Change (IPCC, 2014). It is expected that these regions will become drier and warmer, thus putting even more pressure on already vulnerable water resources (Dong *et al.,* 2013; IPCC, 2014; Ludwig *et al.,* 2011; Olsen *et al.,* 2011; World Bank, 2014). Changes in the hydrological cycle will lead to an increasing risk of tension and conflict in social, ecological, political, and economic spheres (Dong *et al*., 2011; Ludwig *et al*., 2011).
In design of irrigation and drainage systems, estimation of water requirement for cultivation of crops based on cultivation pattern, in order to avoid of water logging, water shortage and excessive consumption of water and produce run-off more than capacity of drainage system is essential, therefore accurate estimation of evapotranspiration is necessary, especially in arid and semiarid climate like Khuzestan province to manage water resources intelligently. Development and implementation of effective adaptation and preventive policies requires interdisciplinary collaboration and exploitation of advanced technologies for environmental monitoring, modeling, and analysis. This study is done aimed to mapping and classification of land surface temperature pattern in lands scope of Minoo Island. In order to evaluation of land surface temperature in Minoo Island.

Material and Methods

Minoo is an Island in the Khuzestan province, in southwestern Iran and is close to the city of Abadan. Minooshahr is on the island, in recent months, project of irrigation and drainage of Minoo lands started, this location is a strategic location (Fig 1).

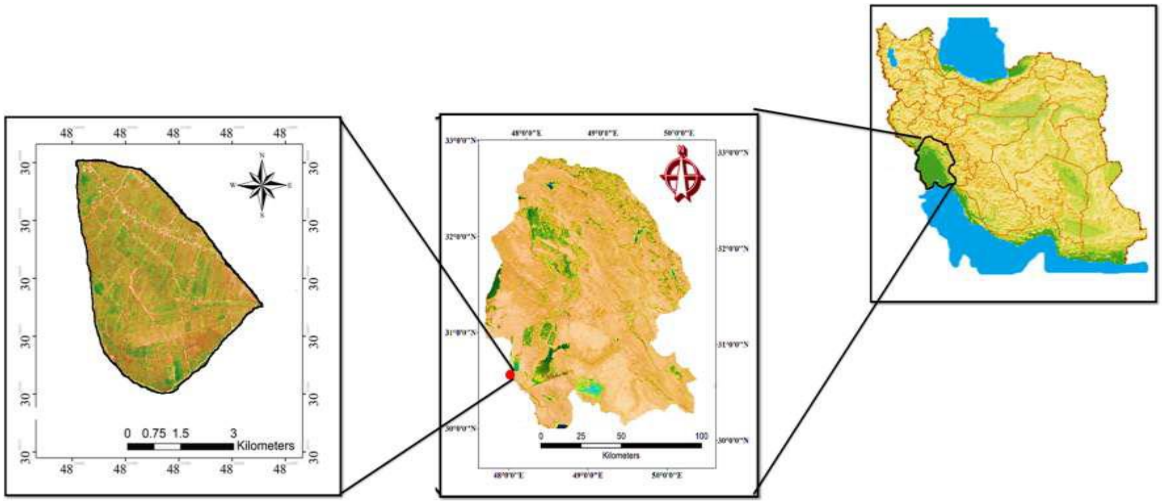

Fig1: schematic location of Minoo Island

There are not enough information about Minoo environment and ecosystem and because of this project there are a few valuable data now. As usual in irrigation and drainage projects, temperature data recorded by meteorological stations is used to estimate evapotranspiration by Penman-Monteith equation, these stations recorded temperature as spot in a small spatial scale and land cover variety does not consider in large spatial scale. Exactly because that, engineers and designers should be careful in using of data obtained by meteorological stations in big scale especially when distance between meteorological stations is away. One of the most effective and newest tools to investigation about land surface temperature (LST) is thermal remote sensing, this technology is related to remote sensing science that process and interpret data obtained in the thermal infrared region of the electromagnetic spectrum is used and can be applied as an alternative or at least complementary selection. In order to evaluation of land surface temperature in Minoo Island, Landsat satellite images (OLI sensor) was used. We compared two recent thermal images acquired in 06/25/2015 and 07/22/2016 before and after logging operation respectively to show dynamic of temperature pattern in spatial and temporal scales. After downloading satellite images from USGS[1] website, in preprocessing step order to eliminate errors caused by atmospheric and radiance sensor and the atmosphere calibration by ENVI 5.0 software has been done, as next step by calibrated images and according to satellite imagery mapping metadata file constants the land surface temperature was investigated.

Results and Discussion

1 United States Geological Survey (https://www.usgs.gov)

In recent decades thermal pattern of a large region of Abadan Island has been changed clearly, a part of this change relates to man-made activities and another part belong to natural changes, important fact about this situation is natural changes affected by man-made activities indirectly. Javadzarin and Alavipanah (2016) investigated changes of thermal pattern during three decades in Abadan Island from 1985 to 2015 by satellite images of Landsat series, their results showed a big change belong to thermal pattern that caused by destruction of groves in this area.

Results of this research demonstrated there is an important different between these two patterns before and after logging operation, as different period of time, pattern of LST changed with regards to land use too, in other words we observed for same places before and after logging operation (variability of time) and according to land use (variability of location) a difference between 8 to 10 C^o (Figs 2 and 3). Most affected area of Minoo Island is southern lands.

Some of parameters of Minoo Island drainage and irrigation project like water requirement, drainage coefficient and its related variables (including depth and distance between open drainages and laterals) designed *before* logging operation and need to be revised, because water requirement and content of run-off in both irrigation and drainage systems of this project designed before logging operation and *after* cut downing more of 300,000 trees (mainly Tamarisk trees), pattern of LST and consequently rate of evapotranspiration changed deeply (Fig 4).

These results show importance of spatial and temporal changes of temperature and its role to effect on water requirement, especially in drainage and irrigation projects. Finally, authors recommend strongly application of TRS technology as an alternative for or at least a complementary method beside of traditional methods to estimation evapotranspiration by databases like NETWAT that is based on meteorological stations data provided as spot small scale.

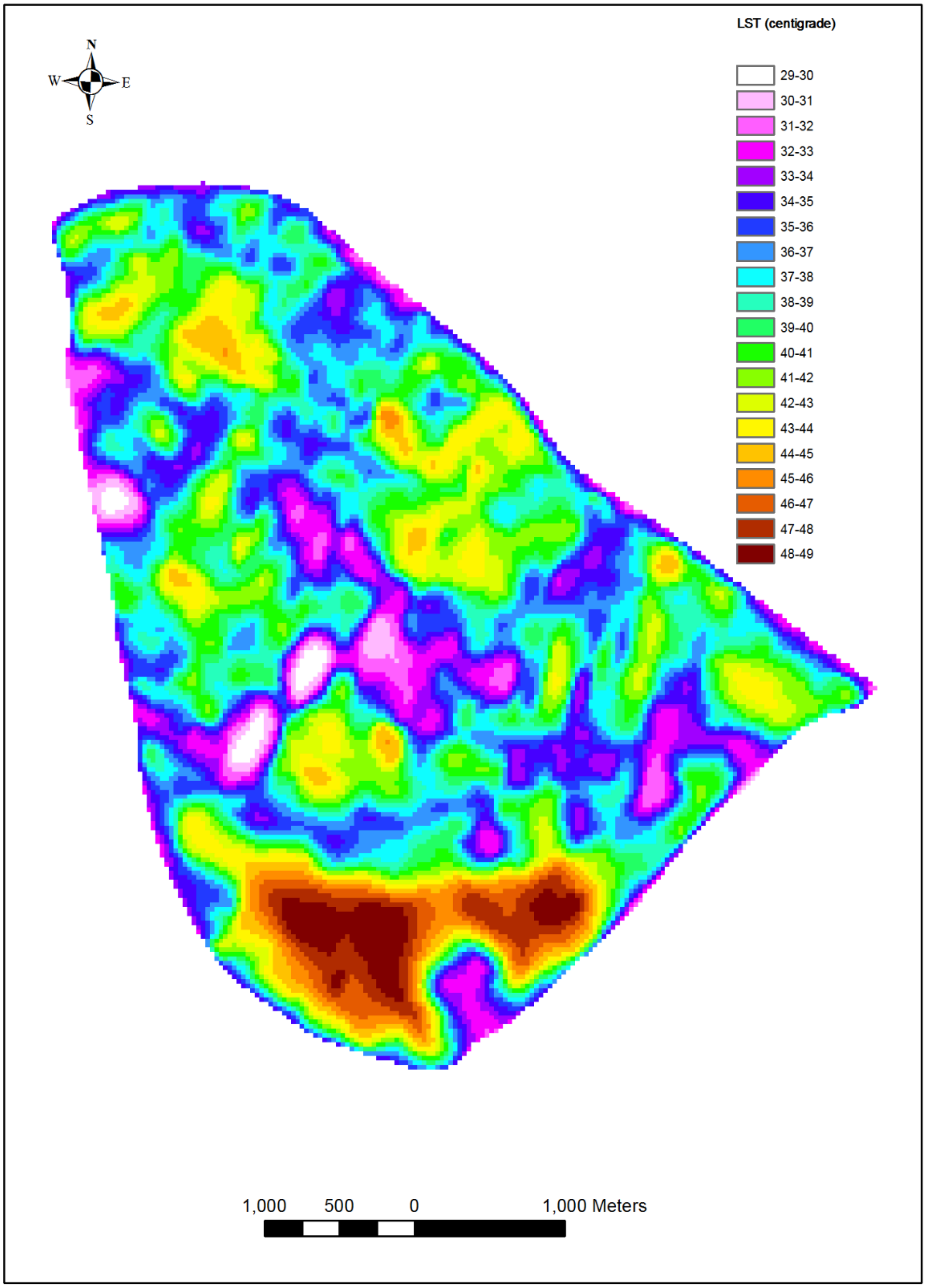

Fig 2: Spatial changes of Minoo Island LST (11 July 2015)

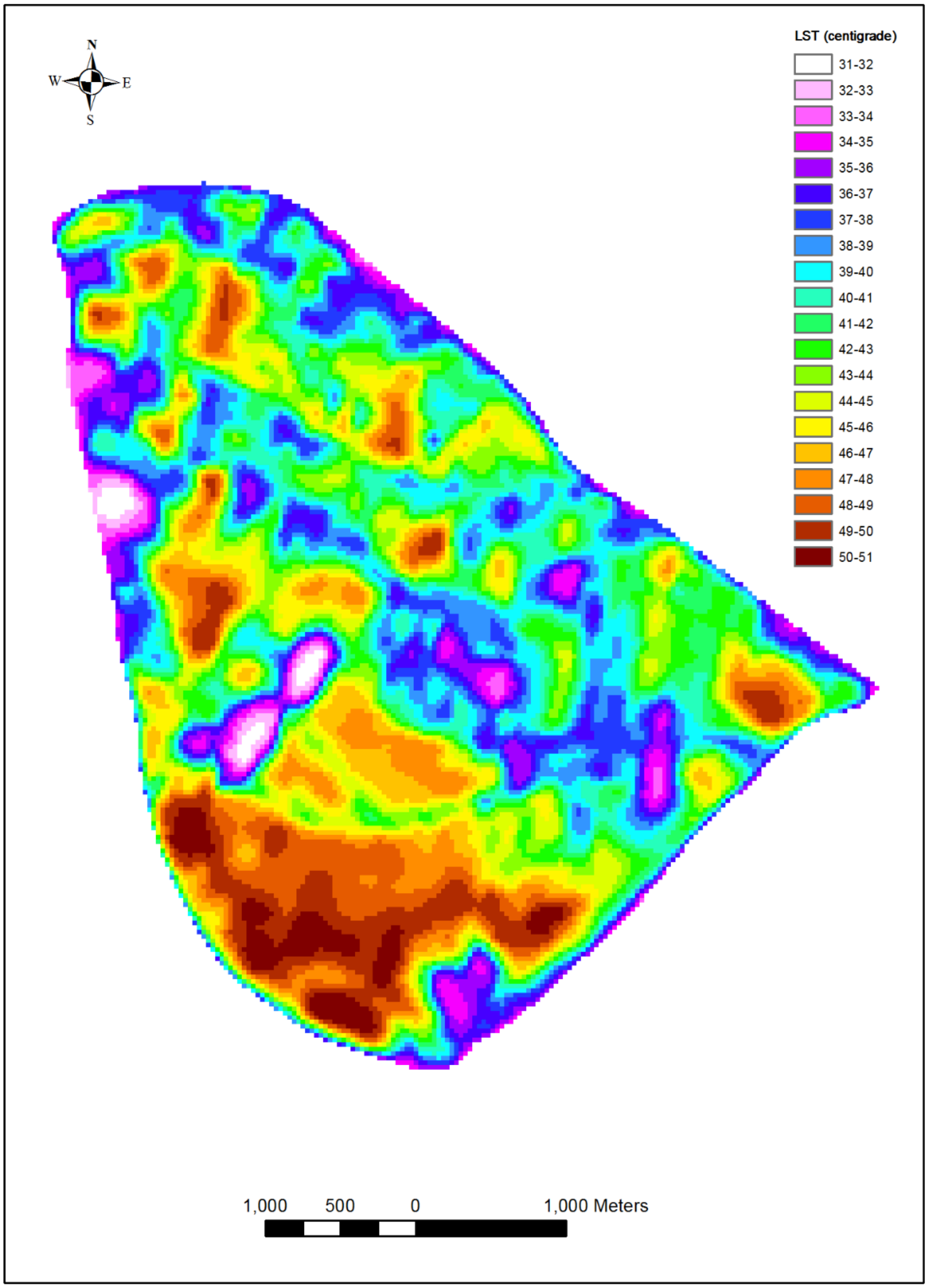

Fig 3: Spatial changes of Minoo Island LST (13 July 2016)

Fig 4: situation of vegetation Minoo Island before (left, 11 July 2015) and after (right, 13 July 2016) of logging operation

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CLIMATE CHANGE RESILIENT WATER MANAGEMENT MEASURES IN AGRICULTURE IN FINLAND

Elsi Kauppinen[1,*], Markku Puustinen[2]

Abstract

In Finland only about 15% of agricultural fields can be cultivated without drainage. About 58% of field areas have subsurface drains and 27% have ditch drains. The distance between the point of discharge of field drainage and the closest body of water is on average 2.3 km (median 1 km). Presently the drainage systems are utilized only in rare cases for wetlands and other elements to reduce nutrient flux and for balancing water flow.

In Nordic regions climate change will deteriorate in winter time weather conditions: snow cover has had a greatly reduced duration, and most of the precipitation is rain instead of snow. This has had repercussions for agriculture and drainage and their environmental impacts. Previously snow cover protected agricultural fields during winter from erosion and nutrient leakage. It has been already observed that agricultural fields have become more prone to erosion and consequently unprecedentedly high nutrient concentrations have been recorded in rivers downstream from agricultural areas after heavy rains and during a time when the fields have a small amount of vegetation cover. In addition the changes in the time and amount of precipitation has resulted into a need to change recommendations for the dimensioning of drainage systems.

Sustainable practices in drainage such as two-stage drainage channels, constructed in wetlands, sedimentation ponds and floodplains should become the standard practice in Finland in order to control the eutrophication problems caused by agricultural drainage. In order to reach this goal several social and political problems should be resolved. For example there is a need to reserve larger land areas for drainage. This is especially problematic when considering the EU's Common Agricultural Policies, which include agricultural subsidies paid to farmers per cultivated hectare – the farmers see it as being especially problematical if they have to give up farming area. Despite the social and political problems two-stage drainage channels have been implemented in few cases in Finland. Several good examples of the usage of wetlands, submerged dams and floodplains also exist. The paper reviews some of the examples and presents the environmental benefits of the solutions.

KEY WORDS: Two-stage drainage, Sustainable agriculture, Climate change, Finland.

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Introduction

Rethinking drainage

In Finnish agriculture effective drainage systems are the most important component of infrastructure. Without it agricultural production in the cold and rainy climate of the northern Europe would not be possible**.** While enabling agricultural production, the drainage systems have decreased the water holding capacity of watersheds, caused increased vulnerability to erosion if measures for erosion control are not utilized and also carbon leakage from organic soils. The general problem is that the drainage systems using traditional designs do not include elements which withhold flux of particulate matter.

In the Nordic areas effects of climate change will cause increases in erosion and in leakage of nutrients by year 2050. This will cause a higher eutrophication pressure of the aquatic systems especially in watersheds with high amount of agricultural areas. There is a potential for avoiding this scenario, if more environmentally friendly agricultural practices are used or if new practices are developed.

There is still an untapped potential in drainage systems with benefits for aquatic systems and biodiversity. Restructuring drainage would require changes in many subsidies, policies and even in attitudes towards water protection in agriculture.

History of environmental effects of agriculture and drainage in Finland

There has been a long road of development with water protection, as well as with environmentally friendly agricultural practices and their research (Vuorenmaa et al., 2002), (Tattari et al., 2016). At the same time agriculture has gone through fundamental changes.

In Finland drainage channels are privately owned. They are governed through communities of local landowners (drainage communities). State of Finland has been compensating for the costs related to drainage operations for several decades. Lately there has been a discussion, if the compensations are anymore justified.

Almost whole agricultural land area in Finland had basic drainage networks by the end of the 1960's. The drainage networks opened new straight and fast connections from agricultural fields to lakes and rivers. Traditional main ditches were designed to be straight, even and with steep sides – as efficient hydraulically as possible. This kind of basic drainage networks channel water efficiently away from fields, and offer no means for reducing the environmental impact of nutrient flux from agricultural fields to natural aquatic ecosystems (Puustinen et al., 1994).

Drainage depth was for a long time determined based on the depth which is most beneficial for cultivated plants (60-80 cm). Nowadays the depth is determined by the soil's load bearing capacity for heavy machinery (120-130 cm). Deepening of drainage depth has caused increased environmental impact from organic soils, as organic matter became vulnerable to erosion and degradation. Large areas of drained organic soils have since slowly turned to mineral soils. On mineral soils deeper drainage depth does not cause increases in environmental impact, if agricultural practices are otherwise sustainable.

Because of the increase in drainage depth and new connections between agricultural fields and natural aquatic ecosystems, water flow from agricultural fields to aquatic systems has become more variable than before i.e. the buffering capacity of drainage areas has decreased. This has been especially notable in watersheds where also forest areas have been drained.

Finnish agriculture has gone through a lot of changes on the long timescale. According to national statistics since the 1960's agricultural land area has decreased (from 2.7 million ha to 2.2 million ha), there has been a change from grassland farming to spring cereals (grassland area has decreased from 1.4 million ha to 0.6 million ha), fertilizer use has increased and mechanical tillage has become widespread. All this has been possible because of efficient drainage systems.

As drainage and agricultural practices became more efficient, also erosion and nutrient flux from agricultural fields has increased. Anthropogenic eutrophication of water systems originates mainly from agriculture (50% of nitrogen and 60% of phosphorus). After Finland joined the EU in 1995, several agricultural practices for reduction of water pollution have been implemented through agri-environmental schemes, which have been widely popular among farmers.

Despite the popularity of agri-environmental schemes, only slight reductions of phosphorus loading of water systems have been observed in agricultural areas and nitrogen pollution seems to have even increased. On the average water pollution caused by agriculture have remained on the same level as during the 1990's, around 15 kg-N ha^{-1} yr^{-1} and 1.1 kg-P ha^{-1} yr^{-1} (Vuorenmaa et al., 2002), (Tattari et al., 2016).

There have been several different views about reasons behind the low effectivity of agri-environmental practices. Suggested reasons have been for example changes in arable land area and centralization of non-cereal and animal farming (Aakkula and Leppänen, 2014). Another reason could be that the effects are masked by high variability in other anthropogenic and natural sources of nutrients.

Now the main problems are: how to prepare for impacts of climate change in drainage operations and in agri-environmental schemes, what kind of role drainage systems should have in future, and is it possible to reduce environmental impacts of agriculture through drainage practices. These problems are related to the following questions, which will be addressed in this article:

1) how widely should water protection measures for agriculture be implemented
2) what kind measures would improve the buffering capacity of catchments
3) can two-stage drainage systems improve the state of the environment.

This article will go through the history of development and the needs to improve water protection measures within Finnish agriculture, and how have we reached these conclusions.

Materials and methods

Hydrology – precipitation and runoff

Long-term (1960-2015) average precipitation in southern and southwestern Finland has been 700 mm (Table 1), of which 40% becomes runoff and about 60% evaporates. Typically during growth season evaporation is 120-130 mm larger than precipitation, causing a deficiency of water. The runoff during growth season is only 10% of total runoff during a year and the rest occurs outside growth season – during a time, when a large proportion of agricultural fields lack vegetation cover (tillage is usually done during autumn).

Majority of yearly runoff has typically, until the last few years, occurred during spring when snow cover melts off. Precipitation during autumn season is usually also high. The most relevant issue is, that the majority of runoff and fluxes of nutrients and particulate matter occur outside growth season, during only few weeks (when temperatures are above zero Celsius) (Puustinen et al., 2007), (Veijalainen, 2012).

Table 1. Average precipitation during a year (mm), average runoff during a year (mm) and proportion of seasonal runoff of the total annual runoff (%) during years 1961-1991 (statics of Finnish Meteorological Institute published in for example Vakkilainen 2009).

Region	Precipitation mm	Runoff during a year (mm) and proportion of seasonal runoff of the total annual runoff (%)				
		Year	Spring	Summer	Autumn	Winter
Southern Finland	700 <	300 - 400	45	10	25	20
Central Finland	600-700	< 300	50	15	25	10
Northern Finland	500 - 600	400 <	45	25	20	10

Runoff and agricultural drainage

Drainage water from agricultural fields flows on the surface, in subsurface drains and as groundwater. Several factors such as slope of fields, soil type and soil compaction influence the routes water flows take.

In Finland about 60% of arable land has subsurface drains. About 25% of agricultural plots have open ditches, and there drainage intensity is weaker. Only about 15% of arable land is cultivated without open or subsurface drainage. There is no significant difference in water pollution if fields are drained through subsurface or open drainage.

Basic drainages have typically dimensions to fit in floods which occur once every 20 years. However, the dimensions are calculated based on the climate conditions which have prevailed over the last decades.

Average distance between place of discharge from field drainage and inflow to closest natural aquatic system is 2.3 km (median 1.0 km). Especially during spring floods the delay between discharge from fields to receiving body of water is very short. This inevitably means that the buffering capacity of drainage areas is small and that drainage water have the same quality when inflowing to a body of water as they had when they were outflowing from agricultural fields (Puustinen et al., 1994).

Evaluation of water pollution levels - monitoring and models

Nutrient pollution from various sources has been monitored through water sampling for over 30 years in small catchments (Tattari et al., 2016). In addition particulate matter and nutrient fluxes have been researched at experimental setups for decades (Puustinen et al., 2010), (Uusi-Kämppä, 2010), (Turtola, 1999). The research and monitoring have given a good picture about the factors which influence the load on aquatic ecosystems.

In addition to field research, several internationally and nationally developed models have been introduced to practice. The most important ones are ICECREAM, INCA and SWAT models (Malve et al., 2016). For practical work in Finland VEMALA and RUSLE models are most commonly used (Lilja et al., 2016), (Huttunen et al., 2016). Additionally, a model based on experimental research was developed (VIHMA tool) (Puustinen et al., 2010). It can be used to estimate particulate matter and nutrient loading from agriculture on aquatic systems. The models and the data they are based on have been utilized for decades in estimation of environmental impact of agriculture and in designing agri-environmental schemes for reducing the impacts.

Up to last few years monitoring practice has been based on water sampling, but lately there is a move towards continuous water quality measurements. Continuous measurements enable acquiring better quality of data about flood situations and nutrient concentrations in discharge (Linjama et al., 2010). It has been observed that nutrient load on water systems is probably higher than previously has been assumed. The error has been caused by too infrequent water sampling, which has often missed the high discharges of water and nutrients which occur after heavy rains and snow-melt events (Figure 1).

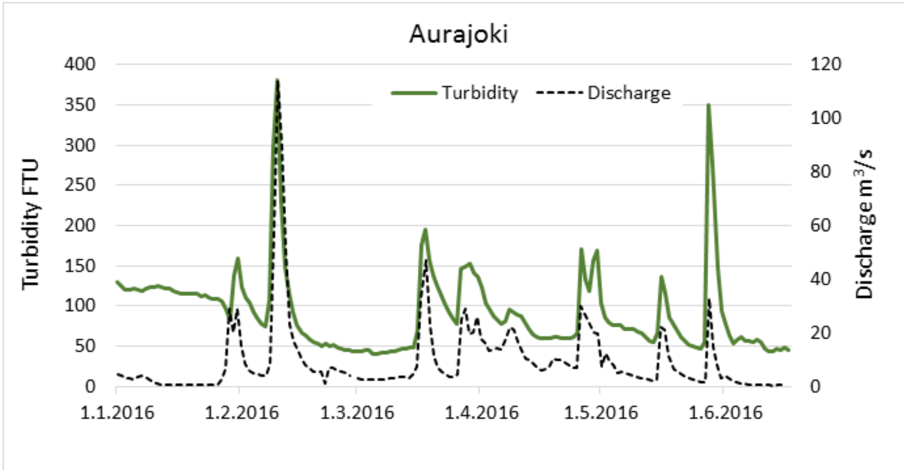

Figure 1 (Marjo Tarvainen, unpublished). Turbidity and discharge volume measured in Aurajoki with continuous water quality and quantity monitoring from January to June in 2016. If turbidity was estimated based on water sampling during the same period, conclusions could vary a lot based on timing of sampling.

Nutrient loading of aquatic systems

Many different point and diffuse sources cause nutrient loading on aquatic systems (Table 2). Notably, natural background loading is very large. Agriculture is clearly the largest source of anthropogenic nutrient pollution. On average agricultural nutrient pollution is 15 kg-N ha^{-1} yr^{-1} and 1.1 kg-P ha^{-1} yr^{-1} (Vuorenmaa et al., 2002), (Tattari et al., 2016).

Table 2. Average particulate matter and nutrient loading from various sources to aquatic systems. Here both diffuse and point source loading have anthropogenic origin.

Character of nutrient source	Particulate matter and nutrient load 1000 kg yr^{-1}		
	Particulate matter	Total phosphorus	Total nitrogen
Natural background flux	155 000	1500	39 500
Diffuse sources	1 621 600	3550	51000
○ *Agriculture*	1 340 000	2 400	33 000
Point sources	18 800	485	16334
Total	1 795 400	5 535	106 834

Agricultural particulate matter and nutrient loading to aquatic systems have been increasing since 1950-60 up to their present levels (Kauppi, 1984), (Rekolainen, 1989). During this time annual amounts of precipitation and runoff have remained stable. Increased nutrient loading to aquatic systems is thus caused by increases in the concentrations of nutrients in discharge. This is related to the many changes which have occurred in agriculture.

Notably, inter-annual variation in nutrient pollution to aquatic systems caused by hydrological climate conditions is very large and is clearly visible in monitoring results (Vuorenmaa et al 2002, Tattari et al 2016). In years with wet and mild winters agricultural loading is much larger than during years with dry and cold winters (Puustinen et al., 2007).

Since 1990's agricultural nutrient pollution to aquatic systems has remained constant. Small changes in arable land area have had no observable influence on the load (Vuorenmaa et al., 2002), (Tattari et al., 2016).

Management of discharge and nutrient fluxes in agriculture

Presently used measures targeted at preventing water pollution are: sustainable farming practices on the fields, vegetative buffer zones along the edges of fields and measures which are done outside of arable land area such as constructed wetlands. Their main goal is to decrease erosion, which will also reduce nutrient discharge.

Both sustainable farming practices and vegetative buffer zones are supported through EU's agri-environmental schemes programme. Since 1995 farms increasingly took part into the programme and at present about 90% of arable land area has joined it.

The effects of the programme were positive. As usage of mineral fertilizers decreased, also gross nutrients balance on arable land decreased by 35% for nitrogen and by 60% for phosphorus by year 2010. Land area ploughed during autumn decreased from 1.2-1.3 million hectares to 0.5 million hectares. Autumn tillage has been replaced with various forms of practices which have vegetative cover during winter: stubble cultivation 200 000 ha, spring tillage with stubble during winter 360 000 ha and direct sowing 156 000 ha. Area of established vegetative buffer zones is about 8000 ha and also a few hundreds of new constructed wetlands have been implemented (National agricultural statistics).

The systematic implementation of basic drainage network was a long term project, which was mostly finalised by the end of the 1970's. After that drainage projects have been mostly major overhauls or refurbishments. Overhauls are done based on the old designs and dimensions. Two-stage drainage or other sustainable solutions have not been implemented except for few exceptions.

Impacts of climate change on precipitation and discharge

In Finland the impacts of climate change will be most pronounced during winter - the winters will be much milder and will cause the Southern Finland to remain without a continuous snow cover through winter (Jylhä et al., 2008), (Olsson et al., 2015). Majority of precipitation during winter will be rainfall instead of snow. Later the same effects will occur also in Central Finland. The milder winters will lead to disappearance of typical spring floods, because there will no longer be a lot of snow melting away at once. Instead of continuous snow cover the snow will fall and melt away several times per winter. The same will happen for frost in soil. These changes will lead to high amount erosion and discharge of particulate matter and particulate phosphorus - even when the total amount of discharged drainage water would remain constant (Puustinen et al., 2007). If also the amount of precipitation will increase during winter, then the erosion rate and phosphorus flux to aquatic systems can be triple on agricultural fields without wintertime vegetative cover (Puustinen et al., 2007).

Results and conclusions

Effectiveness of agri-environmental schemes and management of water pollution

Even though changes in agricultural practices and in the amount of agri-environmental schemes taken into practice have been large, it was not observable in monitoring results of small catchments (Tattari et al., 2016). The effect of the agri-environmental schemes was estimated with VIHMA-model by comparing year 2010 with a year before Finland joined the EU (pre-1995): the schemes reduced the amount of particulate matter, nitrogen and phosphorus flux from agriculture to water systems by 16-22% (Table 3) (Puustinen unpublished). The estimation was done for years when hydrological climate conditions were average.

However, if the climatic change towards milder winters is taken into account (Table 3), the effect of the improved practices and agri-environmental schemes is significantly smaller. In practice, the improvement would be within the natural variation and not observable in monitoring results.

In Table 3 the listed estimates of effects from measures on the fields (implemented agri-environmental measures on arable land), riparian buffer zones, constructed wetlands (too few for statistical significance), total (total estimated effect of implemented measures in 2010 in hydrologically average years), mild winters (estimated effect of measures implemented on arable land in 2010, taking into account a change towards milder winters) and total potential (what could be achieved if measures were implemented more efficiently – taking into account change towards milder winters) are given for suspended solids (SS), particulate phosphorus (PP), dissolved reactive phosphorus (DRP), total phosphorus (TotP) and nitrate (NO_3-N).

Table 3. Impact of agri-environmental schemes on agricultural nutrient discharge to water systems (%), when comparing years 1990-94 to year 2010 (Puustinen unpublished). See text for further explanation.

Environmental measures	Change in agricultural nutrient discharge (%) at present amount of implemented measures and at different scenarios				
	Erosion (SS)	PP	DRP	TotP	NO_3-N
Measures on the fields	-22	-16	11	-6	-19
Riparian buffer zones	-2	-3	1	-2	-1
Constructed wetlands	-	-	-	-	-
Total	-24	-19	12	-8	-20
Mild winters	-9	-4	14	3	-10
Total potential	-32	-25	12	-13	-19

Similar preliminary results were obtained from ICECREAM and VEMALA models, which predict increase in phosphorus loading from arable land area by year 2050 (Figure 2) (Huttunen unpublished). These estimates show a variable change for different catchments in years 2020-29, because the base years (2005-2014) were already unusually warm and wet.

If all potential environmental measures were put into use, it would possible to reach big reductions in nutrient leakage from agriculture - if climate change was not happening. Because of that, in future Finland will need more efficient measures than are presently used - larger land area covered by present measures, better targeting to vulnerable areas, and also completely new measures (Silander et al., 2006), (Huttunen et al., 2015). Measures targeting soil and drainage have potential and will be a major focus in future.

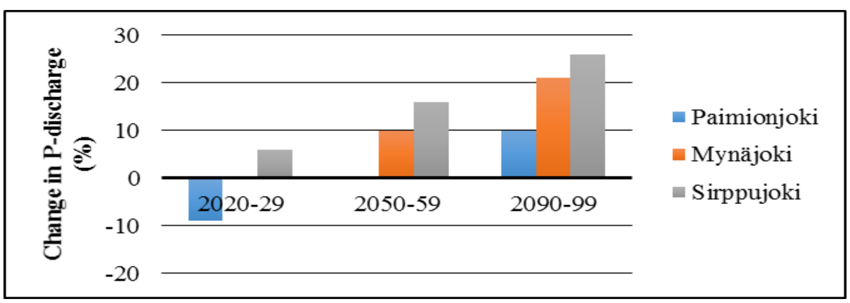

Figure 2. Preliminary estimation of impacts of climate change on phosphorus discharge from agriculture in three catchments in Southwestern Finland (Paimionjoki, Mynäjoki, Sirppujoki) in comparison to years 2005-14 (Huttunen unpublished). The phosphorus discharge will increase by year 2050, assuming the present level of agri-environmental practices. Results from ICECREAM and VEMALA models, using A1Bmean climate change scenario.

It is also possible that within few years continuous monitoring of water will improve the knowledge about nutrient fluxes from agriculture, as well as and will improve the understanding about the need for agri-environmental measures.

New measures targeting drainage

Several different arguments for implementing into wider practice the two-stage drainage have been presented: they are part of blue and green infrastructure in rural landscape, forming corridors for various species, improve biodiversity, and at the best case scenario bring back habitats which were lost when open field drainage was changed to subsurface drainage. They are one type of catchment scale agro-ecological solution (Wezel et al., 2016) with both water quality and ecological benefits.

In management of drainage water and nutrient loading an essential feature of catchments and drainage areas is buffering capacity: how much can different structures delay the flow of water without causing waterlogging or other problems. Two-stage drainage with channels for normal water and high water can easily be supplemented with sedimentation ponds and constructed wetlands. All of these structures can improve the buffering capacity.

The implementation of sustainable rural drainage systems should take place whenever a need for major overhaul occurs. It will be needed to estimate how much of the climate change impacts can be compensated with increasing the implementation of agri-environmental measures and how much with two-stage drainage. It is also needed to research: how important factor is buffering capacity or delay between point of discharge from a field and inflow to a body of water, how it influences nutrient loading and if the effect is comparable to constructed wetlands. Also the most environmentally efficient dimensioning of a two-stage drainage is still an open question.

A related question is how will climate change influence precipitation and how will it affect discharge. It will remain to be seen if disappearance of spring floods will cause more continuous discharge throughout winter. This could allow using smaller dimensions for ditches.

There are still several practical problems, which prohibit a wide use of two-stage ditch design. The problems are often related to agricultural subsidies and present agri-environmental schemes. Agricultural subsidies were not planned to allow easy cooperation between farms, which would be needed for reforming basic drainage networks. Despite these problems a few pilots of two-stage drainage has been carried out in Finland.

Functional principles of two-stage drainage

In contrast to several other agri-environmental methods, two-stage drainage channel's main functional principle is based on flood situations (Figure 3). During floods water level rises until it reaches the flood plains, where speed of drainage water is slowed down and particulate matter can settle down on the flood plain. If the channel also includes constructed wetlands and wider areas of flood plains, then the efficiency of particulate matter removal is improved.

Environmental benefits of a two-stage drainage channel were estimated in a PhD-thesis published in 2016 (Västilä, 2016). According to the estimate up to 20% of particulate matter flux could settled on the flood plains of a 1 kilometre long two-stage ditch. Also the results suggested that vegetation should be kept quite short, so that it will not restrict water flow during flood events too much.

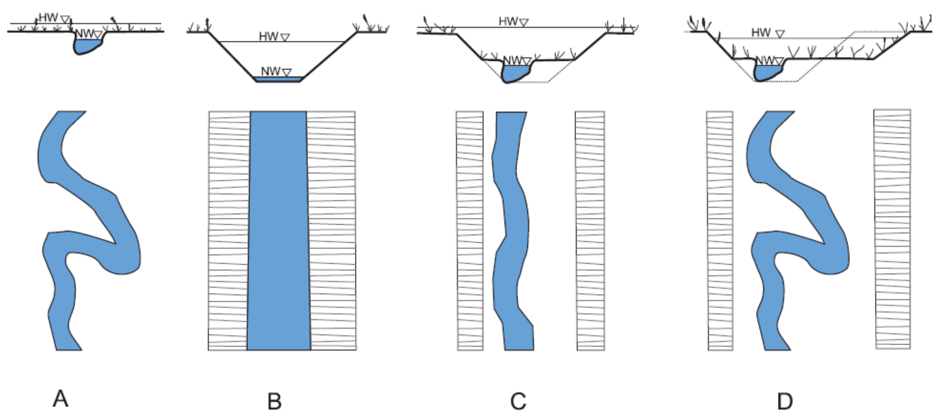

Figure 3. A) Natural brook, B) traditional main ditch, C) two-stage drainage channel, D) two-stage drainage channel after several years of operation.

Example 1: Ritobäcken

Ritobäcken is a small brook in Southern Finland. The brook is part of the Natura 2000-network, flows through agricultural area before discharging to a national park and is a habitat for a protected population of trout.

When a major overhaul of the part flowing through agricultural area became under evaluation, it was recommended that drainage depth should not be increased and the channels vulnerability to erosion should be especially considered. Because of these reasons a major overhaul using old designs and dimensions was considered to be not allowable.

In 2010 Ritobäcken was overhauled into a two-stage channel (Figure 4). Since then no maintenance has been needed, but now bushes are taking it over slowly. Now there is a need to plan how maintenance should be carried out – there is no previous experience with it in Finland.

Experience with the pilot showed that subsurface drains which discharge to a two-stage channel should be shortened, so that the drained water from fields is discharged on top of the flood plains. If sub drains continue below the flood plain, they will get blocked up very easily.

Figure 4 (Elsi Kauppinen). Two-stage channel at Ritobäcken six years after construction work.

Example 2: Leppioja

Leppioja is a ditch at a region with acid sulphate soils in Northern Finland. Because of the soil type, it is not allowed to increase drainage depth. However, the area had regular flooding on the fields during spring time. These reasons left as an only option to renovate the ditch to a two-stage drainage channel (Figure 5). Some sedimentation ponds and erosion control measures were also incorporated into the plan.

Figure 5 (Elsi Kauppinen). Two-stage drainage channel at Leppioja, a few years after construction work. Connections to subsurface drains for easier flushing are visible on the sides.

At Leppioja subdrains were cut short to end before the flood plains. This is especially valuable at this region, because at acid sulphate soils subdrains are very prone to becoming obstructed and have to be flushed once per year. The flood plain offers an easy access and working area for the drain flushing work.

Other experience gained at Leppioja was that at acid sulphate soil areas the renovation to a two-stage drainage channel should be carried out as one sided work whenever possible. Some parts of the channel still have no vegetation after few years, because the soil is too acid. If one side of the channel was left as it was, without construction work, it would limit the amount of erosion.

Example 3: Mättäänoja

Mättäänoja is a drainage ditch in southwestern Finland (Figure 7). It will hopefully be the first example of a two-stage channel in Finland, where the original idea came from land owners. The plans for the overhaul have been prepared, and at present the landowners are ready to apply for funding. The main goal is to make the area less prone for flooding. The area used to be a swamp, until it was drained for agricultural use. Slowly the organic soils have become more compacted and drainage depth has decreased (now less than 50 cm).

Figure 7 (Elsi Kauppinen). Mättäänoja-ditch in April 2016, before growth season. Low drainage depth is causing the fields to have regular flooding after snow melt and heavy rains.

Conclusions

Impacts of climate change in Finland will mainly cause environmental degradation. If we want to adapt to the changes and avoid the degradation, then water protection measures should be more efficient in future. Even though adoption of agri-environmental measures was large in scale, its impacts have been not been visible in water systems because the effects of climate change are already eroding away the potential positive results.

In 60's and 70's the state of Finland supported financially the construction of hundreds of thousands of hectares of basic drainage network. Nowadays still every year hundreds of hectares of major overhauls receive funding from the state. In comparison to these numbers, the total amount of established environmental measures within drainage network has been very low: few hundreds of hectares of constructed wetlands and a couple of examples of two-stage drainage channels.

There is a need to evaluate if governmental funding for drainage network overhauls should have more strict environmental standards, how sustainable drainage practices could become the norm and how is it possible to increase the buffering capacity of drainage areas. To solve these problems we still need to improve the possibilities for cooperation between farms by changing the agricultural subsidies. Drainage and blue/green infrastructure will be important aspects in adapting to climate change and in development of sustainability of practices in the future.

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WATER SUPPLY SYSTEM AND THE SUSTAINABILITY OF SMALLHOLDER IRRIGATION IN ZIMBABWE

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Abstract

Irrigation agriculture is critical in enhancing food security especially in Africa where the carrying capacities for most rain-fed agricultural systems have been surpassed. As a result, small shareholder irrigation schemes have been prioritized as a rural development model and have regained renewed attention from global and regional developmental bodies as a climate change adaptation measure. However, there is hardly any case of a successful small shareholder irrigation scheme in Africa as the majority of them have been unreliable and contributed very little to the host countries and the livelihoods of the farmers. The factors leading to the unsustainability of the irrigation scheme are not fully understood. The major objective of the study is to assess the impact of water supply in the sustainability of small shareholder irrigation schemes in the study area. The study targeted 8 irrigation schemes in Zimbabwe. A mixed research method was used and 316 randomly selected farmers were interviewed. Focus group discussion, key informant interviews and field observations were used to allow for the triangulation of information.

Unprecedented siltation of water bodies compounded with inequitable water sharing and poor catchment management was has threatened the sustainability of smallholder irrigation schemes yet interventions in the schemes did not prioritize the sand abstraction water pumping system. The Zimbabwe National Water Authority (ZINWA) as the water governing body proved to be inefficient and detached from the farmers. Farmers could not understand why they were compelled to pay for the water as 70% of them rated its service as poor. A combination of farmers' low productivity levels, debilitating dependency syndrome, ZINWA's poor service culture and political interference in water governance has affected farmers' ability and willingness to contribute towards water bills. There was poor in- field water management and some schemes were poorly designed as there was no consultation with the local people on the designing of the pumping systems. The majority of the schemes faced frequent pump breakdowns and farmers had no reserved funds for repairs and replacement investment.

KEY WORDS: Smallholder irrigation scheme, siltation, Water management, Replacement investment.

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Introduction

Globally, investments in irrigation have been an essential element in increasing food production to feed the ever-growing population (Mutambara et al., 2014). The World's irrigated land constitutes 19% of the land under cultivation and supplies 40% of the world's food requirements (Wiltshire et al., 2013). Irrigation is a possible adaptation strategy for agriculture to climate change and population pressure especially in Africa, where the population relying on farming has long surpassed the carrying capacity of many dryland agricultural systems (Kortenhorst et al., 2002; UNDP, 2012).Wiltshire et al., 2013; Maliwichi et al., 2012). Unfortunately, throughout Africa, there are hardly any cases of successful and sustainable farmer-managed smallholder irrigation schemes despite all efforts by different development agencies (World Bank, 2008). Irrigation development and rehabilitation interventions targeted towards the poor in the arid and semi-arid regions of Africa have not yielded expected results and the countries in these regions remain among the most disadvantaged in the world (Darkoh, 1992; Darkoh, 1998; Biggs et al., 2009; Magombeyi et al., 2012; UNDP, 2012). Most of the small-scale irrigation schemes have been associated with poor performance and little sustainability of the investment that seem to be locked in a 'build-neglect-rebuild syndrome', where the established scheme would have a time when they were neglected or non-functional and then get rehabilitated, only to be neglected again latter (Venot et al., 2013).

Small scale irrigation schemes have been prioritised as a rural development model by many developing countries in the past 5 decades, not only because they had higher returns on investment but also because they were found to be adaptable to the local farming systems (World Bank, 2008; Venot et al, 2013). Seventy percent of Zimbabwe's rural population live in Natural Regions III, IV and V where rainfall is erratic and unreliable, making rain-fed agriculture unreliable (FAO, 1997; Poulton et al., 2002). There is a direct positive correlation between Zimbabwe's agro ecological region and the prevalence of poverty in the country as shown in Table 1. (Poulton et al, 2002; Mutambara and Munodawafa, 2014). This correlation suggests that irrigation is the best way of alleviating poverty in the drought prone regions of Zimbabwe. Unfortunately, only 38% of Zimbabwe's smallholder irrigation schemes were functional in 2013, 40% in 2014 and 21% in 2015 (ZimVAC 2013; 2014 &2015).

Table 1. Poverty prevalence in Zimbabwe by agro-ecological zone. (Poulton et al., 2002).

Natural region	Prevalence of Poverty	Prevalence of extreme poverty
I	62.4	36.2
II	71.6	41.2
III	77.3	51.4
IV	81.6	57.2
V	79.5	55.7

In the face of climate change and chronic poverty in developing countries, investment in irrigation agriculture is getting renewed attention from world and regional development bodies (UNCSD, 2012; NEPAD, 2008; UNDP, 2012; WFP, 2010). Yet, the factors that have been affecting the sustainability of irrigation schemes are not well understood (Manzungu & van der Zaag, 1996; Chancellor, 2004).

Although Asia has a lot of literature covering the water supply systems of irrigation scheme and how farmers have been responding to the changing demand in the water supply and how the government, the private sector and the individual farmers have been reforming the water and energy sector connected to the water supply system (Vermillion, 1997; Monari, 2002; Kadigi et al, 2012; *Mukherji*, 2012; Mukherji et al, 2012; Bryan, 2013; Falcon, 2013; Mundra & Garg, 2013), there is limited literature on the water supply system of smallholder irrigation schemes in Zimbabwe (Makurira & Mugumo, 2010). The majority of available literature on the water systems in Zimbabwe focused on the causes and effects of water related disputes and how they were resolved (Mombeshora, 2003; Svubure et al., 2010). As yet, no significantly known research has focused on the entire water supply system of smallholder irrigation schemes. The green fuel/ethanol plant along the Save catchment was the new establishment that was commissioned around 2012 and little has been done to study the downstream effects of such a giant water user on the smallholder irrigation schemes. Although siltation has been studied previously little was done to show the effects of the unprecedented siltation levels especially along the biggest river across Zimbabwe, such as Save River on the production systems of smallholder irrigation scheme (Morton 2013; Ncube, 2013) and how the farmers and other stakeholders have been responding to such problems in the water supply system. Several reports have highlighted on the poor capacity of ZINWA and ZESA with regard to water supply in the urban areas (Svubure & Zawe, 2010; Mapira, 2011) but none of these has focused on the effects of the inefficiencies of these parastatals on the functionality of smallholder irrigation schemes. The water supply system for smallholder irrigation schemes is a dynamic sector and little research has been done to gain an understanding of the water challenges faced by the irrigation schemes in the light of the unprecedented siltation and changes in the water use patterns in Zimbabwe (Morton 2013; Ncube, 2013).

The major objective of the study is to assess the impact of water supply in the sustainability of irrigation schemes in the study area. In order to meet this objective, the study had the following research questions:

- To what extent does the farmers' access to irrigation water affect the sustainability of irrigation schemes in the study area?

-Is the water supply adequate and reliable?

-What is the state of water source and irrigation water delivery system?

-To what extent are the irrigation schemes affected by the upstream competing water uses?

Materials and methods

An integrated research approach involving the use of quantitative and qualitative methods was used in this study. Questionnaire survey, key informant interviews, FGDs (Focus Group Discussions) and observations were employed to allow for triangulation of information. A commitment to inter-disciplinarity is often seen as a necessary precondition for successful sustainability research, connecting people's time use patterns with their spatial and material footprints (Fahy & Rau, 2013).

Eight community small-scale irrigation schemes in the south-eastern low-veld and the Midlands province of Zimbabwe (Tsvovani, Dendere, and Rupangwana in Chiredzi district, Zuvarabuda and Vimbanayi in Chipinge district, Insukamini, Mutorahuku and Mambanjeni in Gweru district) were purposively selected for this study. The targeted irrigation schemes lie within the agro-ecological region V which receives very little rainfall (less than 400mm per year) and very high atmospheric temperatures, making the need for irrigation technology more critical in the area than any other region in Zimbabwe.

A simple random sampling method was used to select participating farmers through a self-weighting system or proportional representation whereby a scheme with more farmers had relatively more respondents that were selected for the questionnaire interview. Random samples were taken by assigning a number to each plot holder and using a random number table to generate the sample list. A total of 316 farmers were interviewed from the 8 irrigation schemes. Key informant interviews were conducted with the following stakeholders; 8 Irrigation Management Committees (IMC), 8 traditional leadership, 4 Agritex officers, 4 Department of Irrigation officers and 2 staff members from the Zimbabwe National Water authority (ZINWA). Eighty one (43 females and 38 males) farmers were interviewed in 8 Focus Group Discussions. Purposive sampling was used to determine the FGD participants. A farmer needed to be a member of the scheme in the 10 years preceding the day of the survey to participate in the FGDs. Field observations were carried out in the targeted irrigation schemes with the guidance of an observation checklist. Observations focused on the functionality of irrigation schemes, structures design system, land utilisation patterns, condition of distribution structures, erosion, siltation of rivers or water sources and canal, weed growth in the canal and on farm, water logging, irrigation practices and the state of perimeter fence.

Data from the questionnaire survey was processed in SPSS and was subjected to both descriptive and advanced statistical analysis. Qualitative data from FGDs and key informant interviews were analysed using the thematic framework analysis approach.

Experimental site layout

Over 77% of the farmers had periods of limited access to water and the differences by name of scheme was shown to be significant using Chi-square test (χ^2=1.027, df=7, p=0.000 with 100% of the farmers in Vimbanayi and Zuvarabuda (Figure 1) reporting that they had periods in the year when they had limited access to irrigation water.

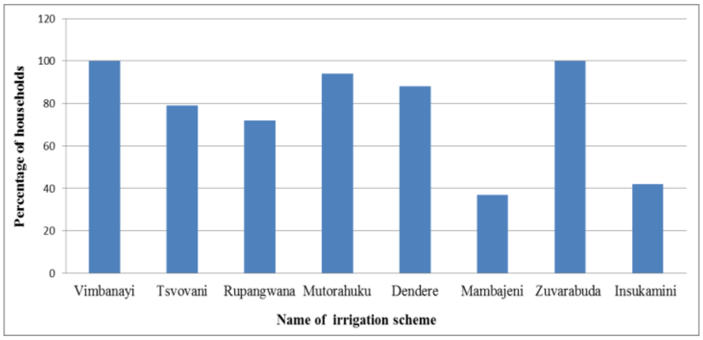

Figure 1. Percentage of farmers experiencing periods of limited access to irrigation water

The challenges farmers faced in accessing irrigation include siltation, selfish upstream users, pump breakdowns, poor water management, poor design of the water supply system and poor water system infrastructure as shown in Table .2. These challenges were discussed in depth in the subsequent section.

Table 2. Percentage of farmers facing water supply challenges in the different schemes

Water supply challenges	Vimbanayi	Tsvovani	Rupangwana	Mutorahuku	Dendere	Mambanjeni	Zuvarabuda	Insuka mini	Total
Siltation of water source	93	85	88	38	94	59	97	0	70
Damage of the delivery canal	0	10	0	85	0	0	0	0	11
Lack of night water storage	17	0	13	0	19	0	0	0	6
Low water level during critical times	42	42	0	59	41	0	61	0	31
Selfish upstream water users	80	83	109	0	94	0	73	0	56
Poor water management	20	75	0	68	13	0	0	5	24
Poor design	8	42	0	0	41	50	24	0	20
Pump breakdown	37	10	0	0	56	100	39	0	29

Siltation

Siltation of the water source was the major reason cited by 70% the respondents for having less water from the water source. All the schemes that had Save River as their water sources had problems of siltation. Field observations made during the survey and during the time when the researcher was working in the low veld of Chipinge and Chiredzi between 2008 and 2013 revealed that the problem of siltation was mainly felt during the dry season between September and December every year. The water would stop flowing; exposing the heaps of sand in the lower parts of Save River with a wide sea of sand platform dissected into tracks of shallow water strips running parallel each other as shown in Figure 2 and 3. According to the farmers interviewed, in Chipinge and Chiredzi, water related conflicts tended to be more prevalent during the dry season as the normal watering schedule became difficult to maintain. One farmer in Rupangwana said; "September to December ndiyo nguva inonetsana vanhu nenyaya yemvura muno. Zuva rinenge richipisa apa mvura yacho inenge yave shoma. Vanhu vanoita kunge vachatemana". (September to December is the time when people fight for water in the scheme as it will be difficult to maintain our normal irrigation schedule due to high temperatures and limited water in the river).

Figure 2. Save River with a small stream navigating through heaps of sand deposits near Rupangwana irrigation scheme

Figure 3. Save River- a week after the onset of rains in November 2014 showing high level of siltation

In Rupangwana, the farmers reported that they would concentrate on 2 blocks during the dry season and get back to their fields when the water situation normalised after the onset of the rainy season. This strategy involved each farmer cultivating less than 0.1 hectare during the period of limited access to water. In Dendere, the night storage was 2500 cubic metres and the 75 hectare scheme was divided into 5 blocks but only 4 blocks were used as the fifth one could not be used due to water shortage. Each farmer was allocated a 0.1 hectare field in each block to make sure that some farmers were not disadvantaged as some blocks were not accessing adequate water. Farmers from Chiredzi and Chipinge felt that the silts that were sucked by the water pump were affecting the normal functionality of the schemes. In Dendere one IMC committee member said, “We started experiencing more frequent pump breakdown the time when we started having a lot of silts on our side of the river and when we took out pump for service, the mechanic said that the sand was damaging the pump’s impeller as it was increasing the pumping load of the pump”. It was also confirmed by farmers in Tsvovani irrigation scheme, that before a new set of pumps was bought, more pump breakdowns were experienced during the dry season when the water discharge was low and sand would be closer to the pumps. Siltation also added the scope of work for the farmers as it required backbreaking scooping. In the case of Tsvovani, the sand that was sucked in by the pumps was deposited in the main delivery canal or the first reservoir and the farmers would scoop both ends, the suction point at the river and from the delivery canals. If allowed to accumulate in the canals, the silts from Save River would not only lead to the siltation of night storage dams but would also reduce the water holding capacity of the delivery canals leading to water spillage. In Zuvarabuda, the farmers had the extra responsibility of diverting the water that was usually prevented from flowing along the Chipinge bank side by the silts so that the water would flow near the suction point of the pump for the scheme. Each time the farmers were irrigating, they would use their shovels to direct the water to their pumping pool, scooping sand in the process. One farmer said; “Tinombobvisa zvedu ivhu nemafoshoro asi ibasa rinoda dozer kuti mvura iuye kuside kwedu, mavhu acho awandisa” (Although we do scooping using our own shovel, the work requires some earth moving machinery like dozers to direct the water to the side of the pump as the mass of sand to be moved is just too much). Farmers for Mutorahuku irrigation scheme reported that the scheme was severely affected by the reduction in the water level as it reduced the pressure needed to allow the syphoning system to suck water from the dam following vandalism of the original system that used to drain water from underneath. Initially, the system was designed in such a manner that an underground pipe would drain water from the bottom of the dam to the delivery canal. In the 2005 drought, the water level for the dam was so low that the whole dam was reduced to a small pool around the suction point. The illegal fish mongers who were taking advantage of the reduced dam water level to fish in the dam blocked the suction pipe to prevent fish from hiding in the pipe. By the time they learnt about the blockage, it was already too late to rectify it as the suction point was at the deepest end of the dam, making it inaccessible. The service of sea divers was needed to remove the stones that closed pipe. However, ZINWA reportedly, could not enlist the service of sea divers due to financial constraints. The farmers were told that sea divers were very expensive to hire. Instead, they inserted a syphonage system (see Figure 4 and 5) that played a similar role but only when the dam level was above 70%. Consequently, the system only works until August every year when the dam level would still be high. The moment the water level fell below 70% full, the reduced volume of water from the dam would not give the needed pressure build-up to force the water to be siphoned through the pipe. The poor water abstraction at Mutorahuku was preventing farmers from growing wheat in winter as the water supply could not irrigate the crop to maturity, considering that the dam would be below 70% full by August every year, when the wheat crop would still be in its late vegetative stage.

Figure 4. Mutorahuku irrigation scheme-showing the gravity powered system from the dam to the irrigation plots

Figure 5. The syphoning system of water abstraction at Mutorahuku dam in Sept. 2014

At Insukamini, farmers get their water from Insukamini Dam through gravity. The dam was constructed across Ngamo River, and was believed to be so big that, even if the catchment of the dam failed to receive any single drop of rain in 5 years, farmers would continue to irrigate in the scheme. Unfortunately, one of the dam's outlet pipes developed a small leak by the end of 2013, which was manageable in the first few days. With time, the leak grew bigger and became unmanageable (See position of the leakage in Figure 6). By the time of the survey, the ZINWA official based on the site indicated that the water that was coming out of the leaking pipe was more than what the farmers were using in the irrigation scheme.

Figure 6. Insukamini leaking dam wall

The farmers' fear was that, at that rate of water loss, the water in the dam would be finished before their crops reached maturity stage during the last week of November 2014. Unfortunately, ZINWA was taking time to rectify the problem, to tame the unaccounted for water losses and the ever increasing pipe leak which the ZINWA official based at the dam and the farmers believed could threaten the dam wall. As was the case with Mutorahuku, sea divers were needed to search for the rod that was used to close the gate valve located at the deepest inner side of the dam. It was a very dangerous spot and only sea divers could assist. Farmers were told that ZINWA had no money to enlist the service of sea divers. Since the leaking started, engineers from ZINWA never visited the site to weigh different options of solving the problem or to share with the farmers what they should brace for in the face of the new challenge. Farmers were never made aware of the estimated cost of hiring sea divers. For farmers who have been paying their water bills for almost 2 decades, they could not understand why ZINWA was failing to secure money to stop the leaking dam. This possibly explains why 74% of the farmers felt ZINWA's service was poor. Investigations by the researcher on the cost and procedure of getting the sea divers further exposed ZINWA's appalling lack of service delivery culture and commitment. The sea divers were found at the Police's Sub Aqua unit based at the Zimbabwe Republic Police Morris Depot in Harare. One needs to pay US$500 consultation fee and pay their subsistence allowance of $100 per day for every member of the team, which for a team of 5 divers could cost $500 per day. If the job takes 2 days, the service requester would just pay the subsistence allowance for the divers, giving a cumulative total of $1500. ZINWA's claim that they could not afford the service of the sea divers raised 2 issues. One being that they never bothered to inquire about the cost in the first place as it was cheaper than the syphoning system they introduced at Mutorahuku. The other issue is that ZINWA was so detached from the problems of the farmers that they never bothered to weigh the cost and benefits of the new system at Mutorahuku.

Competition with upstream water users

The Save River siltation, causing water shortage in smallholder irrigation scheme on the lower Save catchment during the period between August and December, was exacerbated by the fact that Macdom Sugar Estate, which feed into the Chisumbanje Ethanol plant usually block the whole river during the same period, to create a dam around their pump house (See picture in Figure 7 and 8). The water would only escape the barricades as seepage underneath the sand. The blocking of the whole river was done at the expense of the smallholder community irrigation schemes downstream at a time when the temperatures would be very high and the need for irrigation would be very critical in the schemes. Farmers in all the schemes expressed that reduced water discharge became more serious from the time Macdom resumed agricultural operations in 2009.

Figure 7. The Save River blocked to create a pool around the Macdom pump house

Figure 8. The Save River completely blocked at the Macdom pump house a week after the onset of the rainy season in November 2014

What disappointed farmers most about the water sharing violation by Macdom was the fact that ZINWA was not doing anything about the monopolisation of Macdom over the river water, although they had water permits allowing them to access water freely from the Save River. ZINWA had assured them access to irrigation water throughout the year even during the years of drought as ZINWA would open water from Osborne Dam in the upper Save Catchment. Contrary to their expectations, the water permits were not adding any value as they did not experience any improvement in water access after obtaining the water permits and paying up their water bills. Although several complaints were sent to ZINWA over this mal-practice by Macdom, nothing was done. The failure by ZINWA to enforce such a critical section of the Water Act, in the eyes of the smallholder farmers, showed that it could not support its founding principles. After failing to act decisively on Macdom to share the water equitably, ZINWA was pressing harder on the smallholder farmers to pay their monthly water bills, yet the farmers would have struggled through scooping to access the water. One farmer in Rupangwana said;

"Iyo mvura yatinenge tatambudzikira tichibvisira mavhu, ndiyo yavanouyira pano kuti pengera kuti tibhadhare. Apa vanorega ve Macdom vachitora mvura yese, dei vachichi piwa mari yacho ne Macdom yacho iyoyo" (we struggle to get our water through scooping and ZINWA comes hard on us to pay for the very water that we struggled to get. If they give priority to Macdom, why don't they get all the money from Macdom?).

Poor infield water management practices

Poor infield water management in the schemes was threatening their sustainability. For schemes like Insukamini, farmers started experiencing water shortages when the government extended the scheme using funds from the European Union. The extension of the scheme was done without the consultation of the farmers which in turn reinforced the farmers' perception that the scheme belonged to the Government. It was also done without due consideration of the water supply needs especially the enlargement of the main delivery canal from Insukamini dam. In Tsvovani, the in-field earth canals were in poor working conditions causing a lot of the pumped water to be wasted before getting into the field. The scheme was operating on earth canals since 1984, which were initially rammed but the canals were no longer in good shape. Some parts of the canal system had become so shallow, due to the accumulation of sediments, that the water could no longer take one direction causing leakages all over. Some parts were engulfed by grass that was curtailing the smooth movement of water as shown in Figure 9.

Figure 9. Shallow and grass choked canals at Tsvovani irrigation scheme

Consequently, some fields in the south eastern part of the scheme were failing to access water at all while water was taking a very long time to reach other parts, which challenged the water sharing system amongst the farmers. The poor state of earth canals was therefore causing water logging on some parts of the plots while other parts were completely dry. The farmers were not able to upgrade the earth canals into concrete canals as they were heavily saddled by water and electricity bills. Only those farmers whose plots were being affected by the siltation of the earth canal felt the urgency of repairing or clearing the canal while those served with concrete canals were not worried about the problem. However, the poor flow of water was affecting every farmer, as it was contributing to high electricity bills to the scheme. In Vimbanayi and Mutorahuku, field observations indicated that the embankments of the canals were so heavily eroded that it was a matter of time before they could collapse as shown in Figure 10. Some of the eroded canals had already started leaking. This level of neglect of the critical infrastructure in the schemes raised questions on the commitment of the farmers to the irrigation schemes. The filling of embankments did not require any special resource but importation of sand from one part of the scheme or just outside the scheme to the canal bank using wheelbarrows or buckets.

Figure 10. Eroded canal embankments in Vimbanayi and Mutorahuku schemes

Inability to pump during the rainy season

The researcher' experience along the lower Save river and farmers' reports confirmed that, in a normal or above normal rainy season, the Save River would be flooded from late December up to February. Because their plinths for the pumps were built on the river bank (Figure 11), they would be completely covered by water. In order to save the pump, farmers in Vimbanayi and Zuvarabuda would remove the pump and keep it outside the water until the floods subsided to safe levels.

Figure 11. Pump plinth for Vimbanayi & Zuvarabuda constructed near the river bank

The pumping unit at Zuvarabuda and Vimbanayi were mounted on wheels to allow the farmers to drag the pump off the river before the pump was inundated with the floods. This was an effective way of protecting the pump from the floods but the process was not thought through to cater for irrigation needs during flood times. Reportedly, the flooding of Save River was highly unpredictable because the water that floods this part of the river usually come from the high rainfall receiving areas on the upper course of the Save river. The floods usually happen when the area, being a low rainfall area, would be completely dry and their crops in the scheme are in critical need for water. Farmers indicated that if they were consulted by the engineer on the maximum extent of the flood under normal and extreme flood conditions, they would have helped to site the plinth using their local knowledge about the flooding pattern of the river. Considering that these schemes would have experienced water shortages between September and December due to the combination of siltation and the poor water sharing system with Macdom Sugarcane Estate, the farmers in these two schemes would only be left with 6 months or two cropping cycle of effective irrigation of their plots. Considering the poor level of productivity of the schemes, these two cropping cycles could do little to leverage the continued existence of the scheme in the face of high electricity and water bills. In Mambanjeni, the pump house was constructed near the bank of the Gweru river (see Figure 12) which usually got inundated with water every year and the farmers indicated that if they were involved in the siting of the pump house, they would have helped to avoid this design error to save the pump as all community members were aware of the extent of the flood of the river in a normal rain season.

Figure 12 Plinth and pump house at Mambanjeni built on the river bank

Pump breakdown

Pump breakdown was a major problem in the history of all the pumped schemes although their severity differed across the schemes in the 10 years preceding the survey. Vimbanayi and Zuvarabuda had almost similar experiences in pump breakdowns and how the problems were fixed. Their pumps were washed away by the cyclone and flood of the year 2000 and they were only fixed between 2008 and 2010 by Mercy Corps (NGO). At the time of the survey, moderate pump breakdowns were reported in Dendere, Vimbanayi and Zuvarabuda and Rupangwana. Tsvovani had never experienced any breakdown since the pump was fixed in 2009 by an NGO called Parsel while Mambanjeni was under breakdown by the time of the survey. For Dendere, the long history of breakdowns (since 1997) and how the farmers tried to fix the problem on their own explained how the number of farmers was reduced from 90 to around 50. In Dendere, farmers who participated in the FGDs recounted farmers' participation in the establishment and rehabilitation of the scheme which made them more committed to their scheme than the other schemes. During the year when they were handed over the scheme by of RED Barna (an NGO that helped to establish the scheme), they experienced a pump break down. The farmers had to contribute US$500 for the repair of the pump and those who failed to contribute towards the repair of the pump lost their membership to the scheme. This saw the scheme membership dropping from 96 farmers to 54 farmers. After frequent breakdowns, farmers resolved to buy two new sets of pumps in 2007, with each farmer contributing 100 Rands. The membership shrunk further to the current number of 38 farmers in 2007 after the other members failed to raise the 100 Rands needed for the replacement of the old pumps. The plots sizes were originally 0.18ha but had since increased to at least 0.4ha. In Tsvovani, the sand abstraction pumping system that was damaged by the cyclone and floods in 2000 was never repaired. What was left of it got vandalised during the 7 years of disrepair (between 2002 and 2009), to the extent that by the time of the survey, there was nothing left but a few remnants dumped outside the pump house as shown in Figure 13. In Rupangwana, when the sand abstraction system was damaged, ZINWA as the hitherto custodian of the pumps collected the pumps and its accessories for repair in Mutare in 2003. They never returned the pump. Reports of water pumps being taken away from the schemes by ZINWA or ZINWA related officials were not uncommon in schemes previously run by ZINWA. At St Joseph Irrigation scheme 20km from Dendere along Save River, the Chiredzi side, farmers lost their pumps under similar circumstances in 2004. In Rupangwna, a robust pump was allegedly stolen by ZINWA officials during the time when the Department of Water was transitioning to ZINWA.

Figure 13 Part of the remains of the sand abstraction system equipment at Tsvovani

Challenges in pump repair

All the 8 schemes had no member in their respective schemes that could repair pumps in case of breakdown, and mechanics for the repairs were only found in the towns of Chiredzi, Gweru, Bulawayo and Harare. The spare parts were either obtainable in Chiredzi or in Harare (about 600 kilometres away). The long distances travelled made these spare parts very expensive due to transport costs and the time to travel also increased the down-time periods of the pumps.

Only 31% of the farmers reported that they were contributing towards pump repair (Figure 14). The difference by sex of the number of farmers who were contributing towards pump repair was not statistically significant (χ^2=0.122, df=1, p=0.727).

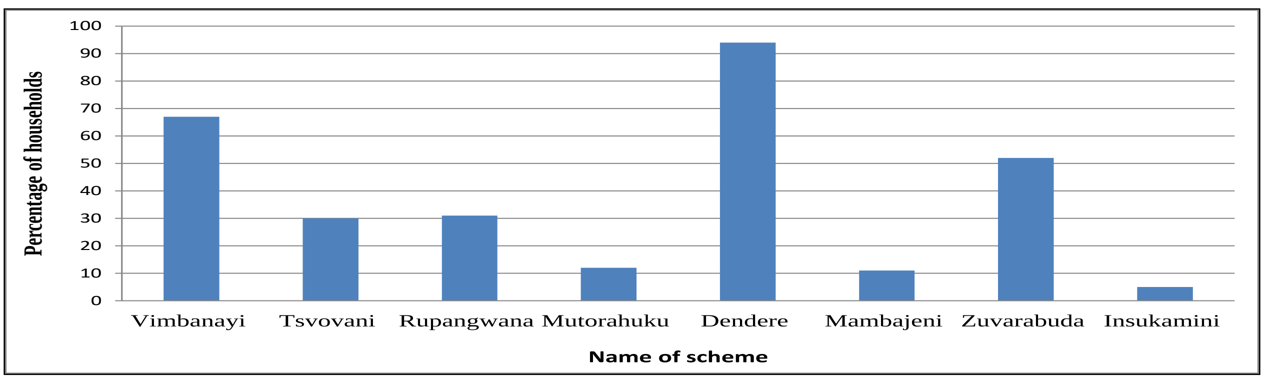

Figure 14 Percentage of farmers contributing towards pump repairs

The only reason farmers gave for not contributing towards repair was lack of money due to poor productivity levels. Sugar bean was the major cash crop for the scheme and the revenue received from the quantity of beans sold was regressed against the amount contributed towards pump repairs. Those producing more beans in the schemes were contributing more towards repairs as the regression analysis shows a positive linear relationship between the quantities of beans sold and the amount contributed towards pump repair R^2 = . 0.304, F=137.13 = 42.64, p < .001. The Pearson's correlation also show that there was a strong positive correlation between the quantities of sugar beans sold and amount contributed towards scheme repairs (r = .0.55, df=1 p =.001). This finding suggests that those who were selling more had a greater incentive to contribute towards pump repair than who were selling less. The Chi square tests revealed that there was a significant difference between farmers with different ownership perception of their irrigation schemes and the amount they were contributing towards scheme repair (χ^2= 217.22, df=1, p=0.000). Those who felt did not own the irrigation plot were contributing less money towards repairs, suggesting that, insecure land tenure was removing the incentive to contribute towards repairs of the scheme. It was also observed in the field that some of the pumps in the smallholder irrigations had outlived their design life and had became obsolete. Interviews with Department of Irrigation (DOI) officials hinted that if the farmers were made to invest in the replacement of these pumps in the preceding 2 decades, farmers could have bought new pumps on their own to replace old ones, instead of relying on Government or NGOs. Owing to the fact that the companies that used to deal in water pumps had closed down in the face of hyper-inflation and the country's economic melt-down, the DOI officials said that they were assisting individual farmers in buying new water pumps from South Africa where they were much cheaper than in Zimbabwe. For example officials from the DOI revealed that, whereas big pumps cost US$9000 in South Africa they cost between US$16000 and US$20000 in Zimbabwe. Unfortunately, it was also reported by DOI officials that these irrigation equipment (including irrigation pipes and drip lines) were still attracting import duty and taxes at borders making these critical equipment very expensive and unaffordable for most of the smallholder farmers in Zimbabwe.

Poor service provision by ZINWA

All the 8 irrigation schemes had water permits although they reported that their level of engagement with ZINWA was not adding any value to their operations as it was not translating into improved access to water. The service ZINWA was offering was rated poor by 70% of the farmers (Figure 15) and the difference in the farmers' rating across the 8 schemes was found to be statistically significant (χ^2=1.174, df=21, p=0.000). Mambanjeni had the highest proportion of farmers (91%) who rated the service poor, while Mutorahuku had the lowest proportion of farmers (26%) who rated ZINWA services poor. There was a significant difference on the amount contributed toward water bill and among farmers with different perceptions about the ZINWA service (χ^2=162.48, df =9, p=0.000) with those who rated it poor having the highest proportion of farmers who were not contributing anything towards water bills.

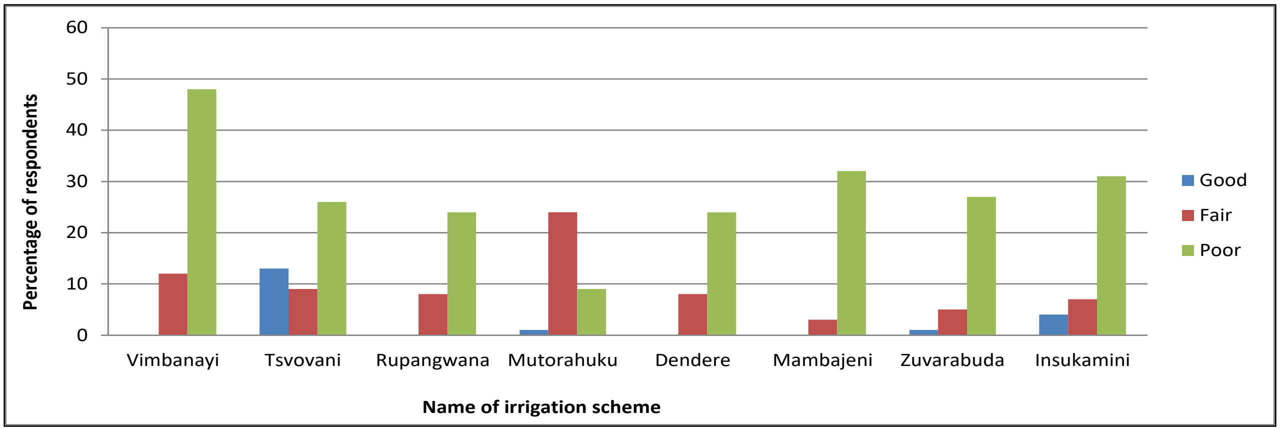

Figure 15 Farmers' rating of ZINWA service

This pattern suggests that farmers were resisting payment towards water bill due to poor service. Key informant interviews with officials from ZINWA confirmed that the organisation was getting resistance from farmers. One engineer from the Save catchment revealed that ZINWA was owed over US$35 million dollars by irrigating farmers across the country excluding those farmers who were irrigating illegally without the water permits. Farmers across the 8 schemes reported that they were no longer committed to clear off their arrears with ZINWA but were just paying enough money to prevent them from getting disconnected to water supply as they were not satisfied with the service from ZINWA.

Unjustified water charges

Farmers across the 8 schemes could not understand why they were compelled to pay for water irrigation from rivers and dam when there was no materiality in the service being offered by ZINWA. Unlike the farmers in Gweru district where ZINWA was actively involved in pump repair (at Mambanjeni), managing and running the gravity powered water system at Insukamini and Mutorahuku, farmers in Chiredzi and Chipinge could not understand why they were asked to pay ZINWA. They were extracting their water from the Save River and felt there was no apparent value addition in the involvement of ZINWA in their water supply system. One farmer from Zuvarabuda said; "Ndinorwadziwa ne ZINWA, Mari yatinobhadhara ndeyei" (I am particularly pained by the money that we pay to ZINWA, what is it for?). The farmers that participated in the FGDs confirmed that they were not getting any service from ZINWA. They felt ZINWA's work was merely travelling to the scheme to collect their money every month and to disconnect the water supply if farmers failed to pay. If asked to attend to a pump breakdown or for any technical assistance, ZINWA would, according to the interviewed farmers, charge the farmer for both the mileage and for the repairs, making their service more expensive than that of private mechanics in Chiredzi. The justification that farmers were given by ZINWA for paying for water was that it was their legal obligation by virtue of The Water Act and The ZINWA Act as bulk users of water. Failure of which could attract a fine or imprisonment. The Water Act (Chapter 20:24), Sections 34 and 39, and The ZINWA Act (Chapter 20:25) Section 30, made it clear that anyone using water for commercial purposes should do so in terms of a permit issued by the relevant Catchment Council or an agreement entered into with ZINWA, and should pay (ZINWA, 2014).

The justification given by ZINWA officials was that the government had invested in dams and was set to recover some money from the investment in keeping with the 'User Pays Principle'. The Government was also expecting ZINWA to be independent in covering some of its running cost and not to depend on the fiscus. Also the dams from which some of the schemes were getting their water were managed by ZINWA and the operational costs and personnel costs attached to it had to be paid by the users as the Government was incrementally failing to cushion ZINWA.

Overcharging of farmers by ZINWA

Although the ZINWA Act requires that irrigating farmers have meters or other measuring devices at their points of abstraction for both billing and statistical reasons, none of the 8 schemes had meters to quantify the water used and charged for by each. The bill was therefore based on the projected water use per hectare and the pumping capacity of the pumps. For schemes like Dendere where the pumps were mal-functional, farmers felt these estimates were not a true reflection of the water consumption of the schemes. Also, crops at different stages of growth have different water requirements and the use of estimates was not smart enough to reflect such fluctuations in water demand. When the Save River was flooded and during times when farmers used less water due to low river discharge, ZINWA would continue to charge the same flat rate. That partly explains why farmers felt the ZINWA billing system was not fair.

In Insukamini, it was reported that ZINWA overcharged farmers during the early days of the introduction of multiple currencies in 2011/2012. The error emanated from the use of a much bigger hectarage than what the farmers were cultivating. By the time of the survey, Insukamini farmers owed ZINWA US$10 000. All the farmers were paying between US200 and US$400 per month towards the water bill. The error was never rectified and the farmers were struggling to service the debt with their own production. Farmers consulted the ZINWA office to get clarification over bills but no feedback was obtained. Each time they visited ZINWA they would meet a different person who knew nothing about previous reports on the matter. The catchment staff, based in Bulawayo (over 200 kilometres away), never visited farmers to talk about their problems and the person they usually met was the official responsible for collection of monthly payments towards the bill and who, when asked about the problem, always said; "ini ndavinga mari handina hurukuru, kana muchida hurukuru endai kwaBulawayo" (I have just come to collect money and if you have queries regarding the bill you should visit the catchment office in Bulawayo).

Political interference

ZINWA officials indicated that the institution's operations in dealing with all categories of farmers were affected by political interference. Without necessarily referring to smallholder farmers, they indicated that defaulters of payments for water permits were usually protected against disconnection by politicians, with indications that although they use disconnection as a strategy to force farmers to pay, an order by a politician to stop the process usually frustrates the efforts. They also highlighted that most ministers and high-ranking officials owed ZINWA millions of dollars and the institution could not do anything to them. The zenith of political interference was demonstrated in July 2013 when the Government ordered ZINWA and ZESA to cancel all the debts owed by rural and urban residents.

Rigidities in operations of ZINWA

ZINWA was using catchment boundaries rather than the political boundaries respected by other institutions. For some water users, this system of defining jurisdictional areas was proving to be very costly as that would entail travelling very long distances to get a service that could be offered by the same organisation closer by, but belonging to a different catchment. For example, although closer to the Sanyati catchment (20 kilometres in Gweru), Mambanjeni and Insukamini Irrigation schemes were working with ZINWA Gwayi Catchment with offices Bulawayo in Bulawayo, over 200 kilometres away. Such rigid adherence to catchment boundaries was expensive to both the farmers and ZINWA itself and one would wonder why ZINWA could not make a discretional decision to allow users closer to a ZINWA office to use it even if it did not belong to that catchment. That possibly explains why Mambanjeni had the highest proportion of farmers who rated the service of ZINWA as poor. Mutorahuku is in the same district as Mambanjeni which was serviced by the Sanyati catchment in Gweru and had the lowest proportion of farmers who felt ZINWA's service was poor. ZINWA officials reported that the underlying factors against non-payment of water rates was that the farmers were still not self-sufficient and were not operating as commercial farmers but as communal subsistence farmers. One ZINWA official said; "We have fewer problems in servicing estates like Ratings and Macdom sugar estates that feed into the green fuel Ethanol plant at Chisumbanje in Chipinge, than smallholder irrigation schemes. Therefore, the solution for the low production levels and non-payment of rate lies in the commercialization of the schemes".

One ZINWA official from Manicaland Province revealed that Matanuska Banana company was sub-contracting farmers in Tanganda irrigation schemes to grow bananas under contract farming arrangements. It was working very well. It guaranteed farmers with a steady flow of income and the private company was also benefiting from the arrangement. With the land reforms and the fluidity of the land ownership structure in Zimbabwe, the former white commercial farmers in the farming industry survive better by partnering with the smallholder farmers under such arrangements like contract farming. ZINWA's experience with farmers under such partnership revealed that they were paying their water rates more consistently without any serious follow ups than those who were not under contract farming.

Results and discussion

All the irrigation schemes along the Save River were threatened by siltation which was preventing water from flowing on the surface between September and November every year. Farmers had to scoop the sand around the pump suction point to create a pool from which to access irrigation water. In Zimbabwe research has focused on the causes of siltation with Morton (2013) and Ncube (2013) highlighting how illegal mining by gold panners and Chinese mining companies in Matabeleland South were causing siltation of Insiza River and Umzingwane River. Siltation has reduced water holding capacity of Insiza, Inyankuni Lower Ncema Umzingwane and Upper by also most 40% due to rampant siltation (Morton, 2013; Ncube, 2013). In 5 out of the 8 irrigation schemes siltation was shown to be restricting the quantities of water available for irrigation and the scooping of sand was over burdening the already over-burdened farmers. The farmers' experience were similar to what farmers in Koraro village in Ethiopia have been experiencing since 2000, when the rivers' surface flow became seasonal due to both high siltation level and reduced rainfall, forcing farmers to scoop sand or digging holes in the dry riverbed (Ngigi, 2014). It can be deduced from the effects of siltation in the irrigation schemes that the future generation will not enjoy the same access to water as the current generation due to poor land use and mining practices with the catchment areas of the respective water source. In keeping with the concept of natural stock of capital that underpins sustainable development, sustainability of irrigation schemes can only be ascertained if the natural capital/stock, (water resource) remained intact, suggesting that their future will remain hopeless in the face of the unprecedented siltation. The WCED (1987) states that sustainable development happen when exploitation of resources, the direction of investments and institutional change are all in harmony and enhance the potential to meet the current and future human needs and aspiration. Farmers who participated in this study linked the siltation of water bodies to the economic hardships affecting the country as people began turning to gold panning in large numbers in the early 1990s when the country was hit by poor harvests due to droughts and high level of unemployment following the country's Economic Structural Adjustment Programme (ESAP) and its economic meltdown in the 10 years preceding 2009. The link between Zimbabwe' economic meltdown and siltation of rivers was consistent with the SLF understanding of the non-linearity nature of factors that affect livelihood strategies and the SLF assertion that sustainability was constrained by the environment of structures and processes (Davies, 1997). The 2010 report on climate change attributed the change in water discharge to low average rainfall and high evapotranspiration rate from the ever increasing high temperatures (IPCC, 2014). The problem of siltation in the irrigation schemes along Save River was exacerbated by the inequitable water uses between the upstream giant sugar plantation and the smallholder irrigation schemes in the downstream as the plantation would completely block river to create a big pool around their pumps at the expense of the smallholder farmers. ZINWA's failure to effect an equitable water sharing mechanism among the different farmers did not only compromise the sustainability of the irrigation schemes as it did not only affect the cropping cycles of the schemes but also the willingness of the farmers to contribute towards water bills which in turn was critical to sustainable of ZINWA as the organisation relied on what the farmers were paying to finance its operation. The concept of equity that underpins the concept of sustainable development was premised on the realisation that the unjust society or practices are unlikely to be sustainable in environment or economic terms in the long run (Agyeman et al., 2002). In trying to explain the poor state of irrigation farming in Sub Saharan Africa, Barker & Molle, (2004) indicated that there has been a serious lag in the development of appropriate institutions to deal with the equitable allocation of water among competing users and strategically integrate the management of different stakeholders to satisfy the different needs of smallholder farmers. The research study found out that in almost all irrigation schemes ZINWA could not respond to pump breakdowns, failed to avail sufficient quantities of irrigation water throughout the year yet it continued to levy farmers consistently even during the months when farmers had limited access to irrigation water and its officials were reportedly stealing from the irrigation schemes. Farmers also blamed ZINWA for failing to fix the gravity powered water extraction system that was vandalised by fish mongers at Mutorahuku dam and for failing to attend to the leaking Insukamini dam. The institution was also blamed for running a rigid service regime at the expense of the poor farmers. The concept of sustainable development calls for the identification and removal of such accumulated rigidities and impediments as well as the enhancement of the lost renewal capacities in institution to enhance sustainable development (Rigby & Caceres, 2001). The weak response to water breakdowns was contrary to the experiences of farmers in most Asian countries where, when a dam appeared to be leaking, the operating authority was usually under enormous pressure to repair the leak to save farmers from losses and the lives of the people in the downstream (Moore, 2011; International Atomic Energy Agency, 2014).

The fact that farmers were not happy with the service they were getting from ZINWA and yet were compelled to pay and, at times, short-changed, and also lacked the capacity to engage ZINWA and other related stakeholders such as Macdom to hold them accountable, mirrored the problems of insecure water rights which were reported in Philippines, Turkey, Mexico, Colombia and Argentina during the 1980s. The problems in these countries were attributed to farmers' lack of capacity and mechanisms for reliable legal and technical support services and for lobbying in governmental water policy forums (Moigne and Easter, 1992). It can be deduced from the above discussion that ZINWA failed to embrace the basic tenet of sustainable development, the concept of intra-generational equity (fairness in allocation of resources between competing interests), to enhance sustainability of both their business and that of the smallholder farmer (Agyeman et al., 2002). Contrary to the experiences in these schemes, it was revealed that Chile had an effective law enforcement mechanism that protected users from detrimental third party effects, part of which was an independent judiciary system that was monitoring water sharing among different users and reprimanding inefficient water authorities (Moigne and Easter, 1992). The current research discovered that the absence of this link between payment and performance possibly explains why 7 out of the 8 schemes had outstanding ZINWA bills. Although there was no known research in Zimbabwe on the link between performance of service provision and farmers' willingness to pay utility bill, a number of researches in Asia predicted a high defaulting rate on water bill where farmers lacked the incentive to pay due to lack of a sustainable link between payment and performance (Barker and Molle, 2004; World Bank, 2008; Kadigi at al., 2012). In Morocco, increased water charges have been accompanied by improved service, hence greater willingness to pay on the part of the farmers (Kadigi at al., 2012). It was also revealed that the farmers were not taking proactive measures in maintaining proper infield water management practices like maintaining infield canals in good working condition although the activity did not require any monetary commitments. Good stewardship of limited resources, ability to maintain wellness of infrastructure and ability to take responsibility and ownership enhances the sustainability potential of interventions (Grant, 2010). Poor production levels were also shown as the major threat to the sustainability of the smallholder irrigation schemes as there was a correlation between high levels production and demonstrated willingness to contribute towards electricity and water bills. This correlation attests to the inter-linkages of different systems connected to smallholder irrigation scheme as the production system affected the water supply system which in turn was affected by the input, output and financial markets as well as the effectiveness of the IMC and quality of institutional service delivery.

It was revealed that ZINWA was riding on the law to bill and to enforce payment by farmers, yet its engagement with farmers lacked materiality. The concept of social sustainability, inclusion and participation of multiple perspectives, hinted that for development initiatives and engagements to be sustainable, they need not be prescribed by law but that all players and agents must contribute to it and derive value from it (Phuhlisani Solutions, 2009; Rogers et al. 2013). The way the smallholder farmers across the 8 irrigation schemes were enduring the poor services from ZINWA confirms SLA's assertion that the main problems the poor farmers face is that the processes and structures which frame their livelihood strategies may constrain them unless the state adopts pro-poor policies (Carney 2012). The sustainable development concept, as a discourse of ethics advocated for sustainable ways of doing business by organisations and governments (Jabareen, 2012). Therefore, the failure by ZINWA to professionally deliver some value into their service to the farmers predicted unsustainability, not only of the smallholder irrigation schemes but also of their business with and cash-inflows from the farmers.

Researches in Latin America confirmed similar inefficiencies with parastatals for several decades, where the providers of water and electricity were so poor that their services were deteriorating by the day and the poor farmers suffered most (Ferrand et al, 2004). Unlike the case with Zimbabwe where the water and electricity service provision has remained in the hands of parastatals, the provision of these services in Latin America, were handed over to private companies following some dramatic reforms, resulting in improved water and electricity supply to the poor smallholder farmers (Ferrand et al, 2004). The sand abstraction water pumping systems that could have guaranteed continuous water pumping was not given priority by the development agencies that developed and rehabilitated irrigation schemes along the Save River. In the eyes the unprecedented siltation, the water supply systems of the smallholder irrigation schemes would not be resilient to the increasing siltation of the Save river. The fact that the irrigation schemes were affected by floods and reduced river discharge was also a strong indicator of the fact that climate change adaptation was not streamlined in the rehabilitation of the irrigation schemes (Downing et al., 1994; Brown, & Lall, 2006; Brown, 2012). The failure by Engineers to consult locals in the siting of the pump plinth affirms the sustainable development concept of eco-form which asserts that sustainability can only be achieved where planning was done at the local level involving the intended beneficiaries (Grant, 2010). It is only through high level of local community participation that intended beneficiaries share ideas and use their indigenous knowledge to sustain their own projects such as the community irrigation scheme (Carney, 2005; Ofosu, 2011; Nyong et al., 2013). Ostrom (1994), in her study of the community smallholder irrigation schemes in Asia concluded that where community members were actively involved and the traditional management system embraced, most of the schemes were free from threat of inundation and flooding.

Conclusion

Unprecedented siltation of water bodies compounded with inequitable water sharing and poor catchment management were conspiring to frustrate the sustainability of smallholder irrigation schemes yet interventions in the schemes were not prioritizing sand abstraction water pumping system. The Zimbabwe National Water Authority (ZINWA) as the water governing body proved to be inefficient and its engagement of farmers as its major client was very poor. Farmers could not understand why they were compelled to pay water bills to ZINWA as they could not find the link between the water charges and the quality of the service they were getting. A combination of farmers' low productivity levels, debilitating dependency syndrome, ZINWA's poor service culture and political interference in water governance was affecting farmers' ability and willingness to contribute towards water bills. There was poor in-field water management and some schemes were poorly designed as there was no consultation of the local people on the designing of the pumping systems. The majority of the schemes were incurring frequent pump breakdowns and farmers had no reserved funds for pump repair and replacement investment.

Recommendations

- Smallholder irrigation schemes need to invest in sand abstraction water pumping system to adapt to the unprecedented levels of siltation in Save river.
- The Government need to improve the service culture of the water governing bodies and each irrigation scheme should have a replacement investment fund to allow for continuity of operations in irrigation schemes without reliance on external aid.
- ZINWA should work hand in hand with the Environmental Management Agency to reduce river siltation by curbing gold panning along river catchments and stream-bank cultivation. It should also invest in ways of de-silting water bodies or sand abstraction methods of abstracting water.

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MANAGEMENT PRACTICES USING OF AGRICULTURAL DRAINAGE WATER WITH DRIP IRRIGATION FOR CROP PRODUCTION AND LANDS SUSTAINABILITY IN ARID AND SEMI-ARID AREAS

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Abstract

In addition to lack of water, other elements such as high temperature, severe salinity of soil and water quality create problems in arid and semi-arid areas. Nowadays restricted water resources having acceptable quality has resulted into the reuse of low quality water such as agricultural drainage water in these areas. The use of drainage water and saline water in agriculture requires different management practices on the farm, such as increasing the efficiency of water use, leaching and soil desalinization, in addition to proper drainage and other conventional methods. High efficiency Irrigation methods with such as drip irrigation are suitable solutions for the optimal use of these resources. This study was carried out to investigate the effects of drip irrigation management strategies using saline water on corn crop in the research farm of the Water Science Engineering faculty at Ahwaz, Shahid Chamran University. The experiment was performed on split plots based on a randomized complete block design. In this research the effects of three irrigation management options; that is mixing (M1), one-alternate mixing (M2) and half-alternate mixing(M3) of three levels of saline water (S2, S3 and S4) with the Karun river water (S1), and the reviewing of its effects on yield, irrigation water productivity of corn and soil salinity was investigated. Irrigation management strategies and salinity were the main factor and sub-factors. Salinity levels of S2, S3, and S4 were 4, 6 and 8 dS/m respectively. Results showed that the effects of management and salinity and their interaction on yield and water productivity were significant at levels of 5 percent. The application of the half-alternate (M3) method improved yield indexes, water productivity and the leaching of soil surface layers. The Model coefficients of yield- salinity were calculated under different management scenarios of drip irrigation. The yield reduction per unit increase in soil salinity in the plant root zone the mixing, one-alternate and half-alternate management strategies were calculated respectively as being at 9.86, 12.3 and 7.14 percent. The results of this research show that drip irrigation when applied with proper management is a safe method to reuse large amounts of drainages water volumes in arid and semi-arid regions.

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KEY WORDS: Water quality, Drainage water, Water reuse, Drip irrigation.

Introduction

In addition to the shortage of water, high temperature, severe salinity of the soil create problems in arid and semi-arid areas. Nowadays, drip irrigation can overcome particularly any environmental limitations for sustainable crop production. The Increasing water use efficiency in modern irrigation systems and the use of unconventional water resources such as saline and brackish water are the most effective strategies for optimal use of water resources in agriculture. In this regards, nowadays drip irrigation using saline water has been considered for various crops in many parts of the world (Wan et al., 2012; Wan et al., 2013). The studies show that drip irrigation can distribute water uniformly, and control the amount of water used precisely, moreover it aids in increasing plant yields, reducing evapotranspiration and percolation, and decreasing the dangers of soil degradation and salinity (Karlberg and Frits, 2004). Growth retardation is the most important response of plants to soil salinity. With an increasing solute concentration to more than the root threshold of the plant, the growth rate and plant size declines. Irrigation methods can affect the plant response to salinity. Drip irrigation, with its characteristic low rate of water usage and highly frequent irrigation applications over a long period of time, can retrain a high soil matric potential in the root zone thus compensating the decrease of osmotic potential introduced by the saline water irrigation regimen, and the constant high total water potential that is maintained for crop growth. At the same time, well-aerated conditions can be maintained under drip irrigation. Hanson et al. (2010), stated that the only way to solve the problem of soil salinity and drainage in California is the improving of irrigation methods such as the use of drip irrigation. Kang et al. (2010), studied the effects of drip irrigation with saline water on maize yield. Results indicate that irrigation water with a salinity <10.9 dS/m did not affect the growth of maize. As the salinity of irrigation water increases, seedling biomass, plant height, fresh and dry weight of maize decreases. The decreasing rate of the yield for every 1 dS/m increase in salinity of irrigation water was about 0.4–3.3%. Irrigation water use efficiency (IWUE) increased with the increase in the salinity of irrigation water when salinity was <10.9 dS/m. Wan et al. (2012), tested the feasibility of growing maize in a highly saline wasteland with drip irrigation. The results showed that drip irrigation created favorable soil conditions for maize growth through the forming and maintaining of a high moisture and low salinity region in the root zone when the SMP(soil matric potential) was maintained higher than −25 kPa. This research suggests that drip irrigation can be successfully used in dry and highly saline conditions after appropriate management strategies are adopted; therefore, Drip irrigation has been regarded as the most advantageous method for applying saline water to crops when proper management strategies are used. The irrigation water can be used in a mixture of saline water with fresh water (mixing) or saline water which can be applied in cycles with fresh water (alternative). The selection of an applicable strategy depends on many factors such as water salinity levels, availability of water with different qualities, the relative tolerance of the various crops at different stages of growth, soil properties and the cost-benefit analysis of each strategy. Malash et al.(2005), The effect of two water management strategies i.e. alternate and mixed supply of fresh and saline water in six ratios applied through drip and furrow method on tomato yield and growth, and salt concentration in the root zone were investigated in Egypt. The highest yield obtained was due to the combination of drip system and mixed management practice using a ratio of 60% fresh water with 40% saline water. Abdel Gawad et al. (2005), In order to assess the effects of management on crop production with saline irrigation water, many experiments were conducted using mixing and alternating (cyclic) irrigation management techniques, along with traditional furrows and drip irrigation methods, using different water qualities, and different tomato varieties. The results showed that higher efficiency in water use and higher yields using drip irrigation and mixing management were obtained as compared to traditional methods and cyclic strategy.

Maize tolerance threshold to water and soil salinity is 1.1 and 1.7 ds/m respectively, and it is therefore a moderately sensitive plant to salinity (Mass et al., 1983). Khuzestan is one of the most important regions where maize is cultivated in Iran ; whatsmore this region has the, greatest volume of saline water resources in Iran. The purpose of this study was to investigate the effects of drip irrigation with saline water utilizing irrigation management strategies, by mixing , one-alternate and half-alternate of saline water with fresh water, on the yield, and the irrigation water productivity of corn under salinie soil conditions.

Materials and methods

Experimental site and natural conditions

The experiments were conducted in 2013 at the Agricultural Experimental Station of the Faculty of Water Sciences of the Shahid Chamran University in Ahvaz, Iran(latitude 31 North and longitude 41 East). Metrological data during the experimental period and soil characteristics are shown in tables 1 and 2, respectively. The soil at the experimental site was a silt loam type, and the electrical conductivity of saturated paste ranged between 2.5 and 3.45 dS.m-1. The total pan evaporation was 1407 mm during the whole growing season (Figure.1).

Experimental design

The experimental design was a split plot, in which, water management strategies were applied to the main plots and the subplots were irrigated with four salinity levels of irrigation water i.e. 2.5 (control), 4, 6, 8 dS/m as S1, S2, S3, S4, respectively. The experimental plots were arranged in a completely randomized block design with three replications. The management options were mixing (M1), one-alternate (M2) and half-alternate (M3) of three levels of saline water (S2, S3 and S4) with water abstracted from the Karun river (S1). Maize (SC-704) was sown in 2.25×3.5m plots. The field area was 405 m2 including 36 plots where the distance between any two adjacent plots was 1m. Irrigation water analysis are shown in Tables 3. Other practices such as pest control and fertilization were carried out during the season.

Table 1. Weather data during maize growing period

Month	Temperature(°C)		Cumulative rainfall (mm)	Relative humidity(%)
	Minimum	Maximum		
July	24.4	50.2	0	78
August	22.6	48	0	85
September	20	46.4	0	91
October	9.6	42.4	0	78
November	9.4	33.8	56.7	96

Table 2. Soil properties in different soil layers.

depth	Soil texture	ρ_b(gr.cm^{-3})	EC(ds.m^{-1})	PH	F.C(%)	P.W.P(%)
0-30	**Si-L**	**1.4**	**2.5**	**7.5**	**32**	**15**
30-60	**Si-L**	**1.55**	**3.2**	**7.65**	**32**	**15**
60-90	**Si-L**	**1.6**	**3.45**	**7.8**	**32**	**15**

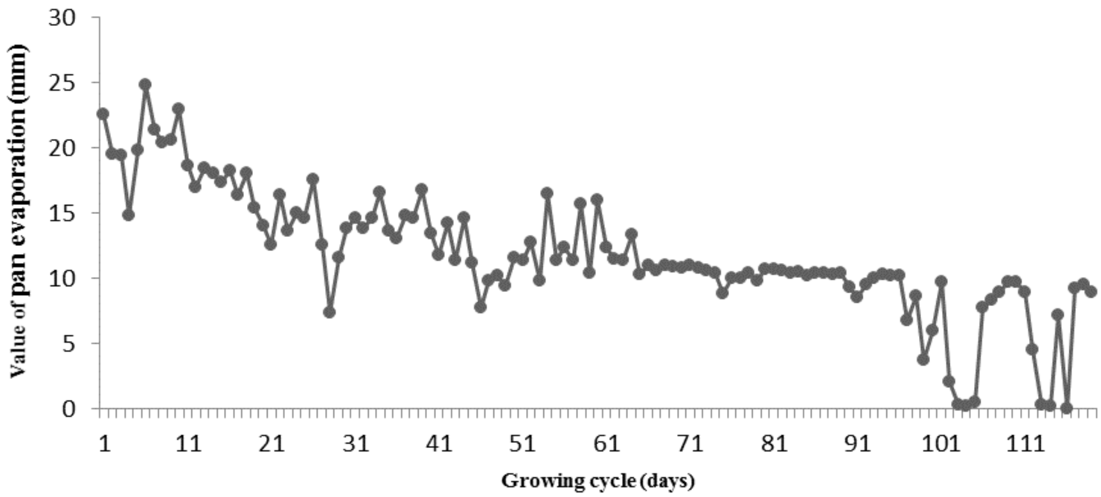


Figure1. Values of pan evaporation in growing cycle

Table 3. Chemical analysis of irrigation water

Salinity levels	EC(ds.m^{-1})	PH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$Hco3^{-}$	cl^{-}	$So4^{2-}$
			(meq.l^{-1})						
S1	2.5	7.42	7.3	4.09	13.7	0.07	3.4	11.37	9.79
S2	4	7.5	14.5	8.3	23.2	0.09	3.36	38.6	9.17
S3	6	7.45	19.2	8.67	37.6	0.1	3.23	41.35	11.73
S4	8	7.8	21.2	9.8	39.6	0.11	3.47	49.8	12.02

Irrigation

The farm was irrigated using drip irrigation tapes with emitter spacings of 20 cm and the output flow rate of 2 L.h-1. The irrigation scheduled was based on the soil moisture content(SMC). To determine soil moisture during the experiments soil samples with three replications were obtained using an auger at the depths 0-30, 30-60 and 60-90 cm before every irrigation in the control group. soil samples was used to determine the soil moisture content (SMC) using a oven-dry method at 105°C for about 24 h. Irrigation depth was determined according to following equation: $dn = (FC - \theta_v) \times Z / 100$

Where: dn is the irrigation water depth(mm); FC is the volumetric soil water content at field capacity(%); θ_v is the volumetric soil water content before irrigation(%); Z is the root depth. The total irrigation depth was controlled using a water meter.

Sampling and analysis

During the period and at the end of the experiments, soil samples at depths of 0-30, 30-60 and 60-90 cm were collected to determine the level of salinity in the soil in all treatments. For each sample, the electrical conductivity of the saturated extract (ECe) was determined.To evaluate the effect of treatments on grain yield, plant samples were taken from each plot at the end of the experiments. Dry weights were measured 48 hours after the placing of fresh samples in an oven at 105°C ; in addition the grain yield was also determined. Water productivity was calculated by dividing grain yield over the used water. The data obtained from experiments were analyzed standard statistical software that is SPSS and MSTATC.

Results and Discussion

Irrigation management and salinity effect on maize yield and water productivity

The comparison of average grain yield and water productivity for different management statratigies and various salinity levels was done with using a Duncan test (table 4). The obtained results show that in the mixing strategy (M1), grain yield is reduced from 7.31 to 5.52 ton/hectare. This means that with the increasing of irrigation water salinity from 2.5 to 5.5 ds/m, maize yield 24.5 % decreases atabout 8 % per unit with the increase in water salinity. Where as Kang et al (2010), reported this as much less for maize under drip irrigation conditions with saline water. It seems that the main reason for this difference is the irrigation scheduling methods of two studies. In M2 management, the grain yield drops from 7.23 ton/hectare in control treatment to 4.63 ton/hectare in S4 salinity; which in itself is equal to 36 %. In other words, the grain yield of M2 management strategy decreases about 12% more than M1 management. In M3 management, the grain yield drops from 7.17 in S1 to 6.02 ton/ hectare in S4 salinity, thus the amount of yield reduction is equal to 16%. Here, despite a 16% decline in yield, there is no significant difference between M3S1 and M3S4 treatments. A review of the compared averages shows that the greatest effect of management on yield occurs in high salinity areas. Water productivity decreases with salinity increase in all three strategies, also. In S4 salinity the value of this index for M1, M2 and M3 is defined as 0.89, 0.47 and 0.96 kg/m3 respectively, which in itself shows that the highest value occurs in M3.

Table 4. Maize grain yield and water productivity mean in different treatments

treatment	Grain yield ($ton.h^{-1}$)	Water productivity ($kg.m^{-3}$)
M1S1	7.31a	1.17a
M1S2	7.09ab	1.14abc
M1S3	6.12abcd	0.98bcde
M1S4	5.52de	0.89ef
M2S1	7.23ab	1.16ab
M2S2	6.99abc	1.12abc
M2S3	5.83cd	0.93de
M2S4	4.63e	0.74f
M3S1	7.17ab	1.15ab
M3S2	7.03abc	1.13abc
M3S3	6.66abcd	1.07abcd
M3S4	6.02bcd	0.96cde

Values in a column followed by the same letter are not significantly different at P≤0.05.

Salinity – yield models under different irrigation management

The values related to the tolerance threshold ECe and slope of the yield reduction per salinity increase unit in different management scenarios has been calculated and is shown in table 5. The results indicate that the value of threshold ECe for M1, M2 and M3 are 3.86, 3.98 and 4 respectively' where highest value is related to M3 and the lowest is related to M1. On the other hand, the slope of yield reduction for M2 and M3 are the highest and lowest value respectively. In other words, the amount of yield reduction per soil salinity increase in unit in M3 is lower than the other two strategies. The plants reacts to the average salinity of root region, where the highest amount of water extraction is done. The highest absorption is done in theupper root region and M3 management causes that this layer of soil to be leached better, so the lowest yield reduction occurs. Finally, the salinity of the soil saturation extract which causes a reduced yield of 25%, 50% and 75% using derived models for each management method has been calculated (table 6).

Table 5. coefficients of yield-salinity model for different strategies

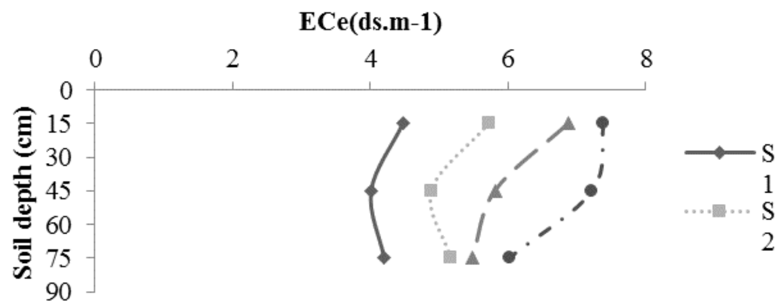
Irrigation management	Threshold EC_e ($ds.^{-1}$)	Yield reduction coefficient ($\%ds.m^{-1}$)	R^2
M1	3.86	9.86	0.91
M2	3.98	12.3	0.85
M3	4	7.14	0.97

Table 6. ECe for different percentages of yield reduction ($ds.m^{-1}$)

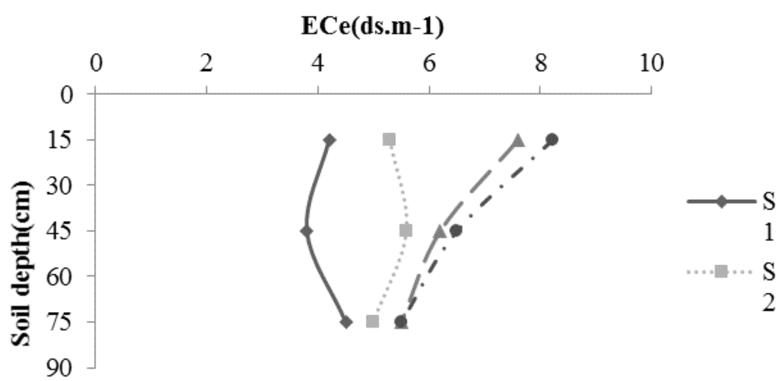
Irrigation management	%25	%50	%75
M1	6.4	8.93	11.47
M2	6	8.04	10.07
M3	7.51	11	14.5

Salinity distribution in the under point of the dripper

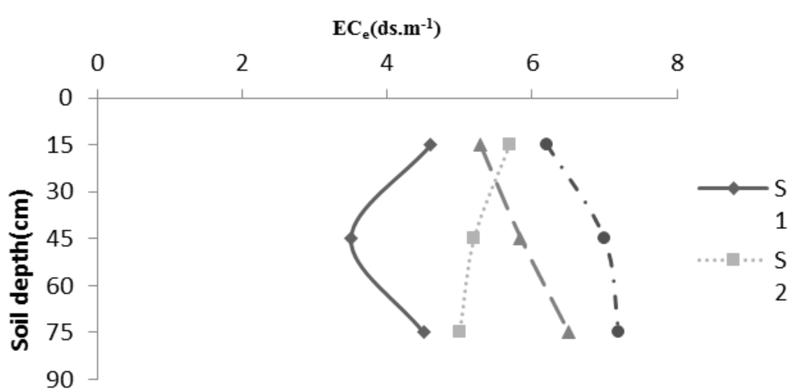
Salinity distribution in the soil profile under different scenarios is shown in figure 2. The Comparison of the figures shows that irrigation management has an effecton salinity distribution in the soil. The first point observed from the comparison of three management strategies, is that in M1 management, salinity distribution is a more regulated trend than the the two other alternative management strategies. Other salinity changes in M2 and M3 strategies are due to the alternative use of water with different salinity that creates a different salinity profile in the soil. Malash et al (2005), research results are consistent with the above results. The highest amount of soil surface layer salinity occurs in M2 management. Since, the greatest density of the plant root is in surface layers ; hence as per uptake patterns, the highest uptake occurs in the surface layer, so in M1 management because of the osmotic potential reduction, water total potential isreduced and plant water uptake is more difficult.



M1



M2



M3

Figure 2. Salinity distribution under different strategies

Conclusion

Drip irrigation, with its characteristic of low rate and high frequent irrigation applications over a long period of time is able to maintain high soil matric potential in the root zone thus compensating for the decrease of osmotic potential which is introduced by saline water irrigation, in addition to the maintaining of a high, constant potential ofwater for crop growth. Moreover, well-aerated conditions can be maintained under drip irrigation. The results of this research showed that the half-alternate management (M3) of fresh and saline water can improve yield performance, water productivity and soil surface leaching using drip irrigation with saline water. The Yield reduction coefficient in M3 management has been shown to be 7.14 which when compared to the mixing and one-alternate strategies (9.86 and 12.3) is at a lesser rate; therefore, sustainable management of irrigation using saline water not only prevents a decline in the level of production. But it also results into land stability.

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FLUCTUATING WATER TABLE QUANTIFICATION USING SATURATED EXCESS WATER CONCEPT (SEW-20 AND SEW-40) AT THE RECLAIMED LOWLANDS OF INDONESIA

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Abstract

Water table within the farm, at the reclaimed lowlands of Indonesia to be used for food production, plantation and pulp wood tree, is a key indicator. The water table position is a function of topography, drainage systems, rainfall, evaporation, crops, operation and maintenance, within a given water management unit. Fluctuation of water table within the farm can be quantified using "Saturated Excess Water - SEW" concept within limit of -20 cm (SEW-20) or -40 cm (SEW-40) below the soil surface. The paper will explain the results of SEW-20 and SEW-40 during one year period covering the rainy and dry months. The value of SEW-20 during the year especially the number of days related with the paddy cropping time. The paddy will be planted if the SEW-20 is more than 120 days. On the other side, the value of SEW-40 will be related with the corn cropping pattern. Corn will be planted when the value of SEW-40 is between 80 to 100 days. The development of rooting zone of rice and corn are determined by the position of water table. The plantation crops and trees would prefer as higher as possible values of SEW-40 during the year.

KEY WORDS: Water table fluctuation, Saturated excess water, SEW-20, SEW-40.

Introduction

Lowlands (swamp lands) in Indonesia is 33 million hectares, consisting of 20 million hectares (60.2%) is a tidal swamp lands and 13 million hectares (39.8%) is non-tidal swamp lands (Dit. Rawa dan Pantai, Departemen PU, 2009). Development of swamp lands for food crops, have excellent prospects in an effort to meet their food needs. This is due to the reduction in productive agricultural land (technical irrigation) due to land conversion for residential, industrial, and other non-agricultural activities. Swamp land reclamation for agriculture has been made by the

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Government of Indonesia since 1969, but the Bugis traditional farmers have opened swamp lands for agriculture and plantations since the 1930s.

A lot of research activities have been done in order to increase production and cropping index (IP) on agricultural swamp lands. At the beginning of reclamation, water management network system built is still an open network system with the main function for drainage. Water regulation are still fully dependent on natural conditions, so the ability of water management services is still very low. In an open network system, the type of tidal flood water becomes a major consideration in the application of the farm system. Noorsyamsi et al. (1984), Widjaja-Adhi et al. (1992), Euroconsult (1996), and Nugroho (2004) classifies the type of overflow on tidal swamp lands based capabilities overflowing tide.

With the construction of water-gate control, then some basic technical issues in agricultural development swamp lands begin to be solved. According to Susanto (1995), the development of tidal swamp lands agriculture require water management at the macro level (the river), meso (hydraulic structures), and micro (plots in farmland level). The rivers are bordered by a reclaimed area, rainfall and tidal water level fluctuations will determine the condition of the water at the macro level. The nature and characteristics of the root zone will be affected by water management at the micro level associated with conditions at the macro level through hydraulic infrastructures (meso level). The design, operation, and maintenance of hydraulic infrastructure must consider the condition of the water at the macro and micro levels.

Suryadi (1996) used the land hydro-topography conditions for preliminary consideration in planning for water management in tidal swamp lands. Hydro topography land is a relative comparison between the surface elevation with the surface water level in the river or nearby channels. Furthermore, Susanto (1998) combines the concepts of land and hydro-topography consideration SEW-30 as a system of evaluation of the status of water in secondary and tertiary blocks. The same system was also reviewed by Edrissea et al. (2000) by using the concept of SEW-30 and DRAINMOD.

According to Susanto (2000), water management will affect groundwater levels in the area. Surface water level in tidal swamp lands fluctuates according to time and space. Control efforts should be made so that the surface water level can support plant growth. Control of surface water level at a specific depth can be done through the strategy planning and/or reclamation network maintenance operations. Consideration of topography, rainfall, tide, type of soil, the type of plants, the depth of layers of pyrite and reclamation system parameters must be done in an integrative manner to support the water management. Objectives of management strategy for water management in swamp lands are to maintain the quality of soil and water, ensure adequate water for the plants, and remove excess water.

This article presents the results of quantification of groundwater level fluctuations in the land with the concept of SEW-20 and SEW-40, so that the pattern and timing of planting can be determined in accordance with the distribution of the depth of the surface water level in a year.

Materials and Methods

The study was conducted in two areas of tidal swamp lands in Banyuasin, South Sumatra Province, Indonesia. Site selection is based on the difference in land hydro topography conditions. The first location in an area of reclaimed land in Delta Telang I is a type B with land elevation 1.27 to 1.34 meters above sea level. Type B land is land that can only be throbbing by the great high tide only, flooding is not take place every day (only occurs on a large pairs in the rainy season), and the drainage lasts longer. Subsequently, a second location in the area of land reclamation Delta Saleh is a type C with land elevation 2.03 to 2.12 meters above sea level. Soil type C is not throbbing tide although when the tide is great, but the surface water level in the soil is influenced by tidal fluctuations.

Observations depth of the surface water level is done through shallow wells (wells) are made of PVC pipe with a length of 3 meters and a diameter of 2.5 inches. The pipe is perforated at the sides and then coated with fibers and planted at a depth of 2.5 meters from the ground. The top of the pipe hole is closed and only opened at the time of observation. Surface water level depth measurement is conducted every day between the hours of 7:00 to 08:00 pm. Furthermore, observations of precipitation is conducted every rainfall event by means of a graduated rainfall manual (ombrograph type observatory) and cup of measuring.

Quantifying fluctuations in groundwater levels in the area are calculated using the concept of Saturated Excess Water (SEW). The calculation result SEW-20 and SEW-40 may show the position of surface water levels at, above and / or below a depth of 20 cm and 40 cm from the surface of the land that is expressed in days per year.

Results and Discussion

Development of swamp lands for cultivation of crops require the management for network of macro water to control groundwater levels in the area, and the network of micro water management to control the level of ground water in the area. Cultivation system in swamp lands must consider the condition of hydro-topography. Hydro-topography of land can be used as a guide to what extent the possibility of flood water may inundate the land, and vice versa for flooding that there can be drained. Hydro-topography is defined as the relative ratio between the elevation of land with the water level of the river or the water level in the canal nearby (Euroconsult, 1996).

In order to optimize control of the surface water level in tidal swamp lands, Ngudiantoro (2009) construct a mathematical model to estimate the groundwater level fluctuations, so the control of surface water level at a certain depth can be done by controlling the water level in the channel.

Furthermore, Ngudiantoro et al. (2011) conducted to manipulate the water system to support increased production and cropping index on tidal swamp lands. By doing network engineering based on characteristics of the water system hydro topography, hydro climatology, as well as the physical and chemical properties of the soil, the cropping pattern can be adjusted as desired.

One of the factor that affect the natural depth of the surface water level in the soil is rainfall. Distribution and thickness of the daily rainfall observations at both locations are shown in Figures 1 and 2.

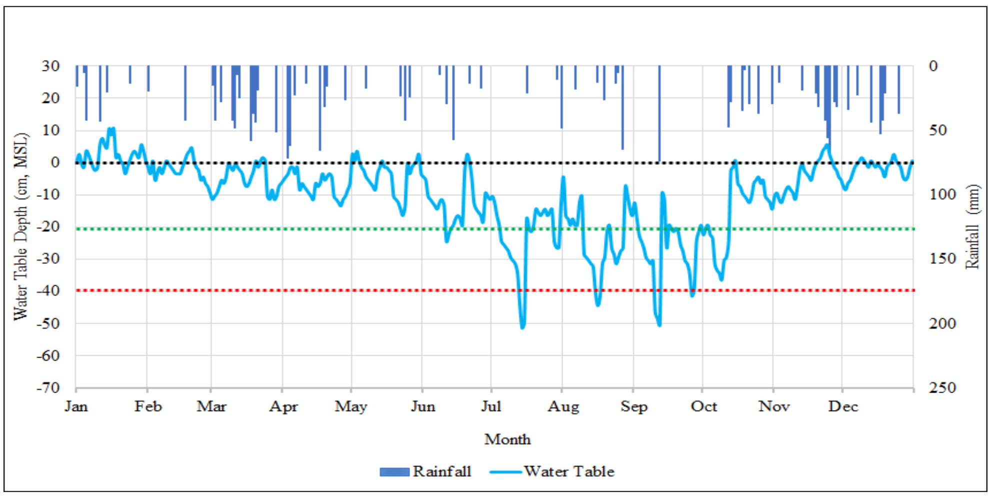

Figure 1. Rainfall and water level fluctuation of the land type-B in Delta Telang I

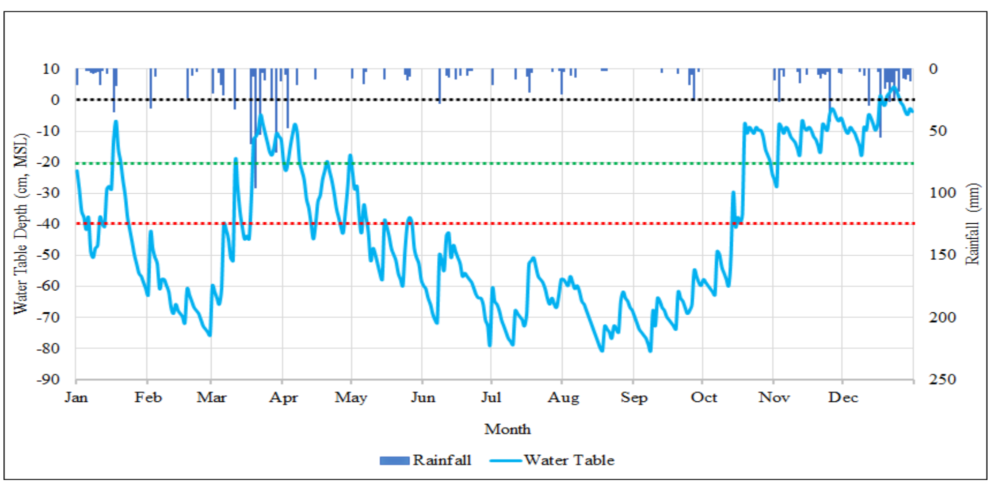

Figure 2. Rainfall and water level fluctuation of the land type-C in Delta Saleh

Number of rainy days in the Delta Telang I is 70 days with the maximum daily rainfall of 74 mm/day, whereas in Delta Saleh occurred 101 rainy days with the maximum daily rainfall of 96 mm/day. Although the rain events in Delta Saleh more and the maximum rainfall is also bigger than the Delta Telang I, but the total rainfall in the Delta Saleh just 1.255 mm/year, less than the total rainfall in the Delta Telang I, that is equal to 2.218 mm/year. The average daily rainfall in the Delta Telang I is 6.1 mm/day, whereas in Delta Saleh of 3.4 mm/day.

In addition to the rainfall, land topography, hydro conditions also affect surface water level fluctuations in the land. The condition of surface water level relative to the dry season, both Delta and Delta Telang I Saleh. The range of the depth of the surface water level in the Delta Telang I was not too wide, these conditions are different from those in the Delta Saleh. This is caused by differences in rainfall and hydro-topography. Differences in surface water level condition at both locations was evident when seen from the calculation SEW. In summary, the results of calculations SEW SEW-20 and-40 at two different locations are presented in Table 1.

Table 1. Summary for surface water level calculated of SEW-20 and SEW-40

Parameter (cm)	Land Hydro-topography	
	Type B	**Type C**
High water table (WT)	+10.6	+4.3
Low WT	-51.4	-80.7
Frequency of flooded	59	7
Frequency for WT below 20 cm	294	98
Frequency for WT upper 20 cm	71	267
Frequency for WT below 40 cm	355	150
Frequency for WT upper 40 cm	10	215

Table 1 shows the difference significant for water status at two different locations. SEW calculation results based on observations of water level fluctuations in the land, Delta Telang I indicate: a) the highest surface water level +10.6 cm above the soil surface and the lowest was -51.4 cm below the ground surface; b) Frequency of flood on land spread over 59 days per year (16.16%); c) The frequency of the depth of the surface water level is less than 20 cm dispersed in 294 days per year (80.55%) and more than 20 cm dispersed within 71 days per year (19.45%); and d) The number of times the depth of the surface water level is less than 40 cm dispersed in 355 days per year (97.26%) and more than 40 cm spread within 10 days per year (2.74%).

Furthermore, the calculation results in Delta Saleh SEW indicate: a) the highest surface water level +4.3 cm above the soil surface and the lowest was -80.7 cm below the ground surface; b) Frequency of flood on land spread over 7 days per year (1.92%); c). The frequency of the depth of the surface water level is less than 20 cm dispersed within 98 days per year (26.85%) and more than 20 cm dispersed in 267 days per year (73.15%); and d) The number of times the depth of the surface water level is less than 40 cm dispersed in 150 days per year (41.10%) and more than 40 cm dispersed in 215 days per year (58.90%).

Related to the farm system, if the depth of the surface water level is less than 20 cm with a frequency of more than 120 days, is suitable for rice. However, if the depth of the surface water level is more than 20 cm with a frequency of 80 to 100 days, then the plant from which is corn.

In the implementation, the condition of the surface water level in the land must be controlled according to need. Control of surface water level in tidal swamp land is a key process that must be done properly through water management, both at the macro and micro levels. Water management at the macro (macro water system) that is water management which starts from the main river channel then the primary and secondary channels, whereas water management at the micro level (micro water management) include water management at the tertiary level, quarter, and farmland.

Micro water management will directly determine the environmental conditions for plant growth. It would be done well if in tertiary channels already available for water control infrastructure. Water gate to control the water in the channel, the water intake at the time of high tide and low tide when the drainage in accordance with the requirements of water for crops.

If water quality is decent (not salty or sour), the inclusion of water to farmland can be done to ensure adequate water for crops and improved soil quality. In certain circumstances, a puddle on farmland need to be maintained for many purposes. Inundation of land in a relatively long time should be avoided to prevent the formation of toxic substances in the soil.

Drainage is done in case of excess water on farmland. Drainage is also required on certain conditions such as prior to fertilization, at harvest time, or when the soil and water quality to deteriorate. Drainage can be done by opening the floodgates in tertiary channel at low tide, and shut the door the water at high tide. In certain areas, the drainage that is too deep can cause the risk of oxidation of pyrite below the soil surface.

If the groundwater level drops to a depth of more than 40 cm below the ground surface, it is necessary to retention of water to prevent water shortages and creates the environment for the absorption of nutrients needed by plants. Water retention can be done by closing the sluice gates at tertiary channel at low tide and opened water at high tide. Water retention should not be done in a long time to prevent the formation of toxic substances in the soil.

Conclusion

From the results of the evaluation of the status of water with the concept of SEW-20 and SEW-40, it can be concluded that:

1. Land type B in Delta Telang I suitable for agro-ecosystem with water saturated conditions, namely rice crops, while the C-type land in the Delta Saleh suitable for corn crops.

2. The cropping pattern matching on lands type B in Delta Telang I was rice-rice-corn. The planting season I and II (November-June) is for rice, while the third growing season (July-October) to corn plants.

3. The cropping pattern matching on land type C in Delta Saleh was rice-corn-corn. I cropping season (November-February) is for rice, while the second and third growing season (March-October) to corn plants.

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EXPERIMENTAL PERFORMANCE EVALUATION OF THREE DRAINAGE METHODS FOR PREPARATION OF SECOND CULTIVATION IN PADDY SOILS

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Abstract

Paddy fields have the ability of multi-cultivation as compared to other crops. Low permeability rate and long term waterlogging of paddy soils cause serious problems for non-rice crops. Therefore, the aim of this study is to evaluate three different drainage methods including: 1- surface drainage, 2- subsurface pipe drainage and 3- trench drainage (filled underground trench with high-permeable material along with drainage pipe). Experiments were implemented in a physical model capable of the simulation of 7.5 meters drain spacing. Drainage water and soil moisture at different depths and distances from the drain pipe were measured. The results showed that the drainage of water via trench drainage was far more than other methods; nonetheless, the performance of trench drainage in the reduction of soil moisture was better. The required time for the top soil to reach its lower plastic limit in the subsurface, trench and surface drainage systems were obtained 26, 22 and 16 hours from the start of the experiments and 14, 11, and 15 hours after the depletion of excess water over the soil surface, respectively. Although surface drainage represents in faster depletion of excess water; eventually, the trench drainage proved to be the most effective alternative to provide appropriate qualifications for second-cultivation operations.

KEY WORDS: Physical model, Hardpan, Trench drainage, Soil moisture.

Introduction

Population growth, and consequently the necessity to produce more foodstuffs has caused the excessive utilization of water resources in recent decades. In the next 25 years, it has been predicted that agricultural cropping water requirements will increase twofold (Ritzama, 2007). On the other

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hand, the excess usage of water resources; especially in arid and prone to drought areas have brought about the current water crisis. In such critical circumstances, one of the means of enhancing agricultural production is the optimal and multi-application of agricultural crops with minimum water requirements on farms. According to the Food and Drug Organization reports, rice which is one of the most important and widely used agricultural products provides nutrition of four billion people around the world (FAO, 2010). Paddy fields due to its inherent characteristics, provides a highly moist medium for the growing of rice. In these farms, the top layer of the soil is puddled and deformed to form paddy fields. In puddling, a highly low permeable layer is formed below the top-layer called hardpan. Based on several studies carried out in the Gillan province of Iran, the hardpan of paddy soils has a heavy texture and a low permeability and its infiltration rate is reported as being 1.5 millimeters per day (Razavipour, 2005; Mousavi, 2008, Kamyab, 2008). The low permeability of hardpan causes soil to become waterlogging and saturated and thus unable to reduce and drain extra moisture in an appropriate period of time. As opposed to rice, other agricultural crops are almost incapable of tolerating long-waterlogging or highly humid soils. Therefore, insufficient soil root zone aeration causes stress and even mortality of crops (Greenland, 1985). Hence, in spite of all the potential capabilities inherent in paddy fields such as ease of access to certain water resources, they remain useless and multi-cultivation almost does not exist subsequently (Darzi Naftchali & Shahnazari, 2014). In addition to the problem of the low permeability of paddy soils, in most cases, precipitation is generally intensive in rice cultivation areas. Natural soil drainage due to lack of appropriate infiltration rate is unable to convey the excess water out of the crop root zone, thus mechanization and field operation procedures for a second-cultivation are nearly impossible (Tabuchi, 2004).

The artificial drainage of paddy fields is one of the operational solutions for paddy soil without any destruction and any substantial change in the soil structure. In some cases, the existence of drainage systems is mentioned as being indispensable (Yazdani, 2007). Appling adaptable drainage system enables multi-cultivation in paddy fields. Specific soil structures and layers in paddy fields make the drainage process different form the conventional drainage of soil. Despite the lack of widespread application of subsurface drainage in Iran, several research studies have investigated the effectiveness of subsurface drainage systems in paddy fields (Soong & Wei, 1985; Karimi et al., 2009; Dzhumabekov, 1996; Darzi-Naftchali et al., 2013).

Inadequate research in the field regarding different paddy drainage and also the planting of a second-cultivation in these farms indicate the importance of this research. The main objective of this study was to evaluate three drainage methods including surface drainage and two types of subsurface drainage; conventional pipe drainage and filled trench with pipe drainage which is known as trench drainage (Tabuchi, 1985). Indeed, the capability of these drainage methods for the depletion of excess water and the reduction of soil moisture within a certain time in order to make second-cultivation in paddy fields feasible is a very important issue. In fact, the rapidity and rate of drainage in minimum time is of great importance.

Materials and methods

In order to evaluate the performance of drainage methods in paddy soils, a physical model was constructed. This model is capable of simulating several drainage methods and providing an evaluation of drainage methods by furnishing measurement implements.

Experimental site layout

The experiments were carried out in the Water and Meteorological Research Center affiliated with the faculty of Agriculture and Natural Resources at the University of Tehran, Karaj, Alborz province in 2015. The physical model was located outdoors in order to create a more realistic environment. The experimental site had a Mediterranean climate with a rather warm summer and 250 millimeters average annual precipitation.

A physical model was built from a metal box 3.75,1,1 meters in length, width and height, respectively; the box was enhanced by piezometers, TDR[1] probes and drainage and a deep infiltration collector container. The dimensions of the box were chosen in such a way that it simulates half of the drainage system at 7.5 meters intervals.

The schematic of the physical model is shown in Figure 1 which consist of: 1-Top soil layer (Puddling layer) 2-Hardpan soil layer 3- Bottom soil layer 4- Surface drainage location 5- trench drainage location 6- Water table control encasement 7- Water table (equal to the center of the drainage pipe) 8-water table control valve 9- Deep percolation outlets 10- Surface drainage collector 11- The subsurface drainage coating area 12- Drainage pipe (10 cm Diameter) 13- High permeable layer to transfer deep percolation to outlets. The properties of different soil layers are presented in Table 1.

[1] Time Domain Reflectometry

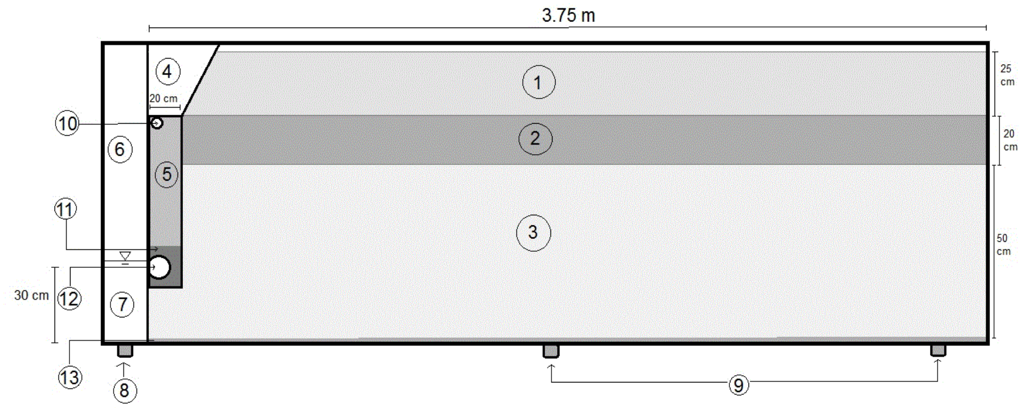

Figure 1. Schematic view of the physical model

Piezometers were placed at various depths and lengths of the metal box in order to observe the water table at different distances from the drain. Also, several TDR probes were placed in different soil layers at different depths and distances from the drainage to measure soil water content. For more reliability, TDR measurements were calibrated for different soil types corresponding to different layers. In order to measure the drainage volume and rate, degraded containers were used. Based on the predominant soil structure and texture in paddy fields, the depths, thicknesses and textures of soil layers were supplied and their characteristics shown in Table 1. In order to assess the paddy farm in terms of preparedness for second-cultivation and mechanization, a lower plasticity level (LPL) criterion has been applied. The LPL of top soil were measured to be 33 percent of the volumetric water content of the soil.

The Drainage systems were tested in the physical model sequentially. To start each treatment, the soil profile was completely saturated and a five centimeters water depth was specified on the surface; due to predominant rice crop submergence. The experiments would resume until the average top soil moisture reached the LPL level.

Table 1. Soil charactristics of different layers

Soil layer	Thickness (cm)	Soil texture	Clay (%)	Silt (%)	Sand (%)	Bulk density (g cm^{-3})	Saturated water content (cm^3 cm^{-3})	Field capacity (cm^3 cm^{-3})
Top	25	clay loam	31.4	42.2	26.40	1.34	51.0	41.0
Hardpan	20	clay	50.56	25.34	24.10	1.22	57.0	43.0
Bottom	50	loam	13.68	41.61	44.71	1.3	47.0	39.0

Drainage treatments

In this research, three drainage methods including: 1- Surface drainage, 2- Subsurface drainage (Pipe drainage) and 3- Trench drainage were evaluated.

The dimensions of the shallow surface drainage system are illustrated in Figure 2. In this system, half of the surface drainage canal was constructed based on half of the drain intervals simulation. Whatsmore, an excess of five centimeters of the width of drainage was considered to align the axis of the surface drainage and drainage pipe below the soil surface.

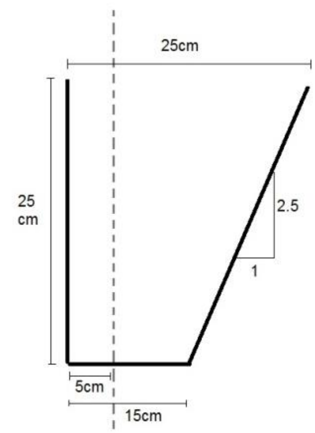

Figure 2. Dimensions of surface draiange

The subsurface drainage consists of a corrugated drainage pipe 10 cm in diameter. Half of the pores in the circumference of pipe was closed due to the simulation of half of the drainage intervals. The pipe was covered by high hydraulic conductivity materials as shown in Figure 3-B.
Trench drainage is a combination of subsurface and surface drainage,. This method extends its envelope materials above the drain pipe to reach the top soil by passing through the hardpan layer. This modification makes a higher hydraulic gradient towards a drainage pipe and connects the top soil to drainage pipe directly through a filled trench. The dimensions and schematics of the trench drainage were demonstrated in Figure 3-A.

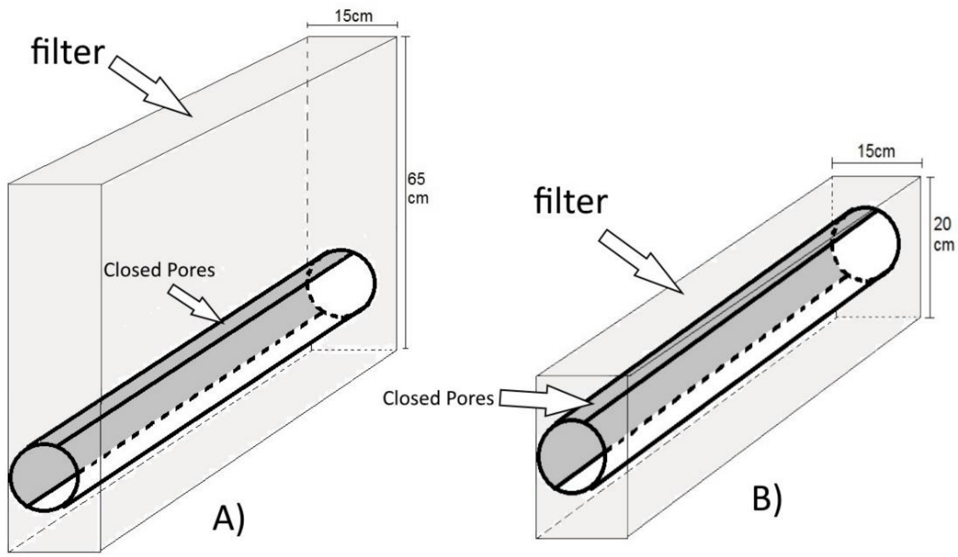

Figure 3. A) Trench drainage dimensions B) Subsurface drainage Dimensions

Results and discussion

The results of the different drainage methods performance on the drainage volume, the drainage discharge, soil moisture distribution and the water table were investigated. According to the results represented in Figure 4, the surface drainage was capable of draining the puddling layer quickly due to its hydraulic characteristics. Surface drainage was able to deplete 175 liters water from the soil surface in less than an hour; however, after that it became practically useless. While the two other drainage systems drained more water than the surface drainage; The Trench drainage was the most effective method for the draining of waterlogged layers and the excess soil moisture in as such that it drained 225 liters.

The hydrograph of the subsurface and trench drainage in Figure 5 indicates that the changes in the drainage discharge is intensive. The surface drainage discharge amount in comparison to other drainage methods is not analogous due to the quick operation of the surface drainage and becomes dysfunctional after the draining of the waterlogging layer.

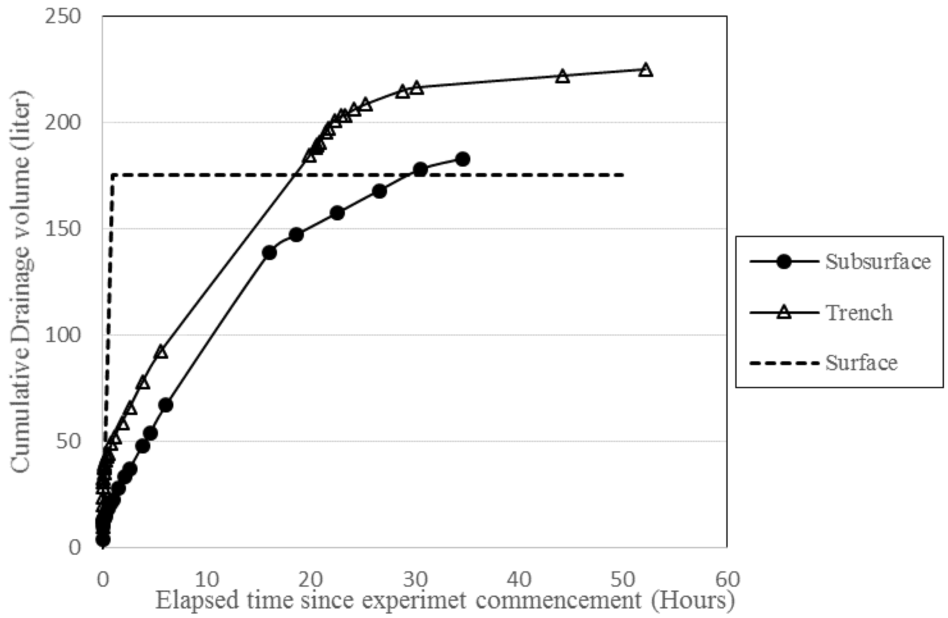

Figure 4. Cumulative drainage volume by Subsurface, Trench and Surface drainage

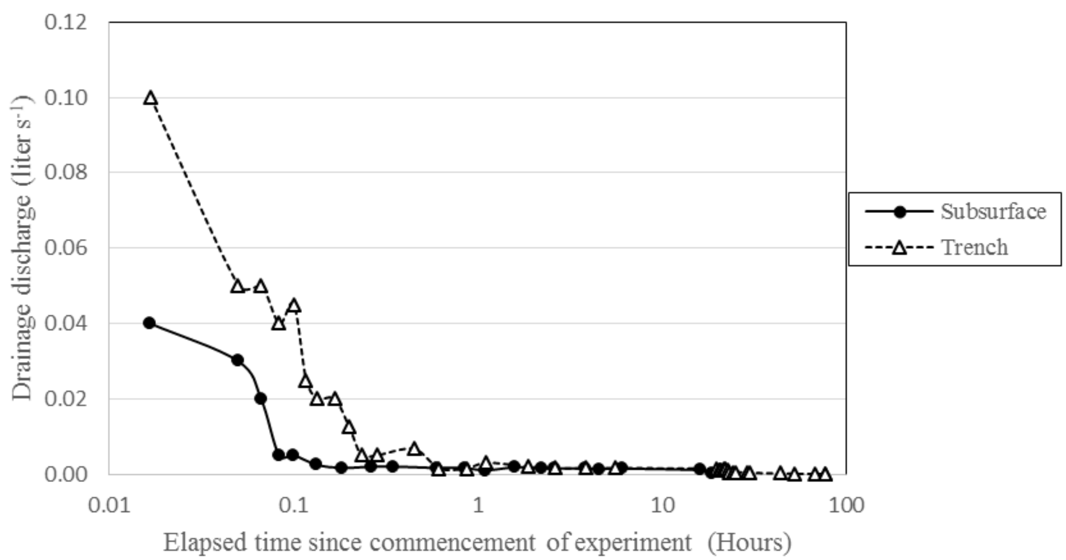

Figure 5. Drainage discharge hydrograph of Subsurface and Trench draiange

The average drainage coefficient of different drainage systems four days after the beginning of each experiment is estimated in Table 2. The results prove that trench drainage has a higher drainage coefficient as compared with the two other systems because of its improved structure.

Other research also indicated that the drainage coefficient of trench drainage is estimated from 10 to 20 millimeters per day (Ebrahimian & Noory, 2014).

Table 2. Average Draiange coefficient in four days since commencement of experiment

Drainage method	Drainage Coefficient (mm day^{-1})
Trench	15
Subsurface	12.33
Surface	11.67

In order to evaluate the performance of different drainage systems, the required time for reaching LPL moisture level was estimated as shown in Table 3. Based on the results, it has been observed that surface drainage reduces top soil moisture to the LPL level in less time (16 hours). The reason that caused surface drainage to be more effective is its ability to deplete the excess waterlogging water in less than an hour; while subsurface and trench drainage require a period of time to drain waterlogging layer. Since the draining of the waterlogged layer is relatively controllable by farmers in paddy fields and the objective of this research is to prepare of the top soil for second cultivation in terms of soil moisture., Therefore, the required time for reducing moisture of tops soils to LPL level after draining of the waterlogging layer is important because the cultivation period for the second crop (winter crop) is very limited due to frequent rainfall events. Based on this assumption, trench drainage, subsurface drainage and surface drainage were able to bring the top soil to the desired moisture level after 11, 15 and 14 hours, respectively. The low variation among the results of different drainage systems is probably due to the effects of climate condition. Experiments were carried out in high temperate days of the year that is in July and August; thus evaporation was shown to be effective in the reduction of top soil moisture.

According to (Figure 6), distributions of average moisture in different depths of soil for drainage methods were represented. Trench drainage proved that it has a better performance in depths of 12.5 centimeters from the soil surface so that the average volumetric moisture in this depth reaches 15% after 80 hours. Similarly Trench drainage demonstrated a better performance in reducing average soil moisture in 20 centimeters depth. No considerable soil moisture reduction occurred in the hardpan layer. Heavy soil texture and low hydraulic conductivity of the hardpan layer caused inefficiency of draining in this layer.

Table 3. Required time after commencement of experiment for reaching the average moisture of top soil to low plastic limit

Drainage method	Required time to reach the plastic limit (hours)	
	After the depletion of waterlogging layer	From start of experiment
Subsurface	14	26
Trench	11	22
Surface	15	16

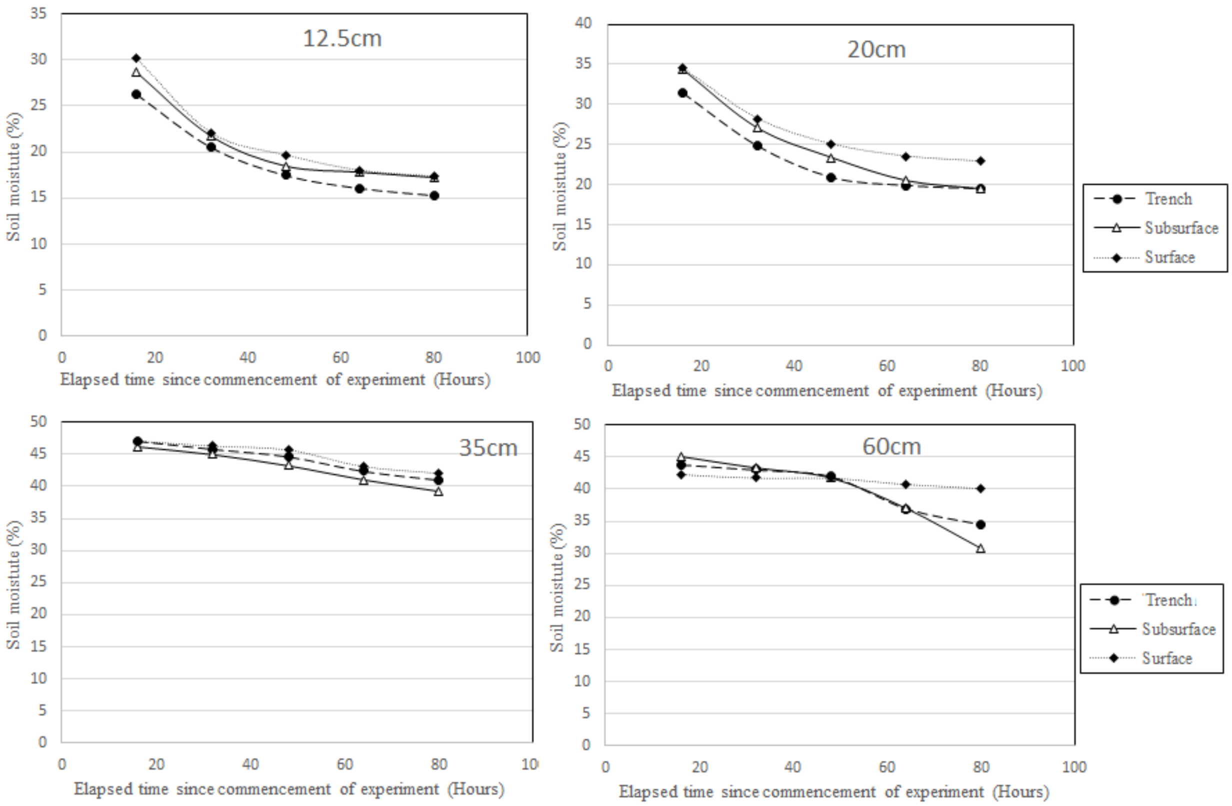

Figure 6. Distribution of soil moisture in different soil depths towards time in different drainage systems after draianing waterlogging condition

The variation of the water table towards the elapsed time after the beginning of the experiment in different drainage systems is illustrated in Figure 7. The Water table drawdown was greater for trench drainage than other drainage systems; the lower drainage flow resistance caused differences between the subsurface drainage and trench drainage. Due to the incapability of the surface drainage system for removing excess water from a deeper layer, it had no significant effect on the water table drawdown.

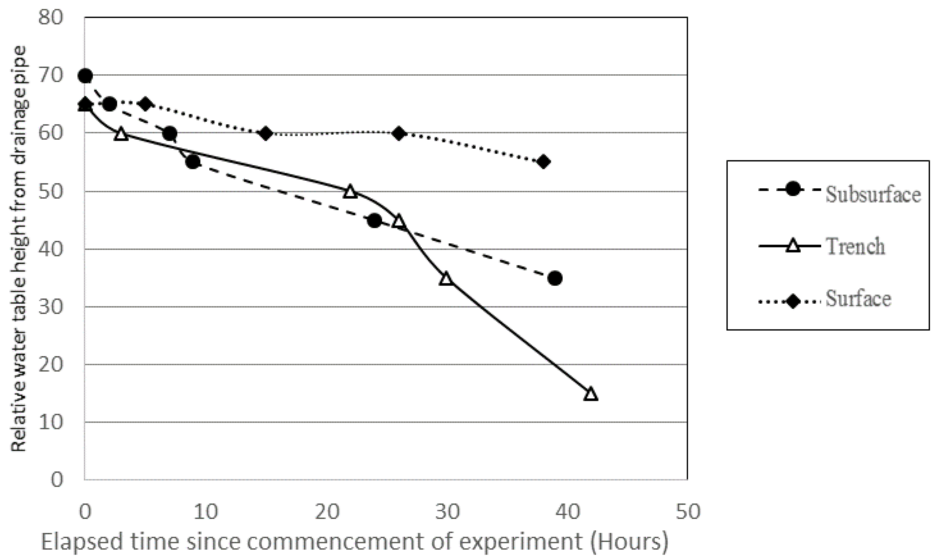

Figure 7. Variation of water table in the farthest distance from drain in different drainage systems

Conclusion

Three types of drainage systems with the aim of preparing a paddy field for second cultivation has been evaluated in this study. A comparision of different drainage systems shows that surface drainage is more capable of draining the retained water from the soil surface more easily than the other methods. Trench drainage which is an ameliorated type of subsurface drainageprovided better results in terms of drainage volume , the drainage rate, the reduction of top soil excess water in the case of post-depletion of waterlogging and water table draw down. Under specific circumstances of paddy fields, a drainage system is capable of draining and controlling excess moisture and the water table in the soil is more efficient. Trench drainage proved to be potential and useful in assisting farmers and stakeholders to exploit more income. It is recommended that futureresearch should in addition to the evaluation of drainage systems in actual paddy field condition, focus on the compilation of surface and trench drainage.

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PROPOSALS TO DIRECT AGRICULTURAL DRAINAGE WATER MANAGEMENT IN THE KHUZESTAN PROVINCE (KARUN-DEZ RIVER AREA) INTO A SUSTAINABLE AND INTEGRATIVE DIRECTION FOR PRESENT AND FUTURE SCENARIOS

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Abstract

Khuzestan, a south-western province of Iran, is the main region of subsurface drainage in the area. Current drainage water management faces major challenges. In particular, high volumes of saline drainage effluent lead to far-reaching environmental, social, economic and political complications. This paper attempts to evaluate possible ways to overcome current inefficiencies. A focus will be put on solutions to achieve a sustainable integrative drainage management approach (IDWM) that focusses on agriculture as the main water consumer within Khuzestan. It integrates water re-use, drainage discharge possibilities, waste water treatment (desalination) and ways to increase water use efficiencies related to irrigation and leaching. All strategies aim to improve the current situation but also to redirect Khuzestan´s drainage water management into a sustainable manner within future scenarios. The ambition is to manage present and future drainage water flows but also future irrigation water supply by establishing monitoring, controlling and modelling structures affecting both water quality and quantity. Moreover, the relation between shallow and saline groundwater within agricultural irrigation and drainage systems plays a key role within agricultural drainage water management and will be examined in detail. The paper is based on collected data and factors of an ongoing empirical research project jointly with Humboldt University Berlin and Khuzestan Water and Power Authority (KWPA).

KEY WORDS: Drainage Water Quality, Integrated Drainage Water Management, Irrigation Control Systems, Methods of Irrigation and Drainage, Monitoring of Quality and Quantity Pollution, Salinity, Treatment Technologies, Water Reuse, Khuzestan, Iran.

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Introduction

The Karun-Dez River basin is subject to a semi-arid to arid climate with fertile but mostly heavy soils. Favourable climate conditions for crop production and water availability have transformed the area to one of the main agricultural production zones within Iran. However, because of low quality of water used for irrigation, low irrigation efficiencies, high salinity of soil and groundwater resources, inadequate drainage technologies, heavy textured soils with low infiltration rates and high evapotranspiration demands, the lands are facing several environmental and agro-economic challenges. One of the biggest challenges to overcome is to reduce the amount of saline agricultural drainage water (ADW).

Agriculture is the biggest extractor of fresh water resources within the Karun-Dez River basin, followed by the industrial and municipal sectors. The current share of water consumption by agriculture in Khuzestan is estimated to be around 88-92% (DADOLAHI-SOHRAB et al. 2012, GHADIRI 2014). This high percentage is related to the need to irrigate and leach agricultural lands in order to enable crop production and to overcome soil salinity problems within the region. Resulting ADW can be defined as the unconsumed part of the irrigation or leaching water applied to crops and soils. Attention, however, must be given the fact that drainage systems constructed in rural irrigated areas are themselves the recipients of foreign (non-agricultural) waste water and that the drainage water considered for reuse may not only have an increased salt content, but may also be polluted by return flows from a variety of other sources and other water users (Williardson et al. 1997).

In Khuzestan, salt has always been a natural part of the soil and groundwater resources and particularly the southern Karun River Basin is defined as a natural salt trap (Afkhami 2003). Subsurface drainage systems are often used in irrigated, waterlogged, agricultural lands in arid and semi-arid regions to reduce or prevent soil salinity. Here the primary goal of agricultural drainage is to remove the accumulated salts from the root zone and to control the secondary salinisation by lowering groundwater levels. With persistent use of irrigation without appropriate salt and drainage management, water quality continues to deteriorate and agricultural land gradually degrades with the elevated levels of salts (Qadir et al. 2015).

The main concern related to subsurface drainage in Khuzestan remains to be the extraordinary high volume of very poor quality drainage water. Even after reclamation periods the drainage outlet is in many cases 5-10 times more saline than the applied irrigation water (Sharifipour et al. 2013). The effluent mostly cannot be recycled into surface water bodies like rivers because it exceeds water quality standards, namely salinity values. Respective discharge salinity thresholds for drainage water in Iran are currently set to a level of 3000 µS/cm. At the present time, there are no re-use strategies/ waste water treatment facilities for drainage water and hence vast amounts are being lost.

Because the drainage effluent is too saline to be fed back into the Karun-Dez River system, main drains are being directed either to western evaporation ponds and wetland structures in close proximity to bordering Iraq or to Shadegan Wetlands in close proximity to the Persian Gulf. The high amounts of saline drainage water ultimately lead to an overflow of evaporation ponds and wetlands in close proximity to main drains and discharge systems.

Although the lack of drainage and wastewater management approaches becomes only visible in certain areas, namely by the overflow of basins and wetlands, Khuzestan´s water management sector in its entirety can be held responsible for this process. Irrigation and drainage inefficiencies, insufficient natural drainage conditions, pollution of water resources, salinity of natural resources and a lack of monitoring and control structures all contribute to the existing situation. Varying climatic trends (higher temperatures, lower rainfall, higher PET-rates, more frequent droughts etc.), population growth and resulting changes in water management strategies and policies, such as an expansion of agricultural production and more domestic water consumption, are threats that vast parts of Khuzestan will be subjected to in the future. Occurring harmful effects will be accelerated by exposing Karun and Dez River to industrial wastewater, urban sewages, and agricultural effluents (Keshavarzi, Mokhtarzadeh et al. 2015). Built on this, it is important to incorporate a well-rounded, holistic water management approach that includes future scenarios and trends as well as strategic water management planning in order to estimate present and future water availability and quality in order to positively affect Khuzestan´s social and environmental development. Corresponding, the implementation of integrated water resource management (IWRM) approaches plays a key role for Khuzestan´s present and future progress. IWRM is defined as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." (GWP 2000) Various studies have already identified the prevailing causes responsible for high volumes of saline drainage water in the Karun-Dez basin (e.g. Afkhami 2003, Akram et al. 2013, GHADIRI 2014, Pazira and Homaee 2010, Sharifipour et al. 2013). However, very little research focuses on the evaluation of operational strategies that have the potential to improve current drainage water management deficiencies. In order to shift the direction towards a more practical, implementable approach, the importance of shallow and saline groundwater within irrigation and drainage systems will be discussed, before several technological solutions of how to improve local drainage water management will be presented. The paper concludes by presenting a strategic operational plan that includes short- and long-term technological strategies in order to overcome current agricultural drainage water management challenges and to facilitate the implementation of further IDWM approaches.

Note: The suggested framework is a first qualitative step to promote further planning. To date, data availability is insufficient to quantify assumptions, conclusions and recommendations for detailed planning. Hence, further investigation on the topic is urgently required.

The importance of shallow and saline groundwater within Khuzestan´s agricultural irrigation and drainage systems

It is important to add, that the salt balance of Khuzestan´s agricultural lands depends largely on the water balance, in which the amount of irrigation water is a dominant term. When sufficient irrigation water is applied, the effect of drainage on the salt balance stems from the discharge of salts along with the drainage water and often additional groundwater that is being pumped because deep drains were installed. It is argued, that drain water salinity is highly affected by ground water salinity – a fact that has often been overlooked in the case of Khuzestan (Sharifipour et al. 2013). The main reason that increases groundwater´s contribution to drain water salinity is the drain depth. Additional saline groundwater contribution increases environmental dangers as well as pumping costs, especially after irrigation periods.

If leaching of saline soils is necessary for salinity control, it is important to establish systems that consider irrigation and drainage as one unit. This is of particular importance in areas with shallow groundwater and/or insufficient natural drainage conditions.

In areas located within the Dez River basin, agricultural production circumstances are different compared to regions within the Karun River basin. In the region around Dezful, surface water quality and quantity is acceptable and no problems regarding saline and shallow groundwater exist. Generally, if agricultural areas are more than 10 m over sea level or if they aren`t located in the Khuzestan plain area, mostly no problems in relation to groundwater exist. If the agricultural areas are less than 10m over sea level and they are either located in the Khuzestan plain or they represent a transition from mountain areas to the plains, problems with shallow groundwater levels exist and have negative impacts on agricultural production. Figure 1 indicates, that the majority of southern plain landscapes is located within 0-10 m above sea level therefore inhabiting shallow groundwater conditions.

Studies show, that existing systems of irrigation and drainage (surface and subsurface) in Khuzestan consider soil and groundwater salinity conditions which reflects the state of international knowledge about the need of leaching for desalinisation.
However, the capillary rising dynamics of salts from saline groundwater towards the topsoil after leaching/ irrigation periods end (usually after harvesting) was not considered in the planning process of current subsurface drainage systems. The influence of saline groundwater on agricultural production within Khuzestan is therefore far reaching, as over 70% of agricultural zones and over 80% of sugarcane production sites are located in the plain area and have more or less problems with high and saline groundwater levels.
In can be assumed, that in such areas the amount of drainage water is actually higher than the

amount of irrigation water plus leaching rate. This is due to pumping of additional groundwater into the main drains. The resulting EC level of the drainage water is so high, that it cannot be fed back into the river system; effluents mostly flow into the wetlands of Karkheh basin (on the border to Iraq) and into the wetlands of Shadegan and Korramshahr. Moreover, it is planned to direct drainage flows into the desert area of the Hendijan network.

In areas with shallow groundwater level (> 2,0 m above sea level), leaching of salts hasn`t been and won`t be successful. The salt level in the soils remains although leaching was done. Because of existing heavy soils (clay and silty loams) in the Khuzestan plain, the capillary uprise can be estimated to be at least around 50 - 70 cm. Within current subsurface drainage systems, capillary dynamics that are dominating after irrigation stop lead to a re-salination of soil resources. Deep drains lead to additional saline drainage water quantity and salinity. These processes are illustrated in Figures 3 and 4.

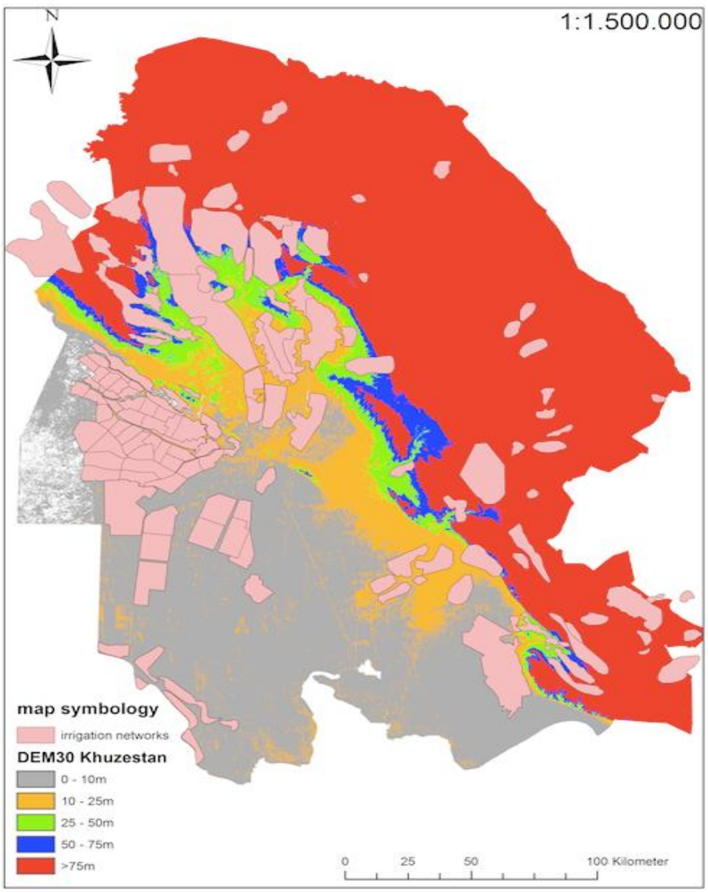


Figure 1: Map of surface level above sea level (Khuzestan Province)
Data Source: KWPA

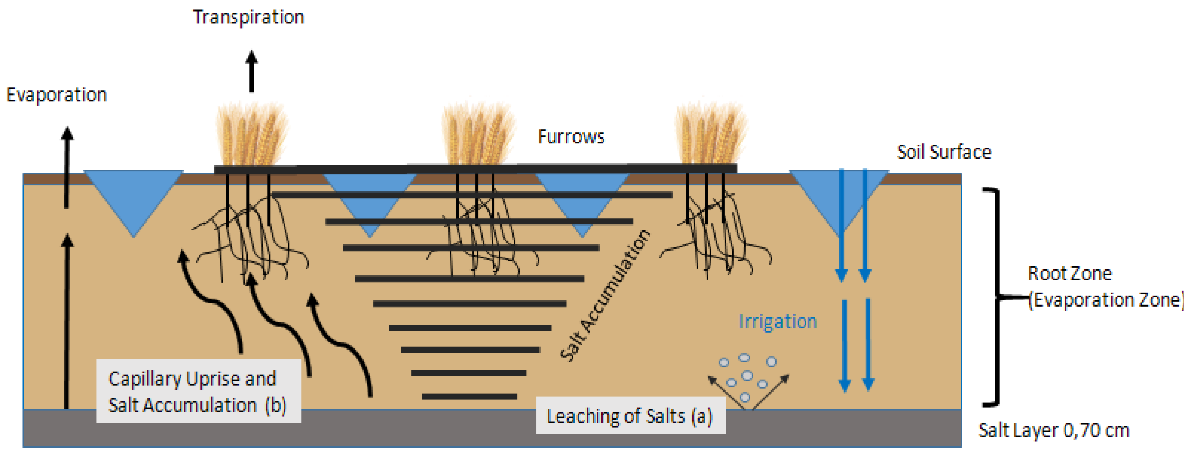


Figure 2: Furrow irrigation and leaching (wheat crops) on saline soil, no groundwater, no sub-surface drainage

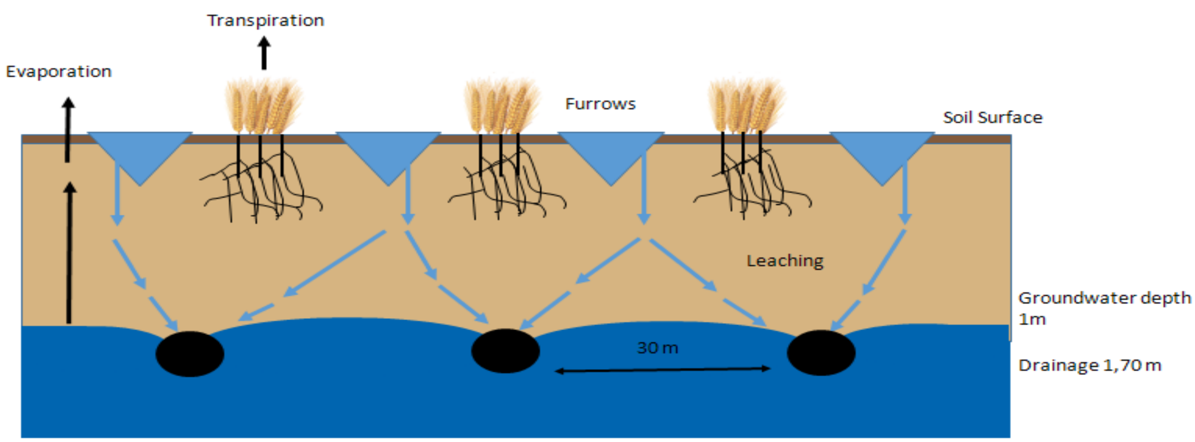


Figure 3: Furrow irrigation and leaching (wheat crops) and subsurface drainage on saline soil with saline groundwater

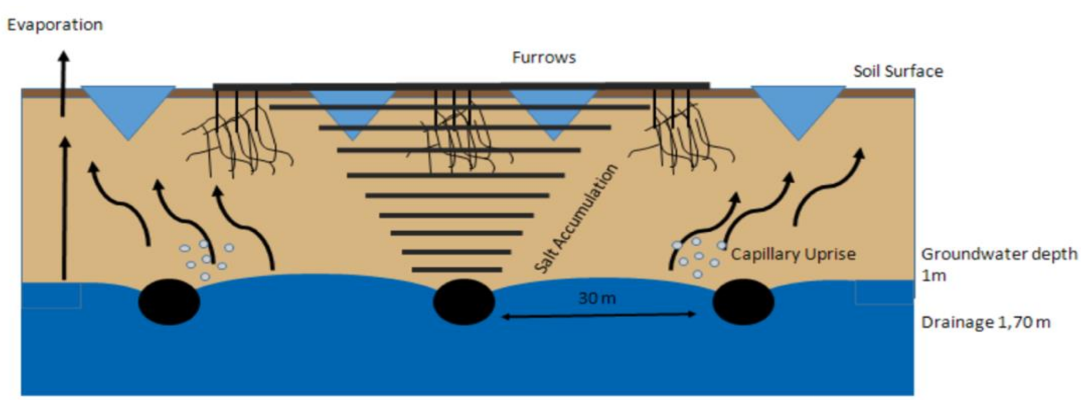


Figure 4: Salinization after furrow irrigation (wheat crops) and subsurface drainage on saline soil with saline groundwater

Proposed drainage water management solutions

Establishing a broader context that facilitates the design of an IWRM approach which positively affects Khuzestan´s natural resources and in turn its society should be a main concern in current strategic planning. As there is an urgent need to overcome drainage water mismanagement circumstances, especially in some southern and western areas, several effective short-term solutions are needed. However, as the overall achievement should be to design and implement a sustainable Integrated Drainage and Wastewater Management System, long-term solutions are equally as important.

Reviewing factors responsible for high volumes of saline ADW in Khuzestan draws a multi-layered picture:

Factors leading to high volumes of saline drainage water in Khuzestan:

- predominance of evaporation over rainfall in non-irrigated lands and anthropogenic influences
- heaviness of soil texture and improper soil drainage conditions (insufficient natural drainage)
- over-drainage (due to over-irrigation, low water use efficiencies)
- improper drain depths and a lack of suitable outlets (Akram et al. 2013)
- additional groundwater pumping: drain water salinity is highly affected by groundwater salinity due to deep drainage (Pazira and Homaee 2010)

Related management strategies should therefore aim on both the quality and quantity of irrigation and drainage water. Embodying monitoring and control devices, ADW re-use strategies as well as water treatment, namely desalination, are seen as key approaches.

Reduction of the amount of irrigation and leaching water (long term solution)

Due to Khuzestan´s semi-arid and arid climate the need to irrigate lands for successful agriculture exists. Whereas precipitation during June-September (Khordad-Shahrivar) is very low e.g. between 0.1 mm to 0.5 mm in Dezful and Hamidiyeh, the evaporation is much higher, e.g. between 322.12 mm to 449.82 mm in Dezful and Hamidiyeh leading to negative water balances. However, from December-March (Azar-Esfand) the precipitation is high e.g. between 25.22 mm to 72.22 mm in Dezful and Hamidiyeh. Contrary, the evaporation is much lower, e.g. between 53.74 mm to 99.11 mm in Dezful and Hamidiyeh. Figure 6 indicates that the annual climatic water balance varies significantly within Khuzestan. Based on these conditions, it is assumed that agricultural drainage water management problems mostly exist during the winter period December-March (Azar-Esfand).

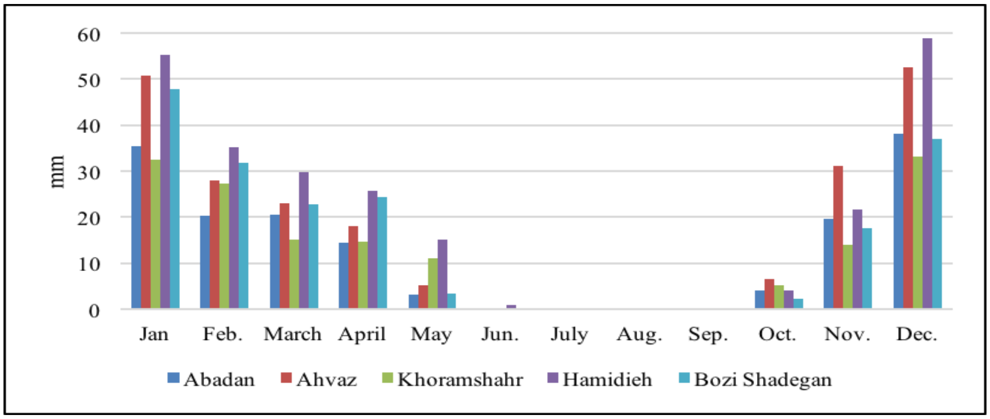


Figure 5 Monthly average rainfall in selected meteorological stations in Khuzestan
Data Source: DCE (2009)

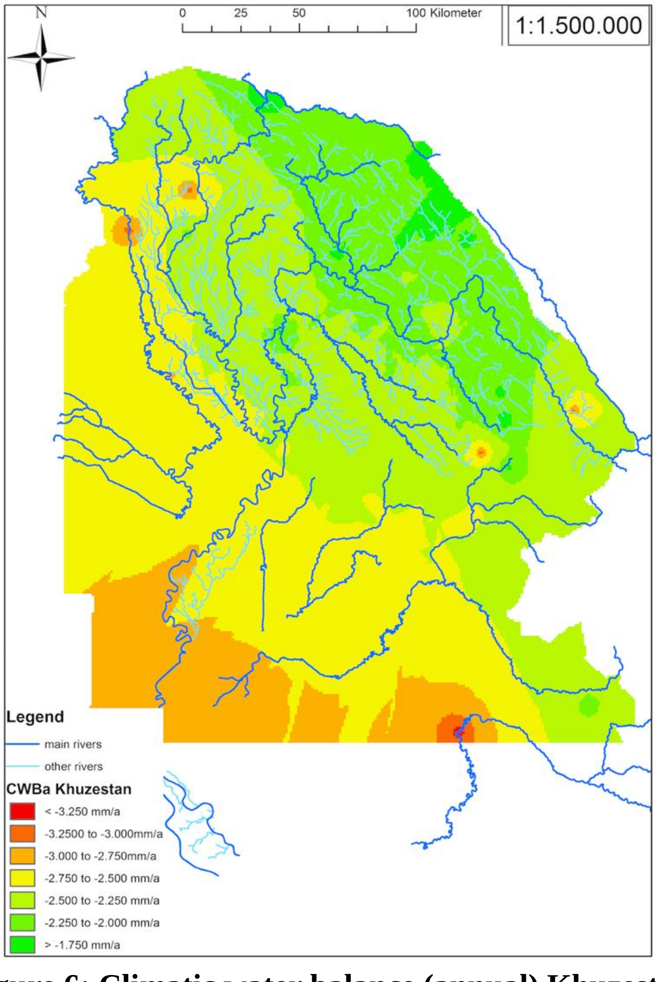


Figure 6: Climatic water balance (annual) Khuzestan
Data Source: KWPA

The annual over-use of water for irrigation is a major problem in Khuzestan. Hence, increasing water use efficiencies automatically leads to a reduction of the amount of the water that enters the drainage network and hence to less drainage water volumes.
Big gaps exist between water delivery from main canals and water application in the field. The emphasis has been much more on the developmental side of water resources instead of sustainably managing existing water resources. High rates of groundwater extraction worsen the situation and due to annual overdrafts, groundwater tables are declining in many areas (Ul Hassan 2007).

One main challenge is to improve the efficiency within existing irrigation techniques: In most parts of Khuzestan, farmers are mainly using traditional irrigation techniques such as furrow irrigation, basin irrigation and border irrigation schemes. There are very few instances of pressurised irrigation systems on large area farms. The comparison between irrigation efficiencies of different systems (surface vs. pressurised systems) shows a big difference in the suitability of the respective method.
Table 1 shows selected irrigation and drainage networks located in the Karun-Dez River basin. In some networks pressurised systems have already been installed (at least partly), whereas in others surface irrigation is the prevailing irrigation technique. Comparing the lowest overall efficiency (Gotvand, 40%) and the highest (Balarood, up to 68%) reveals that pressurised irrigation systems like sprinkler and drip irrigation, can be a better irrigation method, if properly managed.

Due to higher water use efficiencies, pressurised irrigation methods like sprinkler and drip irrigation can increase the surface area under cultivation with the same amount of water compared to traditional surface irrigation techniques. Planning should not only consider new investments into irrigation technology but to optimally equip the respective areas based on local circumstances such as geological conditions and financial budgets. While pressurised approaches can be more effective for irrigation, leaching of saline soils is a prerequisite in some areas. Depending on local conditions, leaching requires surface irrigation methods. Hence, for some cases, a combination of pressurised and surface irrigation methods will be a valuable approach in order to increase yields while saving water.

If the transition of surface irrigation towards pressurised systems is not possible to realise, it is suggested for water resource management to focus on the improvement of the existing system. If these systems are designed well and practiced properly by the farmers, they could still achieve reasonable irrigation efficiencies and fair distribution uniformities in the field without using huge amounts of energy and high costs that are associated with the use of pressurised systems (Heydari 2015).

Table 1: Efficiencies and types of irrigation and drainage in selected networks (Karun Dez basin)

Irrigation and Drainage Networks	Efficiency (%) Overall	Irrigation System	Drainage System
Gargar	65	covered canal + storage basin + pump st. (sprinkler irrigation)	
Mianbandan Shushtar	50	covered canals + pipes (sprinkler, drip, centre pivot)	surface and subsurface
Dez	54	Surface, furrow, basin and border	Surface, sub-surface, concrete canal
Gotvand	40	Border, Basin, Furrow, Sprinkler	
Balarood	64-68	sprinkler-drip- border - furrow and basin	surface; gravity

Data Source: KWPA

Note: If increasing irrigation efficiency equals an expansion of agricultural areas (more fields, higher yields) which requires more additional inputs such as fertilizer and pesticides, the impacts on water quality due to changes in the intensity of cultivation must be considered.

Establishing irrigation control systems

Establishing irrigation control systems based on modern technology to increase water use efficiency will be another step towards reducing the amount of ADW. The incorporation and adaption of historical and future climatic data as well as respective crop water demands is, beside water-saving irrigation technologies, of highest importance towards an increased water use efficiency.

The fact that drainage water discharge lead to an overflow of evaporation ponds and wetlands in Khuzestan means, that the amount of irrigation applied is mostly higher than PET rates. The over-calculation of irrigation water within all irrigation networks of Khuzestan can be seen as one major mechanism leading to the high amounts of drainage water. In order to establish effective irrigation control systems, weekly evaporation rates of respective reservoirs have to be the base for calculations of the required amount. PET rates (mm) accumulated in million m^3 are a basic threshold for irrigation water supplied throughout the year (Tables 2-3). By making use of these factors, respective threshold capacities of drainage discharge structures (e.g. evaporation ponds, wetlands) can be estimated as shown in Tables 4-5. The two examples, Korramshar and Hur ol Azim, can be seen as “hotspots” in terms of ADW mismanagement. Respective drainage water structures as well as their locations are presented in Figure 5.

As climatic data as well as irrigational practices change throughout the course of the year, automated, flexible control technologies, based on weekly or even daily values are needed. As further important input data like salinity of soils and groundwater as well as crop specific water demands do not exist in areas of interest, the scope of research and data collection has to be extended in order to establish adaptive irrigation control systems. By the controlled provisioning of additional water not only the expected improvement of water use efficiencies but also higher yield performance, yield security and product quality can be achieved. This considerably contributes to environmental protection as it leads to controlled nutrient cycling in the soil with optimum soil moisture content and decreased nutrient leaching. For a field-related optimum control of irrigation, information about the course of the weather, soil type, plant stock and irrigation technologies and techniques applied are needed. An example of a commercial irrigation control system presents IRRIGAMA. It can be described as an internet-based modular built expert and management system that is comprehensible and manageable in practice in field-related conventional and integrated agriculture.

Beside quantity control, the establishment of an additional quality monitoring system for irrigation is essential. As irrigation water is almost exclusively taken from surface water bodies without prior treatment, the existing hydrometrical monitoring stations, established and supervised by KWPA, are currently the main institutions for quality control. Additionally, Web GIS, a web-based data portal that delivers basic functionalities on GIS base, would be a valuable extension. GIS in general can deliver huge possibilities and offers an almost infinite amount of tools and functionalities. By incorporating Web GIS, the actual status of the existing water management system could be greatly transformed towards more accuracy and flexibility.

Table 2: Monthly evaporation rate (in Mio. m^3) in the reservoirs Khoramshahr (2005-2014)

Month	Station Bozi Shadegan	Reservoir 1 114 km^2	Reservoir 2 145 km^2	Reservoir 3 66 km^2	Reservoir 4 54 km^2
October	300,71	34,28	43,60	19,85	16,28
November	161,71	18,43	23,45	10,67	8,73
December	92,94	10,59	13,48	6,13	5,02
January	70,82	8,07	10,27	4,67	3,82
February	78,79	8,98	11,42	5,21	4,25
March	126,04	14,36	28,27	8,32	6,81
April	174,43	19,88	25,29	11,51	9,41
May	318,65	36,33	46,20	21,03	17,20
June	442,75	50,47	64,20	29,22	23,91
July	497,98	56,76	72,21	32,87	26,87
August	490,89	55,96	71,18	32,40	26,51
September	428,89	48,89	62,19	28,30	23,16
sum	3184,60	363,00	461,67	210,18	171,97

Data Source: KWPA

Table 3: Monthly evaporation rate (in Mio. m^3) in the reservoirs Hur ol Azim wetlands (2005-2014)

Month	Station Hamidiyeh	Reservoir1 84 km^2	Reservoir 2 293 km^2	Reservoir 3 147 km^2	Reservoir 4 304 km^2	Reservoir 5 182 km2
October	226,25	19,00	66,29	33,26	68,78	41,18
November	139,72	11,74	40,94	20,54	42,47	25,42
December	63,37	5,32	18,57	9,32	19,26	11,53
January	46,78	3,93	13,71	6,87	14,22	8,51
February	68,24	5,73	19,99	10,03	20,74	12,41
March	116,47	9,78	34,12	17,12	35,41	21,20
April	200,45	16,84	58,73	29,47	68,15	36,48
May	286,02	24,03	83,80	42,04	86,95	52,05
June	399,45	33,55	117,04	58,72	121,43	72,70
July	442,62	37,18	129,69	65,06	134,56	80,56
August	416,18	34,96	121,94	61,17	126,52	75,74
September	347,02	29,15	101,17	51,01	105,49	63,15
sum	2753,45	231,29	806,67	404,75	837,05	501,13

Data Source: KWPA

Table 4: Capacity in mio m^3 for the reservoirs 'Khoramshahr' at 1m and 2m depth

depth	Reservoir 1 (114 km^2)	Reservoir 2 (145 km^2)	Reservoir 3 (66 km^2)	Reservoir 4 (54 km^2)
1m	114mio m^3	145mio m^3	66mio m^3	54mio m^3
2m	228mio m^3	290mio m^3	132mio m^3	108mio m^3

Calculations: HU Berlin

Table 5: Capacity in mio m^3 for the reservoirs 'Hur ol Azim wetlands' at 1m and 2m depth

depth	Reservoir 1 (84 km^2)	Reservoir 2 (293 km^2)	Reservoir 3 (147 km^2)	Reservoir 4 (304 km^2)	Reservoir 5 (182 km^2)
1m	84mio m^3	293mio m^3	147mio m^3	304mio m^3	182mio m^3
2m	168mio m^3	586mio m^3	294mio m^3	608mio m^3	364mio m^3

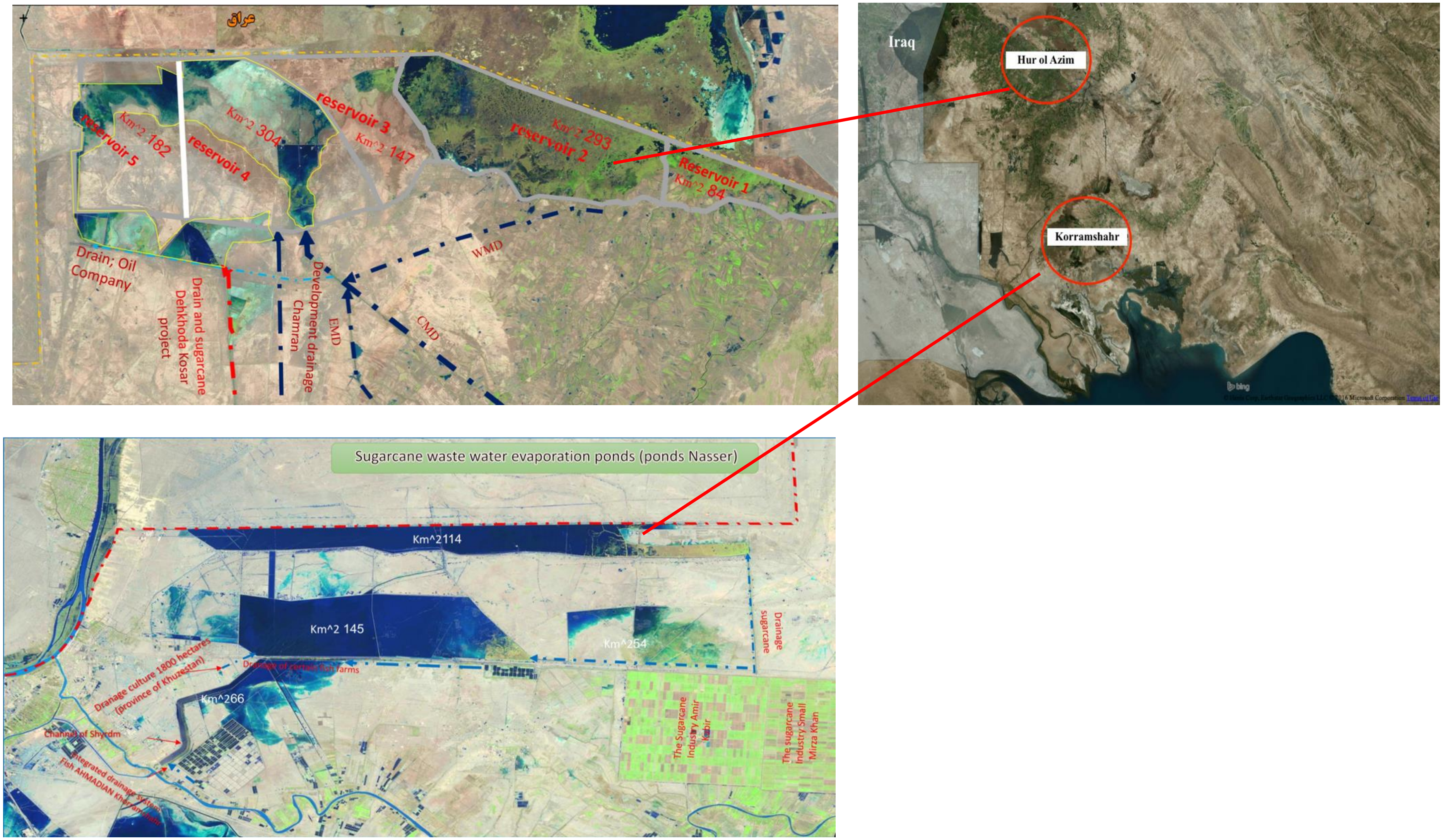


Figure 5: Hur ol Azim and Korramshahr drainage water structures (Data Source: Bing Maps 2016)

Redesign of drainage systems in areas affected by shallow and saline groundwater (long term solution)

In many low-lying parts of Khuzestan, the amount of drainage water is higher than the amount of irrigation water plus leaching rate because of pumping of additional groundwater into the main drains.

Within these areas, it is important to separate the highly saline deep drainage effluent from the leaching and irrigation drainage water. This would positively influence resulting drainage management and reuse strategies in the long run.

In order to solve the problem of saline soils in combination with shallow saline groundwater (<2.00 m under surface), a solution would be to firstly install a dewatering system (deep groundwater drainage) in order to control the groundwater table. In a second step the construction of separate drainage systems that exclusively take care of irrigation and leaching water follows.

Figure 6 illustrates the process: as the groundwater level will be kept low throughout the year by System II and the leaching effluent will be drained by System I (leading to less soil moisture), the evaporation rate will be lower and successful desalinisation can take place.

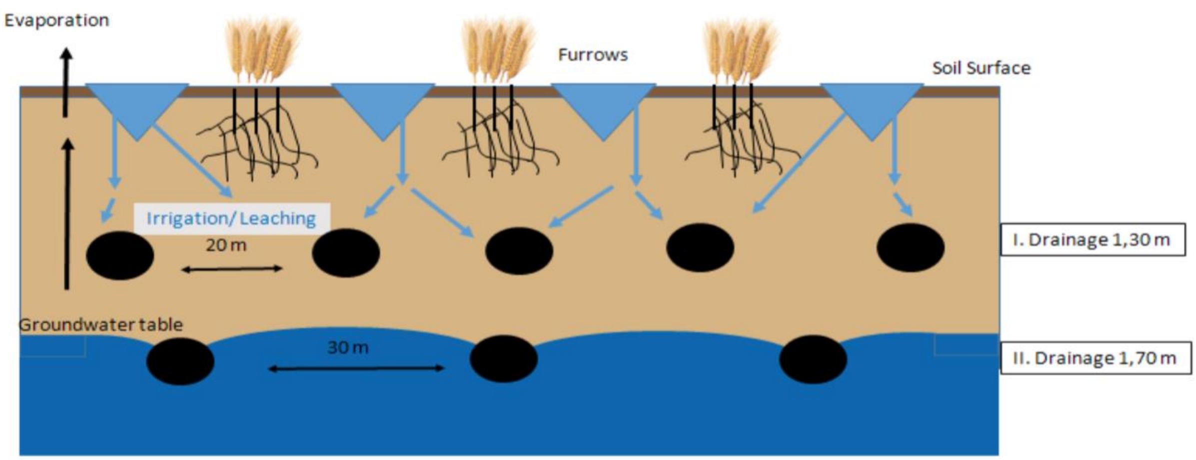


Figure 6: Furrow irrigation (wheat crops) and subsurface drainage on saline soil with saline groundwater (first: dewatering/ second: leaching)

Resulting drainage water within upper soil layers will be less saline over time (as desalination of the soil took place due to efficient irrigation and leaching). Hence, drainage effluents from shallow drainage outlets (1,30 m) can potentially be reused directly without treatment for reuse strategies like the use of salt-tolerant crops or directly discharged into rivers. Highly saline waters should be kept separated from the less saline water supply, to be disposed of in a salt sink.

As the groundwater level will be kept lower (Drainage II) throughout the year and the irrigation/ leaching and precipitation effluent will be drained by System I (leading to less soil moisture), the evaporation rate will be much lower which affects water use efficiencies positively.

Further solutions related to drainage redesign is the establishment of **ring drainage systems** or to install **open ring channel** (moats) systems combined with subsurface drainage. Also here, the saline soil can be leached and drained successfully as no salinisation occurs in the long run and the soil´s salt balance can be lowered significantly over time.

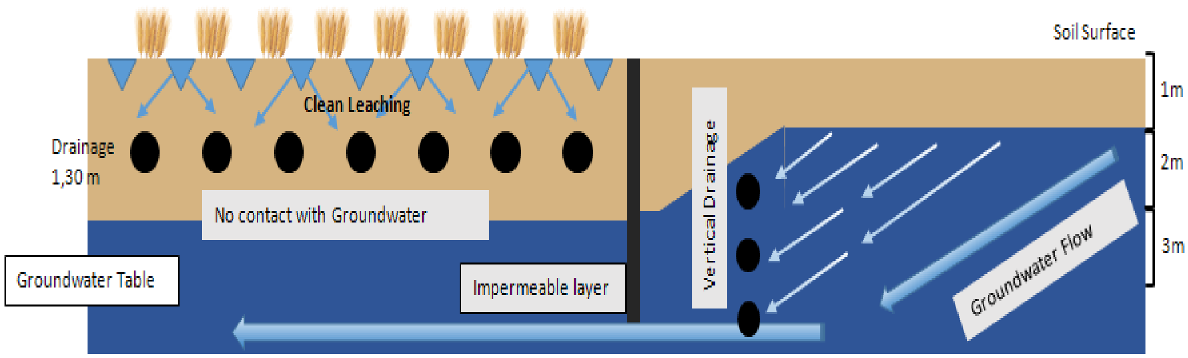


Figure 7: Vertical drainage solution

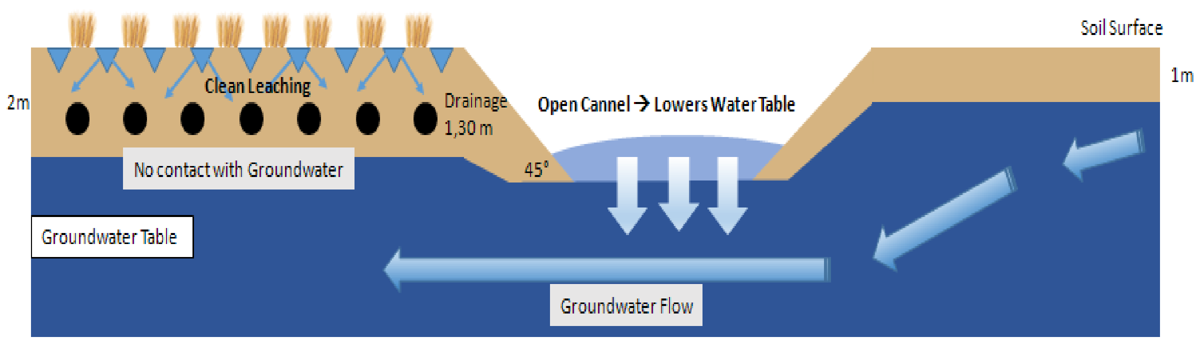


Figure 8: Open ring channel solution

Note: To validate the functionality of the proposed systems at different depths, further data collection and field testing are required. Calibrating and evaluating the subsurface drain flow in order to simulate effective soil and water balances are further important measures to take as part of detailed drainage design planning. Effective simulation should be based on flow data such as saturated and unsaturated hydraulic conductivity, effective porosity and spatial variability in soil and groundwater properties among other factors. Based on such results it can be decided which system would be effective, or if cheaper alternatives are more effective.

Establishing drainage water control systems (long term solution)

Amount of drainage water in Khuzestan

In order to establish valuable long term solutions, a discharge control system in all relevant main drains should be implemented. To fulfil this task, automatisation and control systems in all relevant drainage pump stations/ outlets have to established. Moreover, the establishment of institutions responsible for drainage quantity management, e.g. a Dispatching and Control Centre, as part of the drainage water management by KWPA has to be established. It is of highest importance and a very basic requirement for sustainable IWRM to have full control of pumps and other forms of outlets in order to be able to directly influence discharges and indirectly river and drainage water quality.

As modern irrigation and drainage systems are complex units that are interrelated by the interaction at various levels, systematic modelling is necessary to provide sufficiently accurate information for evaluating drainage water management scenarios. Changes in quantity (and quality) of reused drainage water cannot be predicted merely from historical data. Water management, cropping patterns, climate change are interrelated processes that all affect drainage water management. Therefore, the modelling of allowed drainage water amount discharges into wetlands, based on weekly evaporation rates and other relevant data (2005-2014), is an absolute necessity.

Quality of drainage water (long-term)

As described earlier, water monitoring involves quantity and quality and has to be performed on a regular basis, both at the field level by the farmer and at the catchment level by the water authorities. Management for safe reuse and disposal requires an understanding of the qualitative characteristics of the drainage water, and a matching of those characteristics to the environmental protection needs of the reuse or disposal area. Drainage water is no different from any other water supply and is always usable for some purpose within certain quality ranges. Beyond these limits, drainage water must be disposed of in a manner that safeguards the usability or quality of the receiving water for present established and potential uses (FAO 1997). Hence, quality parameters should be frequently monitored and evaluated. Within the drainage water quality control system, especially salinity values (like EC) should be monitored in all relevant main drains. Regarding the biological filter function of a soil, subsurface drainage water in Khuzestan is not expected to have high levels of pesticides or micro-organisms. It is mainly salt that is captured by a subsurface drainage system. Hence drainage effluents are often highly concentrated with the major cations and anions. These are common non-toxic elements that only become problematic when concentrated in the soil.

Only by quality control of drainage water further reuse options can be assessed. As it is the case for irrigation control, drainage water control systems can be realised by Web GIS and should be evaluated within the near future.

An example of an integrated ADW modelling approach under arid/ semi-arid climate conditions is given with the SIWARE model package. SIWARE stands for Simulation of Water Management in the Arab Republic of Egypt. It has been developed as a decision-support system in 1984 for the Irrigation and Planning Sectors of the Egyptian Ministry of Public Works and Water Resources. SIWARE segments the irrigation and drainage system networks and evaluates all the hydrologic, hydraulic, soil, and crop input data. Hence, various water management scenarios can be calculated. (Anonymous 1995)

Note: In addition to river and drainage water quality assessment, groundwater quality conditions in terms of salinity have to monitored.

Reuse of drainage water

Reuse options are highly variable and differ in terms of geography and quality. Several ways of how to reuse drainage water exist. Realistic reuse solutions for Khuzestan could be:

- Reuse for salt tolerant crops
- Reuse as water for irrigation (either directly or in conjunctive use)

The quality of the drainage water decides which process could be used. Hence, to assess appropriate reuse options, drainage quality monitoring has to be implemented.

If salinity levels don´t exceed certain thresholds several reuse possibilities arise. If, for instance, at certain drains, the ADW has a salinity of less than 3 mS/cm, it can be directly reused for irrigation. If at other parts, salinity levels are higher than 3mS/cm and less than 10-20 mS/cm, the water could be used for irrigating salt tolerant crops or blended with fresh water sources to create water for irrigation. If ADW discharges exceed certain salinity thresholds, treatment or disposal options can be considered.

If ADW is hygienically unsafe, it should not be used for agricultural production without treatment. Hence, drainage water management involves flexible integration of several reuse strategies and eventually treatment if the drain outlet quality is too low for direct reuse.

In terms of crop substitution for drainage water reuse, further investigation has to be made in order to select currently available species for areas within Khuzestan. Salt tolerant trees and bushes for fuel and forage production, for instance, can be irrigated with highly brackish waters (e.g. 19 dS/m). Where irrigation water is too saline to grow conventional agricultural crops, halophytes might be a valuable option. Integrated Seawater Energy and Agriculture Systems (ISEAS) that integrate salt tolerant species and aquaculture could be another way to reuse saline drainage water in Khuzestan.

A key strategy to prevent major overflow scenarios due to high discharge volumes of drainage water is to combine certain drainage water management strategies. Along main drains several methods can be installed in order to use or discharge drainage water flows. These strategies can be perfected in ways that not only total discharge volumes can be significantly reduced, but also important reuse strategies can be implemented (e.g. aquaculture, salt tolerant crops). Figure 7 shows examples of how to combine reuse and discharge solutions within discussed areas.

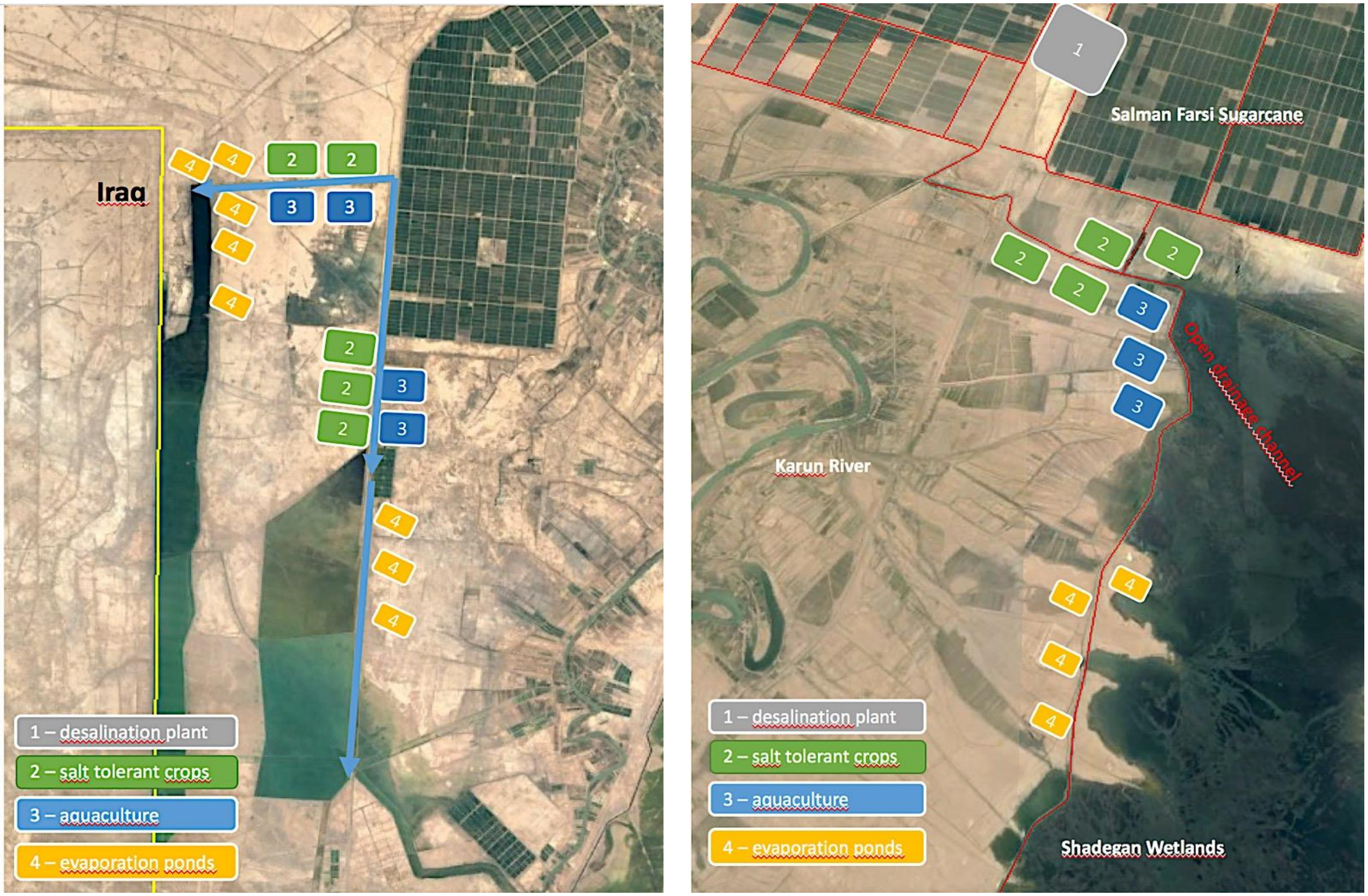
Note: Changing quantity and quality of drainage water directed into wetlands has the potential to affect environmental and social functions of wetland ecosystems. Flora, fauna, flood control and tourism are examples for areas that might be affected. This has to be taken into account in particular for the Shadegan Wetlands, an UNESO Ramsar convention listed site.

Discharge solutions (Arvand River)

Potential discharge solutions for untreated drainage water within Khuzestan are mainly evaporation ponds and wetlands. As already mentioned, it is important to incorporate several reuse and discharge options along main drains that are currently directed into wetlands.

Clearly ADW can be a valuable resource which should be reused in some way if somehow possible (Qadir 2015). One strategy to gain economic benefits from disposing ADW inland would be to use untreated ADW in solar ponds before final disposal. Solar ponds involve constructing deep ponds that allow collection and storage of heat energy in hypersaline water for direct use (e.g. drying ovens) or generating electricity (e.g. using heat-exchange systems to drive a Stirling cycle engine coupled with an AC generator) (Degens 2009). Salt harvesting by evaporation dynamics presents a further potential option that combines discharge and reuse options in a sustainable manner. Regarding the intrinsic necessity of water within southern plain areas of Khuzestan, it should always be of highest priority to reuse drainage water. In order to reduce discharge amounts into wetlands, evaporation ponds should be integrated along main drains. The effect of evaporation dynamics of saline water on surrounding environments (soil, surface water) has to be assessed before construction starts.

Another possible solution is to discharge drainage water into the tidal river Arvand, flowing along the border to neighbouring Iraq. The discharge of drainage water into the saline Arvand River is possible, but highly influenced by the border demarcation (Iran – Iraq). The border situation has to be considered carefully and resulting diversions of main drains planned accordingly. Figure 8 shows a former proposal to discharge the drainage effluent into the Arvand River in close proximity to the border. As political circumstances and regulations about discharging drainage water into neighbouring states can be a very sensitive topic, another solution should be considered. Figure 9 shows the proposed solutions. In this case, drainage water is directed via open drainage channels parallel to the Karun River before it gets discharged into the Arvand River. This would put less pressure on the wetlands of bordering Iraq. Due to high volumes of drainage water, piped solutions would technologically and economically not be feasible. In terms of discharging drainage water into the Arvand River, the best possible outlet location has to be defined. In the solution proposed (Figure 9), the main drain will be directed far enough away from the border in order to prevent political confrontation between Iran and Iraq.



Data Source: Google Earth 2016

Figure 7: Examples of integrating drainage water management solutions in study areas

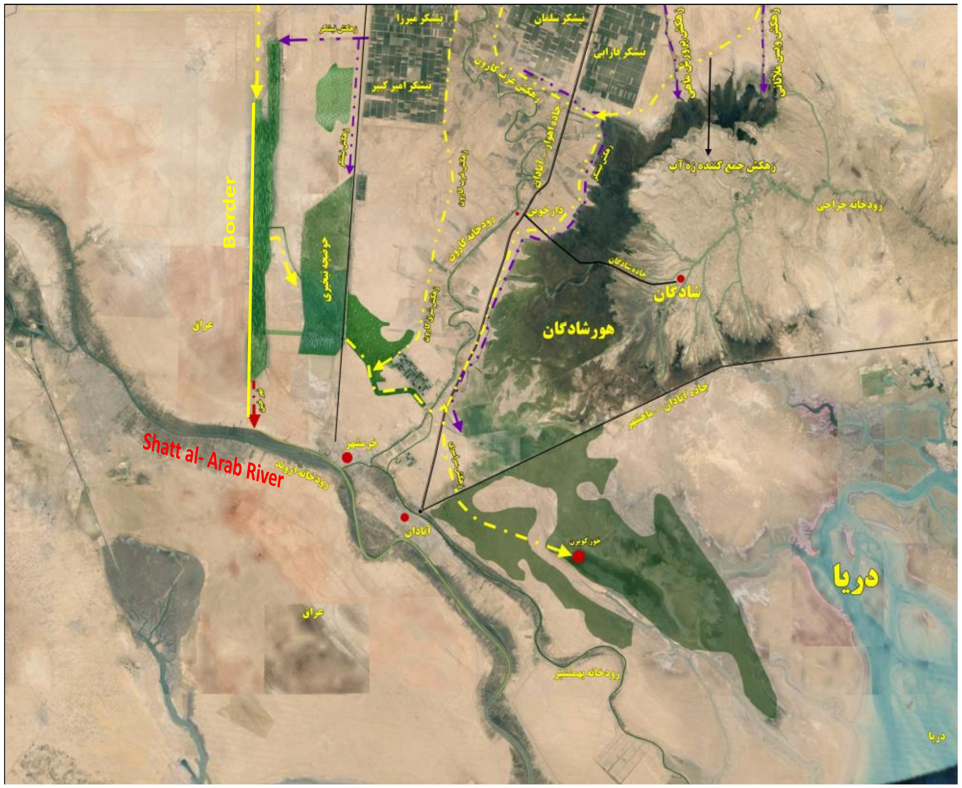


Figure 8: Proposal to divert drainage water into Arvand river via open drainage channel

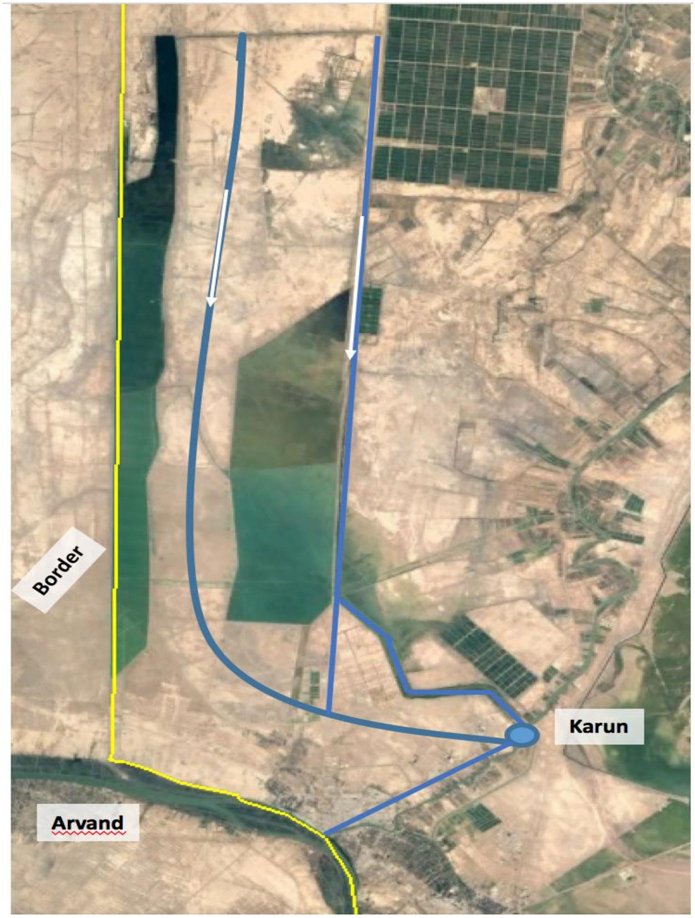


Figure 9: Proposal for diversion of open drainage channel into Arvand River parallel to Karun

Desalination

Feed water for desalination can be sourced from a range of locations including seawater, brackish/ fresh ground or surface water as well as waste water. The quality and consistency of the feed water is important, as it will affect the performance of the downstream treatment processes (UNESCO 2008).

Table 6: Different concentrations of TDS in forms of raw water

Description	Dissolved solids (mg/l)
Drinking Water	< 1.000
Mildly brackish	1.000 - 5.000
Moderately brackish	5.000 - 15.000
Heavily brackish	15.000 - 35.000
Seawater	35.000

(Data source: Clayton 2015)

All desalination engineering processes underlie the same principle: a stream of saline water is fed to the process equipment, a specific form of energy (heat, water, pressure or electricity) is applied and two outlet streams are produced: a stream of desalinated water (product) and a stream of concentrated brine (retentate or concentrate) which has to be disposed of (Clayton 2015).

Around the globe, more than 99-percent of the technologies used for desalination of feed water can be divided into few approaches, namely membrane and thermal technologies (Dietrich 2013). Membrane desalination plants produce potable water by separating molecules, while thermal desalination plants work by breaking bonds between water molecules (UNESCO 2008).

In Khuzestan, desalination plants could potentially be incorporated into already existing industries and other forms of energy-dependent infrastructures. Here the process could be set up by using wasted heat or open power capacities as energy sources. Examples are petrochemical plants, refineries, off-shore facilities, power plants, pharmaceutical and food industries, inorganic and metal industries, textile, pulp and paper and drinking water producers along the Karun-Dez River network. Resulting product water could be directly reused for internal processes or sold as fresh potable water. This possibility needs to be investigated further.

Moreover, renewable energy sources like wind and solar power, maybe in form of off-grid systems, can be combined with desalination facilities. This possibility presents a viable option towards decentralised structures which implies a higher degree of independence from public energy

networks. Regarding Khuzestan´s climatic conditions, renewable energy potential coupled with desalination technologies could be economically and environmentally interesting for future scenarios.
Hereby Pilot and Demonstration Projects (PDP) would be a good option for respective field testing in remote areas that are located further away from existing energy infrastructures.

Current desalination processes within Khuzestan are mainly focussing on purifying river water (especially from the Karun). It is argued, that respective water quality is decreasing making water treatment processes very challenging. Installing desalination plants along main drains instead might be a better option. In particular ADW is naturally filtered to some extend by infiltrating the soil. The soil´s biological filtration function reduces contaminants stemming from microorganisms, pesticides or bacteria (FAO 1997). Treating drainage water that has already been partially filtered by the soil instead of river water containing a variety of pollutants could be beneficial as technological, economic and energy requirements might be lower. Hence treating and reusing drainage water instead of other water sources might entail energy and water saving potentials which in turn have positive environmental effects. Key data regarding technological requirements and drainage water quality (e.g. salinity parameters) for establishing effective desalination concepts have to assessed within pre-feasibility studies.

Connecting desalination plants with singular drains within Khuzestan would facilitate the integration. Within this strategy monitoring drainage water quality and quantity would be easier if compared to an approach that integrates desalination along main drains that are subject to multiple drain inlets (all affecting water quality and quantity). Directly connected to the drains of single producers, it can be expected that the feed water input can be controlled more effective.

At the present time, drainage structures located in the Karkhe, Dez and Karun River basins mainly discharge into wetlands and evaporation ponds of western and central Khuzestan, whereas drainage structures located in the Maroon and Zoreh River basin, discharge via eastern Khuzestan into wetlands connected to the Persian Gulf. No drainage water reuse strategies are currently implemented and vast amounts of water are lost on a daily basis. Especially cities like Ahvaz will face difficulties in meeting fresh water demands in the near future. Climatic changes, population, industrial and urban growth all lead to a steady deterioration of surface water quality and quantity. Treating and reusing drainage water will help to improve this situation.

As far as desalination presents viable potentials within the study region, occurring limitations such as further R&D requirements, high capital and operation costs and the necessity of operator expertise have to be considered. Moreover, the disposal of brine is highly cost intensive. It is argued, that if a desalination plant is further than 80km away from the ocean, or if treated water has to be piped over a compelling distance, the economic as well as environmental costs become too high for the technology to be viable (Weidler et al. 2009). Following this argument, for vast parts of the study region the concentrate management dilemma would arise. Brine discharge inland can affect the physical and mechanical properties of the soil (e.g. structure, the degree of dispersion of soil particles, permeability, and stability of aggregates) which in turn can have detrimental effects on plants and other parts of the ecosystem.

In general, the question about the ratio of desalination costs and costs of drinking water, related to water pricing, has to be examined further.

Note: Integrating desalination and other treatment systems by coupling multiple units can be also done within and not solely at the end of a drain. Deciding which flows will need treatment and when will help in deciding which treatment approaches might be needed (Degens 2009).

Conclusion: Concept of an all-functioning Integrated Drainage and Wastewater Management System for Khuzestan

The main factors responsible for high amounts of saline ADW within Khuzestan´s plain region were identified:

- inefficiencies within irrigation management: the use of water for irrigation and leaching at a rate greater than the evapotranspiration rate leads to higher amounts of drainage water than necessary
- high salinity of Karun River water, which is the main source of irrigation within respective parts of the study region
- heaviness of soil texture and improper soil drainage conditions (insufficient natural drainage)
- over-drainage due to deep drains that continuously pump saline groundwater; 70% of agricultural farm land in the Khuzestan plain is confronted with shallow and saline groundwater levels
- if groundwater levels are higher than 2 m under surface, saline groundwater + irrigation water + leaching water all contribute to increasing the amount of drainage water with high salinity
- saline soils: irrigation and leaching washes out soluble salts, which in turn lead to ADW with high salinity
- lack of waste water treatment and reuse solutions for drainage water
- lack of control structures for water extraction and return flows in terms of quality and quantity; e.g. monitoring, modelling
- municipal, industrial and agricultural pollution sources (drains into river)

Resulting discharges of saline drainage water are likely to exceed the EC threshold of 3 mS/cm by multiple times and can´t be redirected into the river system. Currently, no water reuse or treatment facilities exist. Hence, main drains are being either directed to Western wetland structures in close proximity to bordering Iraq or to Shadegan Wetlands in close proximity to the Persian Gulf.

Figure 10 illustrates and locates recommended strategies in order to implement a sustainable Integrated Drainage and Wastewater Management System in all its entirety. As can be seen, the first and most urgent step is to manage present drainage water flows in order to overcome current environmental dangers and social conflicts. The next step is to strategically think about how to manage future drainage flows in order to prevent further environmental/ socioeconomic conflicts and to enhance water reuse strategies. Last but not least, it is important to manage agricultural water supply, namely irrigation. Respective tasks can be seen as the base of the integrative management system as water input by irrigation and leaching is one of the biggest factors determining drainage water output. The three spheres important to embed in every IWRM system are science, technology and policy. Only policy itself can guarantee safe and effective technology and knowledge transfer, whereas the prerequisite for all systemic parts is a well-rounded academic approach that facilitates the R&D process. Hence further investigation in order to facilitate hollistic IWRM approaches is urgently required.

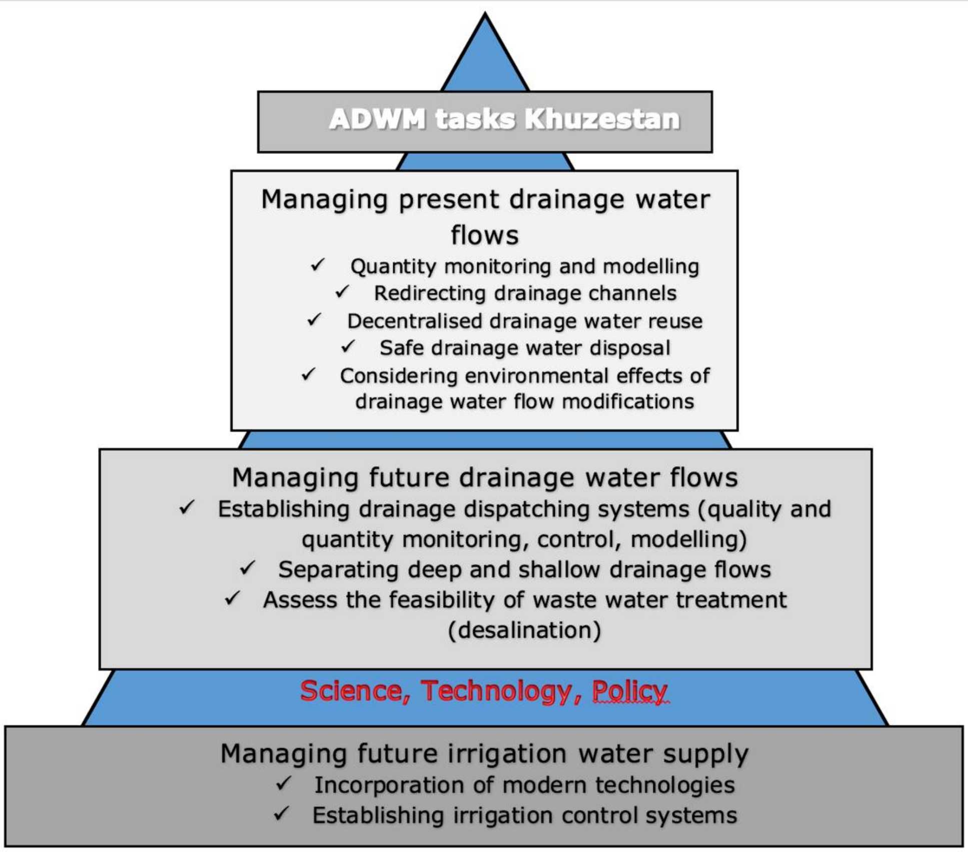


Figure 10: Integrated Drainage and Wastewater Management System Khuzestan

A) Managing present drainage water flows

- Quantity monitoring and modelling based on climatic data:

  In order to assess the amounts of drainage water that can be directed into existing evaporation ponds and wetlands, respective thresholds (based on weekly PET-rates) have to be defined. Assessing maximum discharge allowances will help to overcome current discharge excesses and should be a first step in order to achieve an improvement of the present drainage water excess.

- Redirecting main drains into the Arvand River while taking care to avoid potential political conflict due to the river´s geographical proximity to the Iraqi border:
  A rough outline was given but construction of discharge points and channel systems require detailed planning based on field visits.

- Integrating decentralised drainage water reuse and disposal options in close proximity to drainage systems:
  Evaporation ponds and salt tolerant crops are potential solutions to minimise drainage water discharge amounts into wetlands. They can be installed easily and offer a cost effective management solution. Feasibility studies and PDPs within drainage systems can assess important factors regarding climatic data, drainage water quality, evaporation rates, salt harvesting options and suitable salt tolerant cropping patterns that make use of the soil´s biological filter function.

- Considering environmental effects of drainage water flow modifications:
  Wetlands will be especially affected by drainage water management. Consequences could be far reaching and involve several groups such as environmental conservation organisations (e.g. bird conservation) reaching international levels.

B) Managing future drainage water flows

- Establishment of an intelligent automation dispatching system (drainage), facilitated by modern technological solutions:
  - Quality monitoring and modelling of suggested parameters is of highest importance as the quality of drainage water determines possible reuse options (with and without treatment).
  - Quantity monitoring and modelling: Amounts of current and estimated future discharge with the possibility of efficient automation and control

  - Control system for all pumping stations and outlets

- Separating deep and shallow drainage flows:
  Highly saline groundwater conditions require a dewatering system facilitated by solutions such as double drainage. If saline groundwater is taken out of the drainage effluent, reclamation of saline soils will be more effective as capillarity will be decreased. Hence, leaching and irrigation will be effective processes of desalination and automatically enhance crop yields. The resulting drainage effluent will contain further reuse or discharge possibilities. Highly saline waters should be kept separated from the less saline water supply, to be disposed of in a salt sink. Here PDPs will contribute further information about how to proceed in the future.

- Assess the feasibility of waste water treatment solutions, namely desalination:
  Thermal processes, connected to existing power plants, using wasted heat could be a viable option. The product water is of high quality and has a variety of beneficial usages. Within ADW management, high quality product water could be blended with untreated ADW and/ or river water for conjunctive irrigation use. RO technology should be further examined and tested for local conditions. Renewable energy sources (wind, solar etc.), potentially off-grid, should be integrated. Treating saline drainage water instead of heavily polluted river water might be benefical in orde to meet Khuzestan´s potable water demands. Feasibility studies and PDPs are highly recommended in order to assess probabilities of realisation.

C) Managing future irrigation water supply

- Incorporation of modern pressurised irrigation technologies in order to increase water use efficiencies:
  If investment required for new systems is too large, investigations into the possibilities of modernisation of prevailing surface irrigation systems should be done. Planning requires field visits, which could be conducted as part of PDPs.

- Establishing irrigation control systems based on variable factors (climate, crops etc.):
  Web GIS and IRRIGAMA are suggested methods. PDPs and further investigations will clarify possible ways to incorporate intelligent, web-based control systems. Extensive and frequent quality and quantity control of existing pumping stations used for irrigational purposes is highly recommended.

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A CONCEPTUAL FRAMEWORK OF KHUZESTAN INTEGRATED WATER RESOURCE MANAGEMENT (KIWRM) FOR THE BEST OF SUSTAINABLE AGRICULTURAL AND SOCIO-ECONOMIC DEVELOPMENT (CASE OF KHUZESTAN PROVINCE, IRAN)

Frank Riesbeck[1,*], Md Zillur Rahman[1,] Simon Dupree[1], Hamid Reza Khodabakhshi[2], Arash Mahjoubi[2]

Abstract

The main objective of this paper is to present a conceptual framework (model) of holistic integrated management approach for improving the water use efficiency and agricultural development in Khuzestan, a south-western province of Iran. Given the observable impacts of rapid economic development in Khuzestan and climate change-based extreme conditions (in arid and semi-arid regions), there is a significant demand for a new strategy for sustainable soil/water resource management, agricultural and socio-economic development in Khuzestan. To address these needs a holistic management approach has been designed in this paper, which is based on contemporary literature review from the local and from examples of global contexts as well as collected data and factors of an ongoing empirical research project jointly with Humboldt University in Berlin and Khuzestan Water and Power Authority (KWPA). The main focus of the model is to emphasize the need of multiple approaches and inclusion of all relevant aspects (e.g. social, economic, environmental, policy, agri-crop pattern and technological), which affect the sustainable agricultural development in the province.

The framework is divided into four sub-models to cover broader aspects of agricultural development such as 1) Integrated River Water Management (IRWM), 2) Integrated Irrigation and Drainage System Management (IIDSM), 3) Integrated Drainage Wastewater Management (IDWM) and 4) Integrated Aquaculture and Fish Firm Management (IAFFM). The KIWRM model presented in this paper, is getting implemented through Pilot and Demonstration Projects (PDPs) on several 'Irrigation and Drainage Networks' KWPA. It is to emphasise that one way solutions for agricultural management hardly exist. Instead different strategies, timely adjusted and integrated into one system, are needed for sustainable management and to control the quality and quantity of water stabilizing Khuzestan´s agricultural and socio-economic development. Finally, an example of sub-model IDWM in Karun-Dez River area is presented in a separate paper to demonstrate how this sub-model is an integrated part of the complete (holistic management framework) sustainable water management in the province.

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KEY WORDS: Conceptual framework, Holistic Modelling, Integrated Water Resource Management, Social, Economic, Environmental, Policy, Agri-crop Pattern and Technological Aspect, River, Wastewater, Fish Farm, Irrigation and Drainage, Khuzestan, Iran.

Introduction

In global context, the impacts of climate change are posing huge challenges for water resource management and risking on the sustainability of natural resources (IPCC, 2014; Barros et al., 2015; Chen et al., 2015; Wood and Mendelsohn, 2015) and thus adaptation and mitigation have become the core issues in many countries (Havlík et al., 2014; Makkonen et al., 2015; Gelfand and Robertson, 2015; Domínguez and Fellmann, 2015, Nam et al., 2015). However, lack of necessary capacities to protect water resources are further contributing to water pollution through urban wastewater discharging without treatment, excessive use of pesticides, fertilizers and agrochemicals for agricultural production, release of prohibited or hazardous chemicals to water body (Wooster et al., 2005; Rahman, 2014; Robson, 2014; Hassan, 2015). All of these are contributing to increase the risks of climate change and environmental adaptation as well as posing threats to human health and livelihoods. Moreover, population in urban areas around the world has grown more than four times during the past 60 years to 3.9 billion (Sun, Michelsen et al. 2015). According to UN global urbanization is progressing at an unparalleled speed (van Leeuwen and Sjerps 2015). Presently, about 50 % of people live in cities and by 2050, it will be 67 % (Lyons 2014, UN, 2012). In developed countries, this percentage is even higher (more than 86 %). This is leading to the biggest challenges to water supply, the deterioration of water quality due to pollution, changes in urban land use, drainage and sewage infrastructures in most cities (Bach, Rauch et al. 2014, Martínez and Bandala 2015, Sun, Michelsen et al. 2015, Zimmer 2015).

In the context of Khuzestan, the similar challenges are observed and Khuzestan faces a serious water crisis which will be further accelerated by the very low water use efficiencies, low water quality and increasing water demands. Reports from HU-Berlin (2015, 2016) show an increased concentration of hazardous substances and pollution loads in Karun and Dez River water. A decrease of the water quantity will worsen this situation further and lead to severe ecological and socioeconomic deficits in Khuzestan.

Varying climatic trends (higher temperatures, lower rainfall, higher PET-rates, more frequent droughts etc.), population growth and resulting changes in water management strategies and policies, such as an expansion of agricultural production and more domestic water consumption, are threats that vast parts of Khuzestan will be subjected to in the future. Occurring harmful effects will be accelerated by exposing Karun and Dez River to industrial wastewater, urban sewages, and agricultural effluents (Keshavarzi, Mokhtarzadeh et al. 2015). Built on this, it is important to incorporate a well-rounded, holistic water management approach that includes future scenarios and trends as well as strategic water management planning in order to estimate present and future water availability and quality in order to positively affect Khuzestan´s social and environmental development. Corresponding, the implementation of integrated water resource management (IWRM) approaches plays a key role for Khuzestan´s present and future progress. IWRM is defined as "*a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." (GWP 2000). This research paper starts by highlighting the importance of a conceptual IWRM framework for sustainable agricultural development in Khuzestan.

Developing a conceptual framework: Integrated water resource management and sustainable agricultural development in Khuzestan

Integrated water resource management (IWRM) means to combine pieces in order to achieve the best possible management and sustainable use of water resources. To do so, social, environmental and technological aspects must be considered (Viessman Jr 2011). Moreover, according to GWP (2010), IWRM is a process that promotes the coordinated development and management of water resources in order to maximise economic and social welfare. For analysts, planners, and managers it is vital to comprehend the difference of 'comprehensive' and 'integrated' as different spheres within such holistic management processes (Mitchell 2005, Khanna, Shrestha et al. 2016). Major IWRM strategies are based on the Dublin Principles which were presented at the World Summit in Rio de Janeiro in 1992 (GWP 2010), such as:

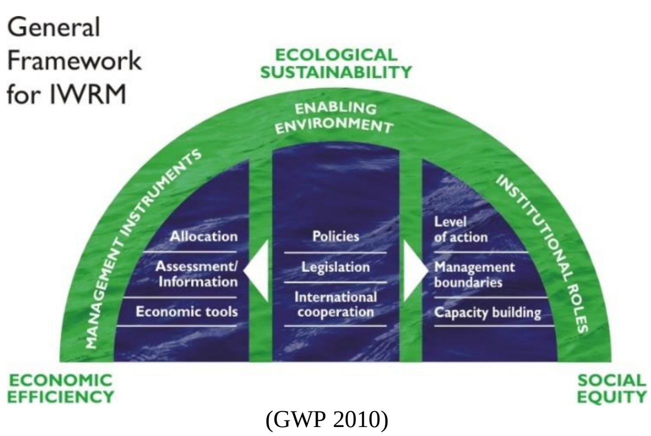
> 1. *Water is finite and a vulnerable resource: Fresh water is essential to sustain life, development and the environment.*
> 2. *Participatory approach: Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.*
> 3. *Women´s role: Women play a central part in the provision, management and safeguarding of water.*
> 4. *Social and economic value of water: Water is a public good and has a social and economic value in all its competing uses.*
> 5. *Integrating three Es: IWRM is based on the equitable and efficient management and sustainable use of water.*

One of the main features of the IWRM approach is to combine several scopes in order to create a well-rounded management approach: hereby, land and water, surface water and groundwater, river basins and adjacent coastal and marine environments as well as up- and downstream interests should be covered within respective agendas. Moreover, the approach focuses strongly on policy-making and planning (GWP 2010, Khanna, Shrestha et al. 2016):

- *water development and management has to take into account the various uses of water and the range of people's water needs;*
- *stakeholders are given a voice in water planning and management, with particular attention to secure the involvement of women and the poor;*
- *policies and priorities consider water resources implications, including the two-way relationship between macroeconomic policies and water development, management, and use*
- *water-related decisions made at local and basin levels are along the lines of, or at least do not conflict with, the achievement of broader national objectives; and*
- *water planning and strategies are incorporated into broader social, economic, and environmental goals.*

In general, any IRWM approach focuses on three basic pillars by considering the following aspects (Figure 1.a):

- *an **enabling environment** of suitable policies, strategies and legislation for sustainable water resources development and management,*
- *putting in place the **institutional framework** through which to put into practice the policies, strategies and legislation, and*
- *setting up the **management instruments** required by these institutions to do their job.*



(GWP 2010)

Figure: 1.a: General Framework of IWRM

Box 1: Main Components of IWRM (GWP 2010)

Managing water at the basin or watershed: *This includes integrating land and water, upstream and downstream, groundwater, surface water, and coastal resources.*

Optimizing supply: *This involves conducting assessments of surface and groundwater supplies, analyzing water balances, adopting wastewater reuse, and evaluating the environmental impacts of distribution and use options.*

Managing demand*: This includes adopting cost recovery policies, utilizing water-efficient technologies, and establishing decentralized water management authorities.*

Providing equitable access: *This may include support for effective water users' associations, involvement of marginalized groups, and consideration of gender issues.*

Establishing policy: *Examples are implementation of the polluter-pays principle, water quality norms and standards, and market-based regulatory mechanisms.*

Intersectoral approach: *Utilizing an intersectoral approach to decision-making, where authority for managing water resources is employed responsibly and stakeholders have a share in the process.*

Khuzestan: In relation to existing experiences from Khuzestan (reported through different HU Study Reports for KWPA), it is important to consider various aspects such as irrigation and drainage, fish production and river water management in order to assist the creation of an holistic IWRM strategy. Built on this, four strategic sub-frameworks are identified within the specific Khuzestan-IWRM framework (Figure 1.b):

1. Integrated River Water Management Strategy,
2. Integrated Irrigation and Drainage Systems Management Strategy,
3. Integrated Drainage and Wastewater Management Strategy,
4. Integrated Aquaculture and Fish Firm Management Strategy,

In the case of Khuzestan, these four strategies are immensely interlinked. However, in this paper a focus will be put on strategy number 3 (Integrated Drainage and Wastewater Management). Within the IWRM approach, according to GWP 2010, there are several other elements to implement, such as (illustrated in the following Figure):

- Policy aspect
- Environmental aspects,
- Socio-economic aspects
- Technological aspects are examples of globally common aspects of integrated management (Sehlke 2016).
- Crop patterns

- In some situation, distribution systems and treatment process are important aspects to include.

All of these aspects are narrowed down with several other factors those influencing overall IWRM in Khuzestan. It is noted that many of them are linked to each other (dot lines in following Figure 1, b).

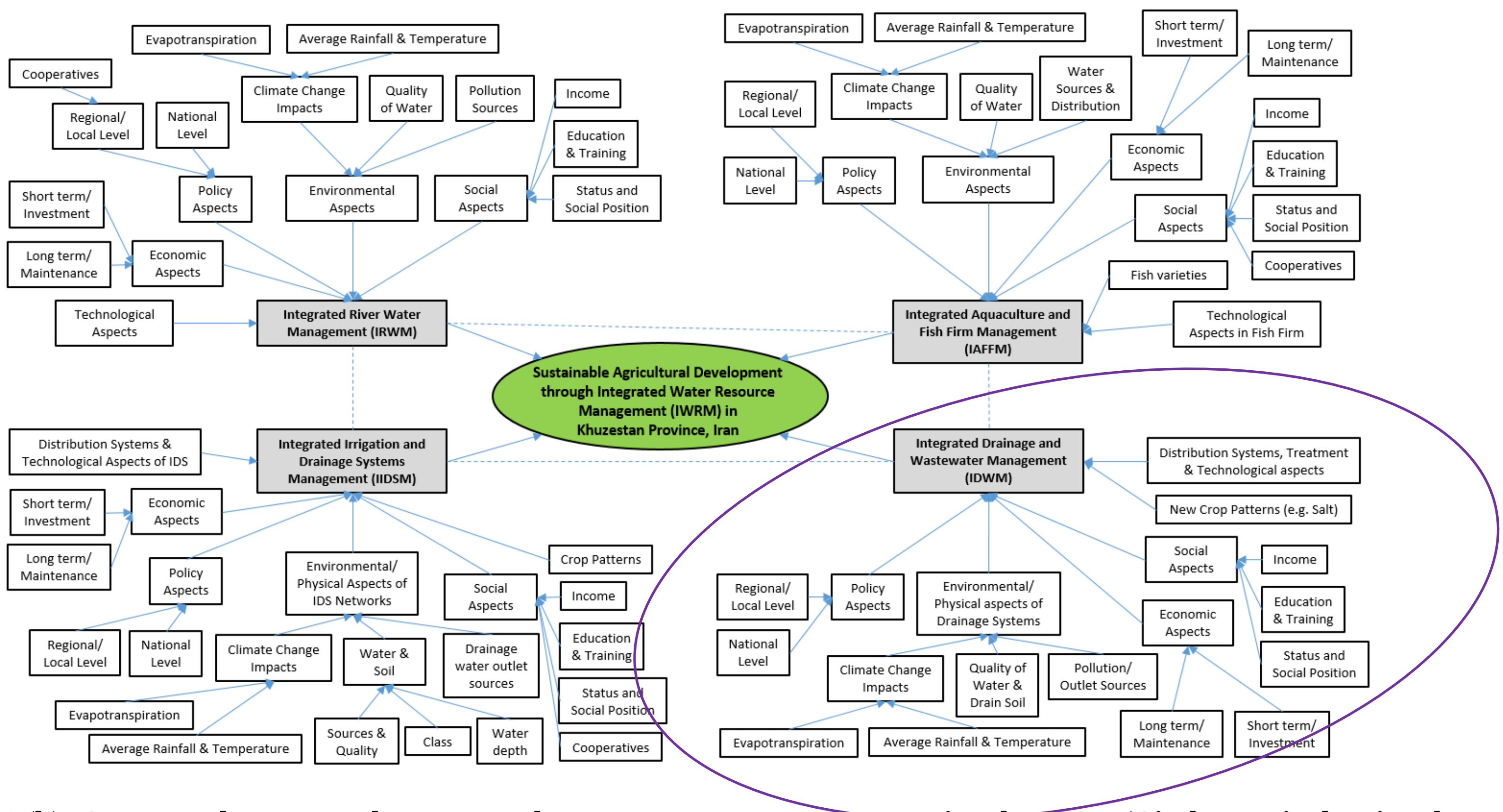


Figure 1 (b): Conceptual Framework: Integrated Water Resource Management in Khuzestan (Circle part is showing the Integrated Drainage and Wastewater Management (IDWM) the main focus for this paper).

Present and Future Challenges of Integrated Water Resource Management in Khuzestan

Present and Future Challenges Due to Impacts of Climate change

The following section is based on the official report "Iran Second National Communication to UNFCCC". The report was published in December 2010 by the National Climate Change Office at the Department of Environment on behalf of the Government of the Islamic Republic of Iran.

Iran is highly vulnerable to the adverse impacts of climate change. Most parts of the country are arid or semi-arid, prone to drought and desertification; limited forests are liable to decay; water resources are scarce; sea-level rise is a threat to very long coastal zones of the country; many urban and industrial areas are heavily polluted; and the country is mountainous with very fragile ecosystems. As a prerequisite to carry out the vulnerability and adaptation (V&A) assessment, a study on climate variability and climate modelling is essential in order to predict the future climate of Iran based on the historical record. In addition, Iran is a country whose economy is highly dependent on the production, processing and export of oil and gas and the associated energy intensive products.

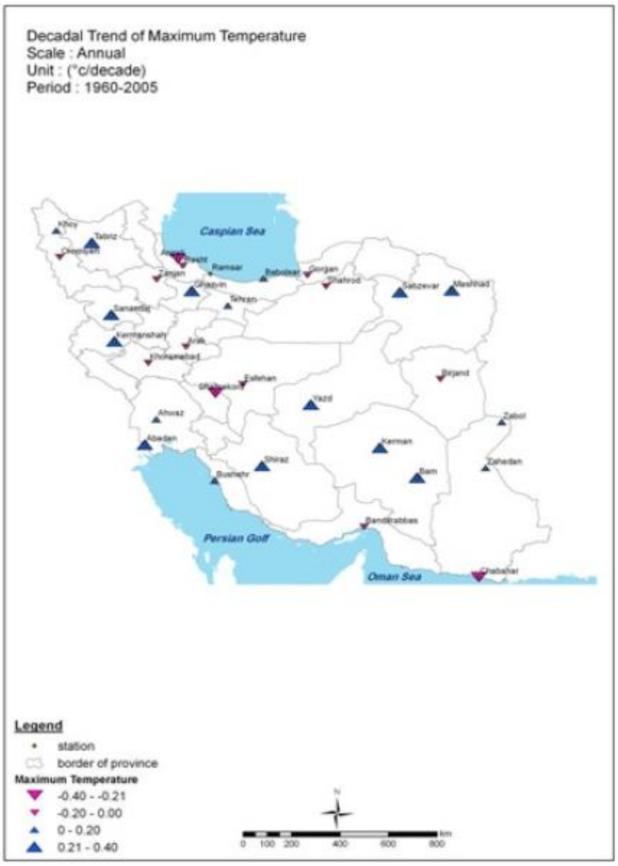


Figure 2 a: Trends in Maximum Temperatures in Selected Stations

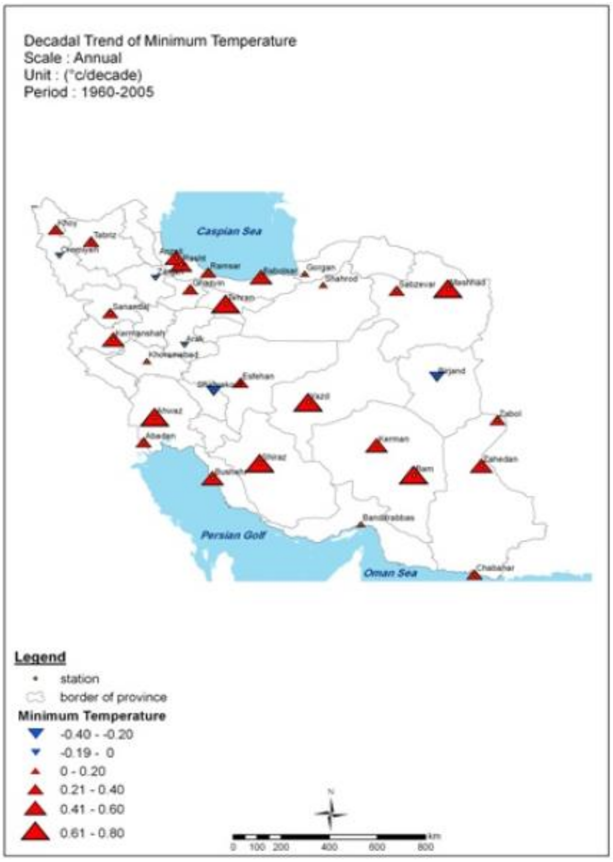
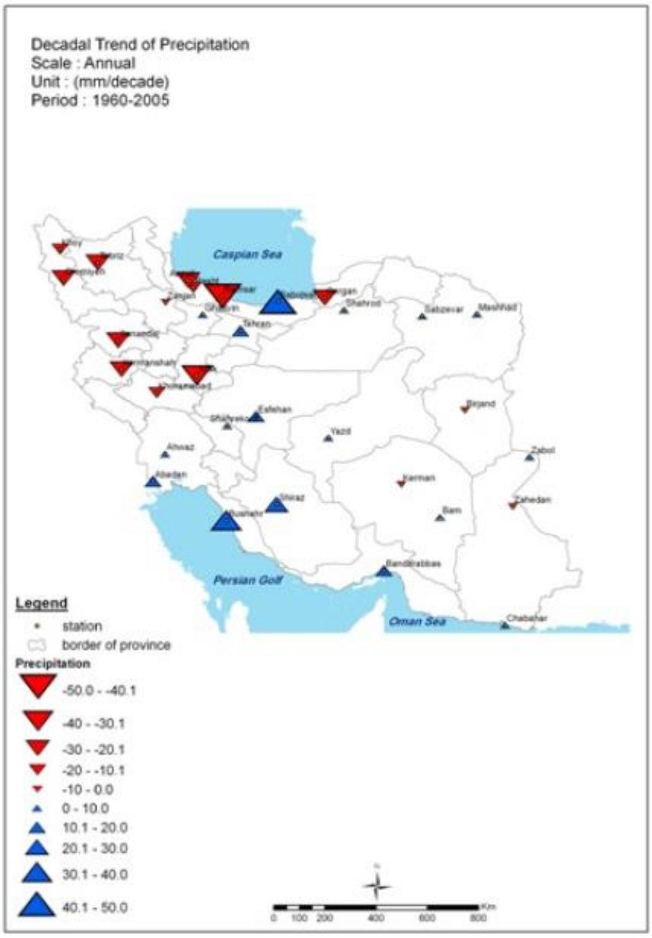


Figure 2 b: Trends in Minimum Temperatures in Selected Station

Precipitation: Following figure (3a) illustrates the changes in the amount of precipitation in selected stations. Accordingly, it could be concluded that the south-western part of the Caspian Sea, northwest and west of the country have experienced the highest rate of reduction in the amount of their annual precipitation. Study shows that the number of days with precipitation is higher than 10 mm, have reduced in the west, northwest and southeast of the country That number has increased in the other regions except in the southeast of the Caspian Sea (Figure 3b).



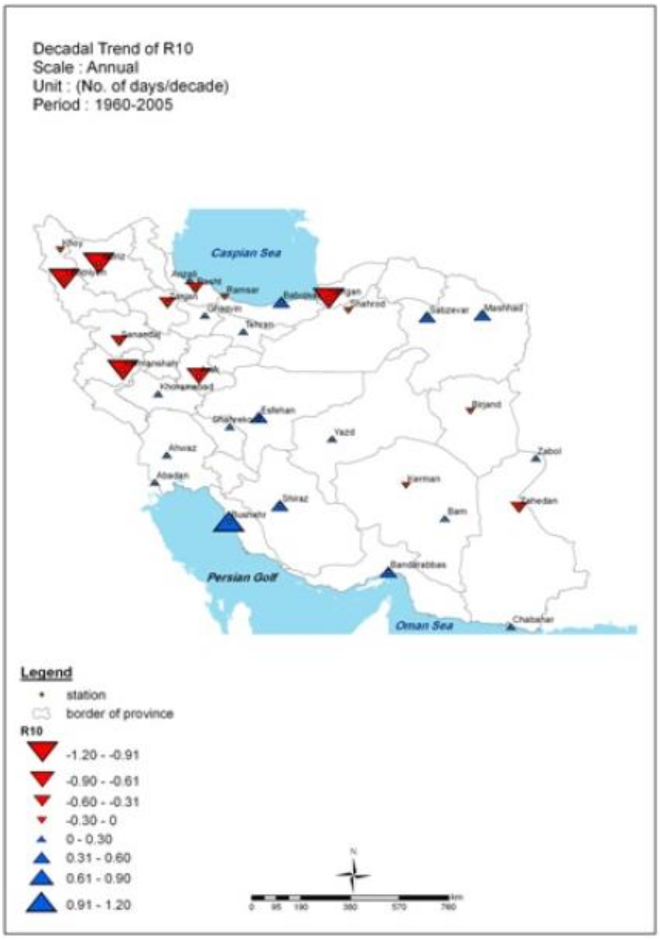


Figure 3a: Trends in Precipitation in Selected Stations

Figure 3b: Trends in Number of Days of Precipitation Higher than 10mm

Climate Change Projection: The two models MAGICC - SCENGEN, Lars - WG have been used to project future changes in the country's climate at the regional scale while the PRECIS model has been used for projection at the local scale. Climate Change Projection using MAGICG-SCENGEN (HadCM2 and ECHAM4 Models) The HadCM2 and ECHAM4 in combination with 18 available emissions scenarios have been utilized to project the changes in the country's temperature and precipitation (as the main contributors to the formation of the climate) until the year 2100. Both GCMs predict a higher temperature nationwide with very little variation. According to HadCM2, the temperature will rise between 0.4 to 3 degrees centigrade, while the results of ECHAM4 suggest that the rise will be in the range of 0.5 to 4 degrees centigrade.

The results indicate that the amount of precipitation will on average decrease throughout the country by 9% between 2010-2039 compared with the 1976-2005 period. However, the number of heavy and torrential rains will increase by 13% and 39% in the same period, respectively. Temperature projections show an average increase in the amount of 0.9 degrees centigrade and minimum and maximum temperatures will on average rise by 0.5 degrees centigrade. The rises are more pronounced during the cold season. The number of hot days in most parts of Iran will increase. The highest increase will occur in the southeast of the country by 44.2 days. The study has also revealed that the number of freezing days in most parts of the country will decrease. The highest decrease will occur in the northwest of the country with freezing days decreasing by 23 per annum. Study of the changes in the number of wet days during 2010-2039 indicates that it will increase in some areas in the northwest, center, south, east, and southeast of the country. In other parts of the country the number of wet days will decrease. The highest decrease will occur in the cold season. The study on the number of dry days shows an increase in many parts of the country. The highest rise at 36 days is expected to occur in the west and southeast of the country. Figures 3c to 3d illustrate the changes in the above-mentioned parameters in the 2010-2039 periods.

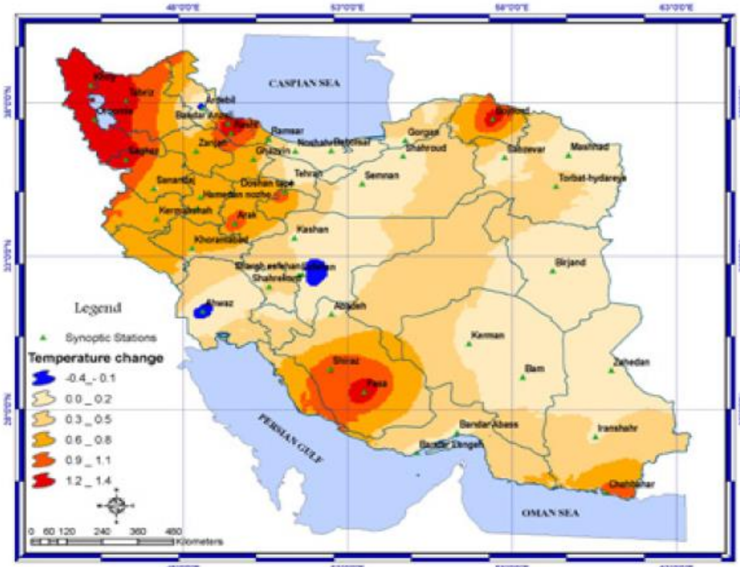


Figure 3c:Temperature Changes Projected for 2010-2039 with Respect to 1976-2005, Projected by LARS -WG

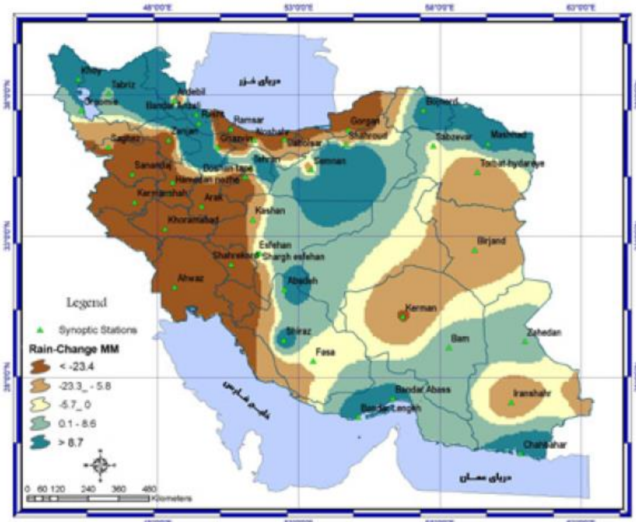


Figure 3d: Rainfall Changes Projected for 2010-2039 with Respect to 1976-2005, Projected by LARS - WG

Potential Water Resources: The Islamic Republic of Iran receives approximately 413 bcm of water from precipitation per annum, from which 296 bcm goes unutilized through evaporation and evapotranspiration. According to 2005 statistics, the resources of renewable water are 130 bcm. Water supply and consumption by different sources are shown in Figures 3e to 3f.

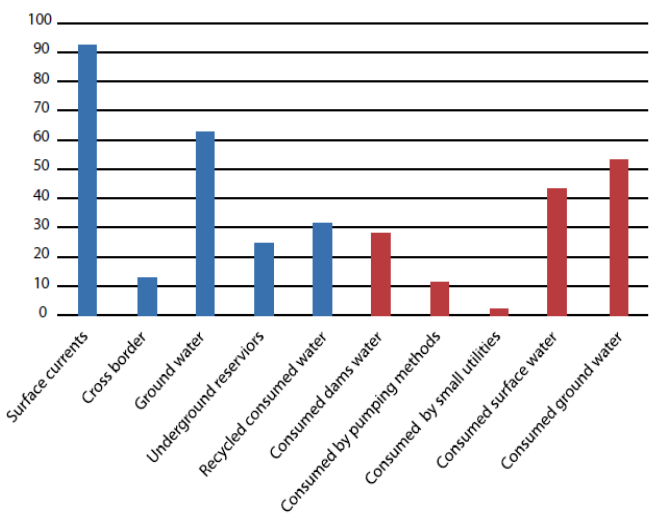


Figure 3e: Water Sources and Consumption Trends in Iran

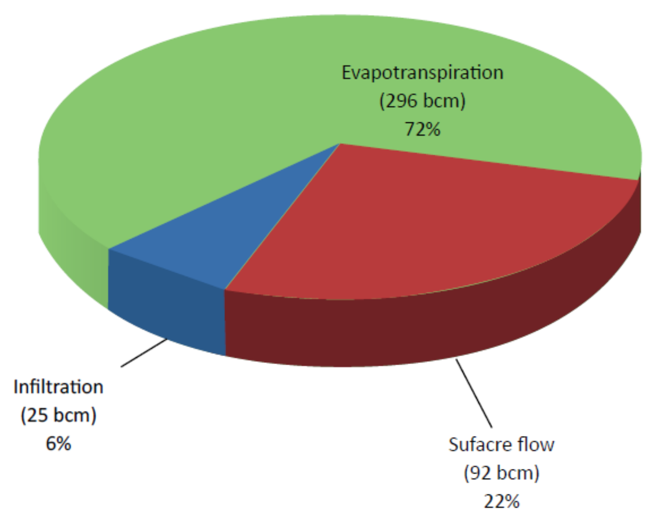


Figure 3f: Total Renewable Water Resources

Iran is located in the arid and semi-arid region of the globe with approximately 70% of the area in the dry and semi-arid region. In addition, in recent decades' climate change has also adversely affected the country's water resources.

One of the consequences of climate change is increased frequency of flood that causes severe damage to water resources and is a major problem in water management. In fact, watershed degradation is an outstanding factor in the overall water crisis that has resulted in reduced production capacity of soil and water resources. Other consequences of climate change are the occurrence of severe and frequent droughts that cause reduced water resources for various uses and the loss of some water ecosystems. Lack of updated planning and management and adaptation appropriate to present conditions has exacerbated the reduction of water resources. Average renewable water resources based on rainfall, vegetation, and other effective elements are about 130 bcm while the total accessible water with return flow is estimated about 111 bcm. Some 105 bcm of the total renewable water is contained by surface water. An estimated 25 bcm penetrates groundwater resources. At present average renewable water per capita is about 1,900 cubic meters (2009), however, due to the increasing rate of population and the impacts of climate change, it is expected that the per capita water availability will be reduced to 1,300 cubic meters per capita by 2021. Regardless of the obvious differences in the country regarding water resources and the extensive arid area of Iran, this Fgure is much lower than the average rate in the country. Furthermore, the data of average per capita of water in the coming years forecasts that Iran is entering a new stage of water stress and scarcity.

IWRM Challenges Due to Future Economic Development Activities (e.g.- More Irrigation, More Industries, Urban development, More Population in cities)

Urbanization and Industrial Development: Human activities, rather than natural forces are the major sources of the contemporary changes in the state and flow of the biosphere, land transformation due to human activities have taken many forms, starting with the urbanization including industrial expansion. Urbanization is one of the most detrimental forces affecting stream health and one of the biggest challenges facing watershed managers. However, methods to determine how large-scale changes in watersheds affect local habitats are still producing varied results. Urbanization affects "patterns of ecologic structure and function" by altering the physical landscape, increasing imperviousness, and changing channel morphology. Modification of the physical landscape by human development can exacerbate erosion, sedimentation, and bank undercutting thus reducing habitat for organisms such as fish and benthic macroinvertebrates. Urban storm water enters creeks and rivers more readily from impervious surfaces and can increase the flashiness of the flow regime. Urban runoff can also affect water chemistry by changing levels of heavy metals and nutrients like phosphorus and nitrogen. These impacts from urbanization can cause changes in the biological communities of the stream ecosystems. In addition, urban impacts are especially concerning because they can be seen throughout watersheds, and not just on a local level. As stream ecosystems are changing, it is apparent that there is a need to develop consistent methods to track these changes, and monitor the environment within streams. Impacts can be seen on multiple scales, and it is important to look

Industrial pollution sources (sewage and wastes): As a result of industrial development, there are many industries and sites in the study area of that most of 30 are important in environmental pollution studies. There are many pollutant industries in in Khuzestan. According KWPA data the industries active Pollution source is 11 at present time. In Dezful to Bamdej reach, the highest concentration of the pollution load is COD and Mollasani to South Ahvaz reach, the highest concentration of the pollution load is TDS.

IWRM Challenges Due to Future Inter-Basin River Water Transfer

According to the initial information from KWPA inside of previously handed HU reports, several projects of interbasin water transmission are in operation at the present time and many similar projects are being implemented. Therefore, in this section the influences of inter-basin river water transfer plus impacts of climate change on Karun River water discharge will be evaluated. Due to the long term inlet and outlet flow time, series to Gotvand and Dez dams were not presented, the above information were derived from Karun & Dez systemic project (DCE 2010). In this study ARSP (Acres Reservoir Simulation Program) software is used to simulate the water resources planning system of Karun and Dez catchments in various operation horizons. ARSP is a powerful tool of modelling and simulation of water resources. A major advantage of the ARSP is its inherent flexibility in defining the operating policies through a penalty structure specified by the user. The ARSP utilizes network flow optimization techniques to handle a subset of general linear programming (LP) problems for individual time intervals. The objective of the LP application is to minimize a cost function, which reflects relative benefits derived from a particular operating policy.

The locations of dams on Dez and Karun Rivers in the existing status and the inter-basin water transmission projects are described in previous sections. In summary, the following dams and water transmission projects are included in the present time.

Table 1: Dams in Karun and Dez Rivers at Present time

Dams in the present term horizon
Roodbar Dam
Dez Dam
Karun 1 Dam
Karun 3 Dam
Karun 4 Dam
Godar landar Dam
Gotvand Dam

Table 2: Water transfer projects in Karun and Dez Rivers at Present time

Scenario 3-1	scenario 3-2
Kharkheh transmission system	Kharkheh transmission system
Dez to Ghomrood	Dez to Ghomrood
Cheshmehlangan	Cheshmehlangan
khedengstan	khedengstan
Koohrang 1 tunnel	Koohrang 1 tunnel
Koohrang 2 tunnel	Koohrang 2 tunnel
Koohrang 3 tunnel	Koohrang 3 tunnel
	Beheshtabad tunnel

The summary of agricultural, industrial and urban consumptions at the present time in Karun and Dez basin are tabulated in following Table. For more information and detail, please see "Inter-basin Water Transmission Report".

Table 3: Agricultural, industrial and urban consumption in the existing status

	Annual Demand Volume (MCM)	Number of Demands
Domestic and Industrial	2382.54	24
Agriculture	12718.11	58
Fishery	1366.75	8

(Source: Karun & Dez systemic project, DCE 2010)

The water resource simulation software (ARSP) result shows that the annual average outflow of Gotvand dam will decrease 10.22% in the case of inter-basin river water transfer plus impacts of climate change, in existing status. Since this project transmits water from Karun basin to Zayandeh rood basin, it has no effect on Dez River discharge. Therefore, outflow of Dez dam is as same as decrease by 5.62 % in comparison to existing status. The influences of the inter-basin river water transfer plus impacts of climate change on Karun and Dez Rivers water quality will be evaluated in the next section. For this reason, a quality model was set-up. In the following, the model set up and simulation results will be discussed.

At the future, in addition to the climate change phenomena, the interbasin water transmission development of Karun and Dez will be implemented and the reduction in river flow will be increased more and consequently the river water quality will be worse. Therefore, in this section the influences of economic development activities plus inter-basin river water transfer plus impacts of climate change on Karun River water discharge will be evaluated. Similar to the previous scenario, the inflow and outflow of various dams are extracted from the systematic studies of Karun and Dez basins performed by Dezab Consulting Engineers. The locations of dams on Dez and Karun Rivers in the the Intermediate term horizon and the inter-basin water transmission projects are described in previous sections. In summary, the following dams and water transmission projects are included in the Intermediate term horizon up to year 2031.

Table 4: Dams in Karun and Dez Rivers at the Intermediate term horizon up to year 2031

Dams in intermediate time
Roodbar Dam
Dez dam Dam
Karun 1 Dam
Karun 3 Dam
Karun 4 Dam
Godar landar Dam
Gotvand Dam
Karun 2 Dam
Liroo power plant
Bakhtiary Dam
Khersan 3 Dam

Table 5: Water transfer projects in Karun and Dez Rivers in at the Intermediate term horizon up to year 2031

Name
Oshtorinan
Kharkheh transmission system
Sarab sefid to Galerud transmission system
Transmission system to Arak city
Sezar tunnel
Dez to Ghomrood
Cheshmehlangan
Khedengstan
Bideh dam tunnel
Koohrang 1 tunnel
Koohrang 2 tunnel
Koohrang 3 tunnel
Solkan tunnel
Shiraz water supply system
Shahid dam tunnel
Dez Environmental waterways
Beheshtabad tunnel

The summary of agricultural, industrial and urban consumptions at the intermediate term horizon up to year 2031 of Karun and Dez basin are tabulated in following. For more information and detail, please see "Inter-basin Water Transmission Report".

Table 6: Agricultural, industrial and urban consumption in intermediate term horizon

	Annaul Demad Volume (MCM)	Number of Demands
Domestic and Industrial	2741.4	27
Agriculture	13168.25	78
Fishery	1865.22	8

(Source: Karun & Dez systemic project, DCE 2010)

The water resource simulation software (ARSP) result shows, that the annual average outflow of Gotvand and Dez dams will decrease by 18.82% and 8.9 % respectively, in comparison to existing status, in the case of the economic development activities plus inter-basin river water transfer plus impacts of climate change in the horizon of year 2031.Also, the water resource simulation software (ARSP) result shows that the monthly minimum outflow of Gotvand and Dez dam will decrease by 66% and 49% respectively in comparison to existing status, in the summer time at drought years,

in the case of the economic development activities plus inter-basin river water transfer plus impacts of climate change in the horizon of year 2031.

The influences of the economic development activities plus inter-basin river water transfer plus impacts of climate change on Karun and Dez Rivers water quality will be evaluated in the next section. For this reason, a quality model was set-up. In the following, the model set up (Figure 4, more on HU Study Report for KWPA).

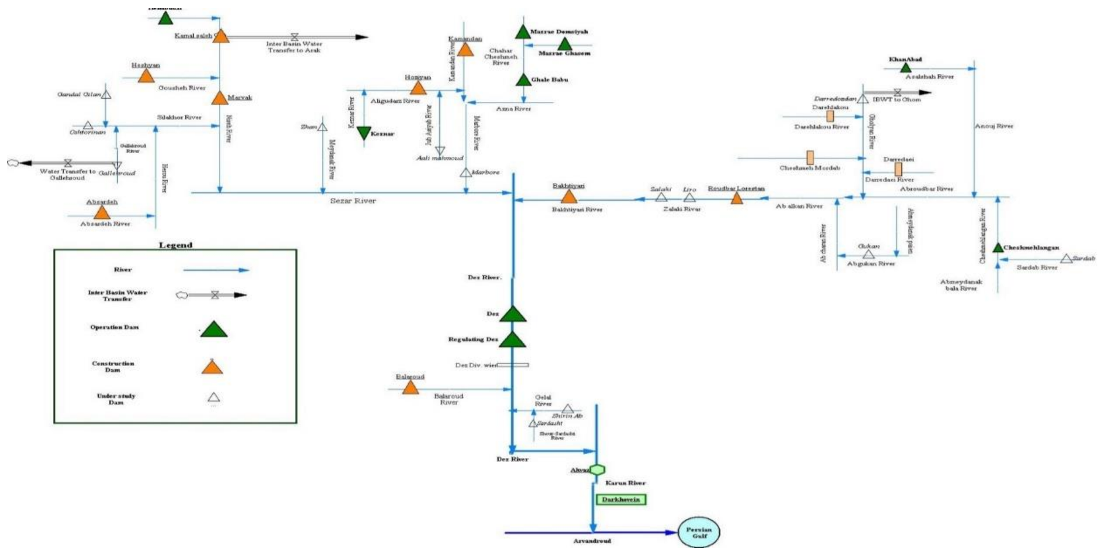


Figure 4: Scheme of Dez River Basin with Dams and Inter Basin Water Transfer (HU Study Report)

(Operational, execution and study)

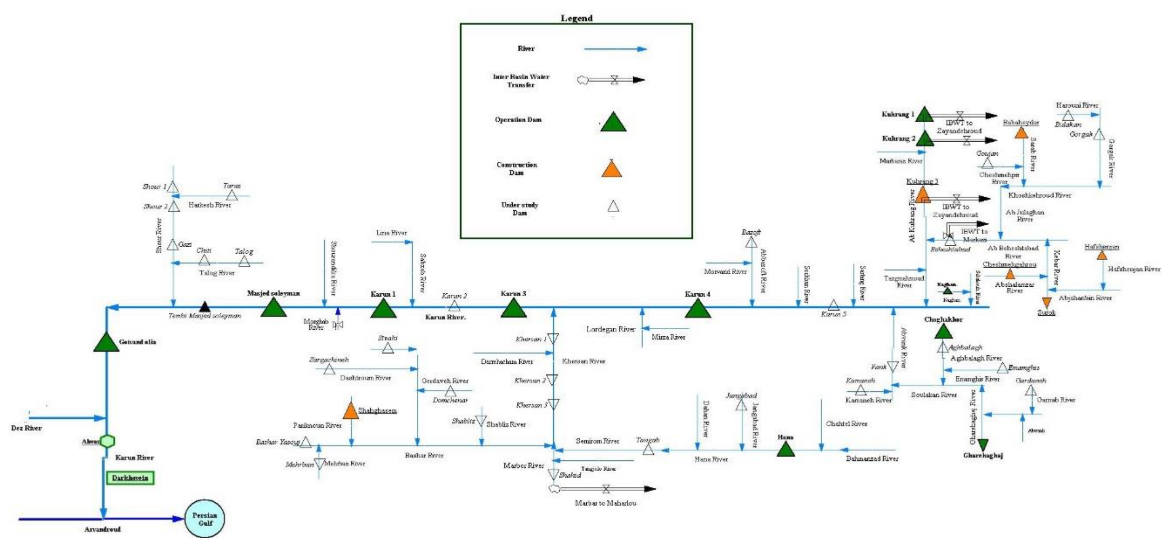


Figure 5: Scheme of Karun River Basin with Dams and Inter Basin Water Transfer (HU Study Report)

(Operational, execution and study)

Decision Support System (DSS) for the Improvement of Integrated Water Resource Management- Case: Improvement of River Water Quality in the Existing Conditions

Case: DSS for the Improvement of River Water Quality in the Existing Conditions

As it is reported about the existing status of the rivers and pollution sources, Karun river water quality is bad and it will be worse in the future due to the climate change phenomena, interbasin water transmission and future development. Thus, it is necessary to find some method of solutions such as the treatment of domestic and industrial wastewaters, improvement of the cropping pattern, improvement of the agricultural wastewater drains, monitoring network implementation, and water quality management for Karun and Dez rivers. In this regards, the salinity and quality models are provided and various method of solutions are used to study the effect of them on the water quality of Karun and Dez rivers. The simulation method (HU Study 2017) of solutions regarded to set four scenarios to improve the salinity of the water are as follows (Table below):

- Existing condition without load reduction
- Without groundwater load
- Scenario two (The second scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 30%).
- Scenario three (The third scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 50%).

Therefore, in order to improve Karun river water quality at Ahvaz city, the following implementations can be regarded respectively according to their significance. Outcome of the scenarios are presented in Table 8.

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Table 7: Results of the mathematical model to calculate salinity load and TMDL of Karun and Dez Rivers

Station Name	Existing conditions-without load reduction				Without groundwater load				Second scenario*				Third scenario**			
	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load	Discharge M^3/s	EC µS/cm	TDS Mg/lit	Salinity load
Ahvaz	230	2680	1876	37280	230	2130	1491	29629	230	1920	1344	26708	230	1715	1201	23856
Mollasani	238	2150	1505	30948	238	2150	1505	30948	238	1437	1006	20685	238	1226	858	17647
Arab Asad	189	1706	1194	19501	189	1706	1194	19501	189	1074	752	12277	189	1045	732	11945
Gotvand	211	1500	1050	19142	211	1500	1050	19142	211	1000	700	12761	211	1000	700	12761
Gargar_Banghir	12	4035	2825	2928	12	4035	2825	2928	12	2843	1990	2063	12	2100	1470	1524
Gargar_Shoushtar	18	1575	1103	1715	18	1575	1103	1715	18.5	1074	752	1202	18.5	1064	745	1190
End of Dez River	55	2885	2020	9597	55	2885	2020	9597	55	2100	1470	6985	55	1470	1029	4890
Bamdej	57	1844	1291	6357	57	1844	1291	6357	57	1347	943	4644	57	1028	720	3544
Harmaleh	50	1038	727	3139	50	1038	727	3139	50	768	538	2322	50	654	458	1978
Dezful	173	459	321	4803	173	459	321	4803	173	459	321	4803	173	459	321	4803

* The second scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 30%.

** The third scenario in which the exit flow from Gotvandolya dam reservoir is reduced to 1000 µS/cm, the urban and industrial salinity loads are entirely eliminated is applied, the salinity levels of the agricultural drains and fishery drains are reduced by 50%.

Table 8: Developing Decision Support System (DSS: Ahvaz Station: Scenarios Load (ton/day) Salinity and Germany EQS)

Parameters	**Cut-off Control Standard value** (KWPA Set-Value & Germany EQS)	**Cut-off Control Load (ton/day)**	**Ahvaz Station (4 different events)**							
			Event 1 Existing Condition- Without load reduction		**Event 2 Without ground water load**		**Event 3 Second Scenario**		**Event 4 Third Scenario**	
Discharge [m³/s] in a Ahvaz	230		230	**Load (ton/day)**	230	**Load (ton/day)**	230	**Load (ton/day)**	230	**Load (ton/day)**
EC [μS/cm]	1715		2680		2130		1920		1715	
TDS (mg/l)	(1715*0.7)= 1201	23866.2	1876	37279.8	1491	29629.1	1344	26707.9	1201	23866.2
DO (mg/l)	>8 (EQS)	158.97		158.97		158.97		158.97		158.97
BOD (mg/l)	<4 (EQS)	79.4		79.4		79.4		79.4		79.4
COD (mg/l)	<7 TOC (EQS)	139.1		139.1		139.1		139.1		139.1

Conclusion: The paper has shown an overview of the integrated water resource management in global context following the explanation of globally accepted Dublin principles of IWRM. It has also highlighted the water scarcity in Khuzestan province and has developed a conceptual framework of IWRM for Khuzestan. Different aspects and factors are considered from various studies done by HU Projects with KWPA. HU reports show the three main challenges of IWRM in Khuzestan (climate change, economic development and inter-basin water transfer). The paper has shown the linkages of these and concluded with an example of decision support system to improve water quality in Rivers in Khuzestan.

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DRAINAGE WATER MANAGEMENT PLAN OF THE SOUTH WEST KHUZESTAN, IRAN

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Abstract

The existence of four large rivers and hundred thousand flatlands have made the Khuzestan province an important agricultural area. Because of soil salinity and saline shallow groundwater, subsurface drainage is inevitable in irrigated lands of the south of Khuzestan. Drainage water disposal to receiving water bodies, usually large rivers, was a common solution for drainage water problems in the 1990s. It caused major damage, especially in the downstream sectors of rivers. Due to the development of irrigation and drainage networks (IDN) after the 2000s, it was decided to manage the drainage waters of the IDNs in the southwest of Khuzestan (with an area of 340,000 hectares) as an integrated plan. Drainage water management is dependent on environmental, economic and social conditions and also on its quality and quantity (Q & Q), which are always changing. Thus, a model for predicting drainage water Q & Q in the operation period of IDNs was developed and validated using a research field of 25 hectares. The model was executed for all IDNs to predict the discharge and salinity of drainage water during the operation period. Predicted drainage water salinity of the IDNs, was used to choose between reusing or disposing of it. Drainage water salinity of IDNs will thus be reduced during the operation period; therefore, the managerial approach will change cin line with the extent of the salinity. The IDNs construction schedule would then be estimated in tandem with the modelled predictions, and a timetable for drainage waters salinity and discharge for each of the IDNs could be provided. In the early operating period, especially in the reclamation stage, drainage water reuse would not be possible because of its high salinity, as a result it will be disposed of in evaporation ponds or the Persian Gulf. Salinity will be reduced over time and the drainage water will be reused for salt-tolerant crop farming, desert greening or will be transferred to water bodies. By applying the said time table, the discharge of the drainage waters that is to be transferred to reusing sites or disposed of, could be calculated. The maximum discharges of reuse or disposal drainage waters during the time will be the design discharge for re-use sites, pump stations, main transforming drains etc. Some on farm methods have also been considered to reduce the quantity and enhancing the quality of the drainage waters.

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KEY WORDS: Drainage water reuse, Salinity, Irrigation and drainage network, Drainage water disposal, Evaporation pond.

Introduction

Drainage disposal is a acute problem that has been reported widespreadly in different parts of the world such as Southern Asia, Eastern Asia, central Asia, Northern Africa, the Middle East, Australia and the United State of America (Tanji and Kielen, 2003). Drainage water re-use planning is considered as an effective solution to this global issue. Drainage water planning and management was not given enough attention to until the 1990s where the majority of studies in drainage became focused on project design and assessment (Snellen, 1997). After the Earth Summit conference in 1992 international irrigation and drainage communities focused chiefly on drainage water management. The Earth Summit conference manifests that not only is there a need for drainage as a complement to irrigation development in arid and semi-arid areas, but also there is a need for the conservation and water re-use in Integrated Water Resources Management (Weiss, 1992).

The re-use of drainage water is practiced worldwide, mostly in arid or semi-arid regions where irrigation water is in short supply, but it is also applied in temperate regions, where re-use is practiced during the dry summer months (Ritzema and Stuyt, 2015). Re-use can increase a country's available water resources. In irrigated agriculture, re-use can be practiced on the farm level, project level, and regional level, often as a combination of official re-use by the government and unofficial re-use by individual farmers. The official re-use of drainage water at a regional level is based on the drainage water which flows in the main drains (Ritzema and Braun, 2006).

While drainage water obtained from a particular field is usable for a particular species, which is salinity resistant up to a given level, and it must be re-used before its final disposal. (Rhoades et al., 1977, Rhoades et al., 1989). Egypt a specific example. In the Nile Delta in Egypt, farmers re-use drainage water by pumping it for irrigation directly from the drains. In the eastern part of the Nile Delta, 15% of the crop water is supplied from groundwater and on-farm re-use (Abdel Gawad et al., 1991). These re-use options have increased Egypt's water availability by 20% (Barnes, 2014). A major disadvantage of this type of re-use is the salinity of the re-used water. Drainage water can never be completely re-used, however, because the salts brought in by the irrigation water have to be exported out of the area (Ritzema, 2016; Ritzema and Braun, 2006).

Safe disposal is a final challenge to drainage having its own place as part of integrated and sustainable water management. Evaporation ponds are sometimes used for salt disposal, e.g. in Pakistan, but they are of limited use as only 13% of the salts that are left behind in the Indus Basin are deposited in the ponds which are located in the desert area outside the irrigated plain in southeast Punjab (Quereshi and Sarwar, 2009). Discharging the salts into lakes and/or rivers that eventually reach the sea or ocean seems logical, but there are consequences to these higher salt concentrations. If the receiving water cannot cope with the amount of salt laden drainage water, a separate facility with a safe outlet, usually the sea, has to be constructed (Ritzema, 2016; Skogena et al., 2014).

Two of the best-known outfall drains, especially created for the disposal of highly saline drainage water, are the Left Bank Outfall Drain in Pakistan and the Third River in Iraq. The Left Bank Outfall Drain has been constructed to drain approximately 0.5 million ha in the Sind Province of Pakistan (McCready,1987). The disposal of the drainage effluent back into the River Indus, or one of its branches, is unacceptable because of the high salinity levels it has: the effluent from subsurface drainage can vary from 4.7 to 15 dS/m and that from tube wells is often twice as saline. Disposal into the river would result into excessively high salinity levels and would make downstream use for irrigation impossible. In Iraq, the Third River, which was completed in 1993, acts as an outfall drain for the area between the Euphrates and the Tigris (Ritzema, 2016).

Thirty hundred and forty-seven thousand hectares of irrigated and drained lands have been built or are being built in the whereabouts of the lower Karun and Karkheh rivers in the Southern part of Iran. Shallow groundwater level and high soil salinity make subsurface drainage inevitable in these lands. Sugarcane agro-industrials were the first areas to have an operational irrigation and drainage network in the area. The drainage water of these agro-industrials was first disposed into the Karun River, which resulted into detrimental environmental, social and economic impacts. The main problem was caused by the high salinity of the drainage water in the first years due to heavy soil leaching in order to make these lands cultivable. Disposing of highly saline drainage water directly into the Karun River increased the river salinity in the Southern parts and made it useless for meeting different demands especially for drinking purpose. To overcome these issues, drainage water was disposed into evaporative ponds in the North of the city of Khoramshahr for years. Considering the ever-increasing volume of drainage water and ever-decreasing evaporation rate potential, due to the increasing of salt concentration, the importance of drainage water management plan becomes obvious. The first step in any drainage water management plan is to forecast the quantity and quality of drainage water yet since there there was no any available data for drainage water disposal prior to the construction of the irrigation and drainage network. The literature review on the long-term fluctuation of drainage water quality in arid and semi-arid regions reveals that an overwhelming majority of soil salinity will be disposed of in the first decade of the projects' operation span. Whatsmore, the most severe salinity disposal happens in the first 2 or 3 years of the project operation. Salt discharge and as a consequence the salinity of the drainage water shows a higher level in the first years especially when the initial salinity of the soil and salinity of the groundwater is high. Drainage water salinity tends to move towards a constant level after 15 to 20 years of the operational start date. If the initial soil salinity is high then the constant level is high too. After this phase, a decrease in drainage salinity occurs gradually (Johnston, 1993, Sharma et al., 1995). These results are consistent with those of Sharifipour et al. (2012) which show that the salinity of drainage water in the Khuzestan sugarcane agro-industrial company decreased from 70 dS/m to 7.5dS/m after 20 years of operation. Thus, the first step in the development of the drainage water management plan is to develop a simulation model which is able to forecast the quantity and quality of drainage water during the operational time span. Such a simulation is essential because it can be used as a guideline to decide whether drainage water should be disposed of or re-used.

Materials and methods

Study area

There are 18 irrigation and drainage networks to the west of the Karun River and to the south of the Karkheh River with a total area of 347,000 hectares of irrigated agricultural land. This area is considered as the spatial boundary of the study.

As Table 1 depicts, the precipitation and temperature related parameters of three synoptic meteorological stations located in the north, middle, and south of the study area, near the cities of Bostan, Ahwaz, and Abadan, respectively (Figure 1).

The prevailing soil texture of the study area is characterized by silt clay loam and soil class Entisol. Based on the Iranian land classification method (Mahler, 1970); A very small part of the argricultural lands (0.5 percent) have no salinity limitations (EC of soil saturation extract < 4dS/m); 9.3 percent have slight salinity limitations (4 dS/m < EC < 8 dS/m); 17.7 percent have moderate salinity limitations (8 dS/m < EC < 16 dS/m); 30.7 percent have severe salinity limitation (16 dS/m < EC < 32 dS/m); And 34 percent have very severe salinity limitations (32 dS/m < EC). However, 7.8 percent of the study area was not evaluated. In some cases, especially in the south of the study area, the EC of soil saturation extract exceeded 100 dS/m.

Groundwater depth is less than 1m in 4 percent of the study area. Moreover, it was reported that between 1 to 2 m in 40 percent of the study area, in 27 percent of the study area it was between 2-3m, and in 49 percent of the study area it is more than 3m. Groundwater salinity is more than 60 dS/m in more than 90 percent of the study area.

Table 1. precipitation and temperature parameters in the north, middle, and the south of the study area

Station (City)	Average annual precipitation (mm)	Precipitation percentage of each season (%)				Average temperature of warmest month; July (C°)	Average of maximum temperature of warmest month (C°)	Average temperature of coldest month; January (C°)	Average of minimum temperature of coldest month (C°)
		Winter	Spring	Summer	Autumn				
Bostan (North)	193	51	13	0	36	36.6	45.5	11.7	7.4
Ahwaz (Middle)	220	48	14	0	38	37.0	46.2	12.4	7.4
Abadan (South)	159	51	11	0	38	37.0	45.4	12.5	7.4

surface irrigation was used throughoutI all of the projects, mostly in the form of closed-end furrows and borders. The Annual need for irrigation water was reported as 4.629 billion m^3, and was supplied from the Karkheh river (2.972 billion m^3) and the Karun river (1.657 billion m^3). The annual average of irrigation water for both rivers was about 1.5 dS/m. According to the U.S. salinity laboratory water classification, the most frequent class of irrigation water samples is C3S1 followed by C3S2.

Saline soil and saline shallow groundwater, make subsurface drainage inevitable in the irrigated lands of the South of Khuzestan. PVC pipes with synthetic envelopes are being used as lateral drains which disposed the drainage water to open collectors, except for the Amir Kabir and Mirza Kouchak Khan sugarcane Agro-Industries in which concrete pipes were used as collectors. Lateral drain pipes were installed at depths of 2m in old projects, thus avoiding environmental problems; however, installation depth is limited to 1.4m in the projects under development; in addition lateral drains were spaced from 30-80m.

Among the 18 networks, three of them belonged to the sugarcane agro-industries and others belong to local farmers which had a mixed crop pattern. Eucalyptus, which is salt tolerated, is cultivated in the region and its water demand is met from the sugarcane fields' drainage water, which now after 20 years its salinity has been reduced to a level that is suitable for re-use. Table 2 demonstrates the general information of irrigation and drainage project in the study area.

In the design phase, the main drainage network to the West of the Karun river and to the South of the Karkheh river , including the main drainage channels of the projects of which the disposal end of them was considered to be bodies of water such as rivers or marshes. The mains drainage channels and their area is illustrated in figure 1.

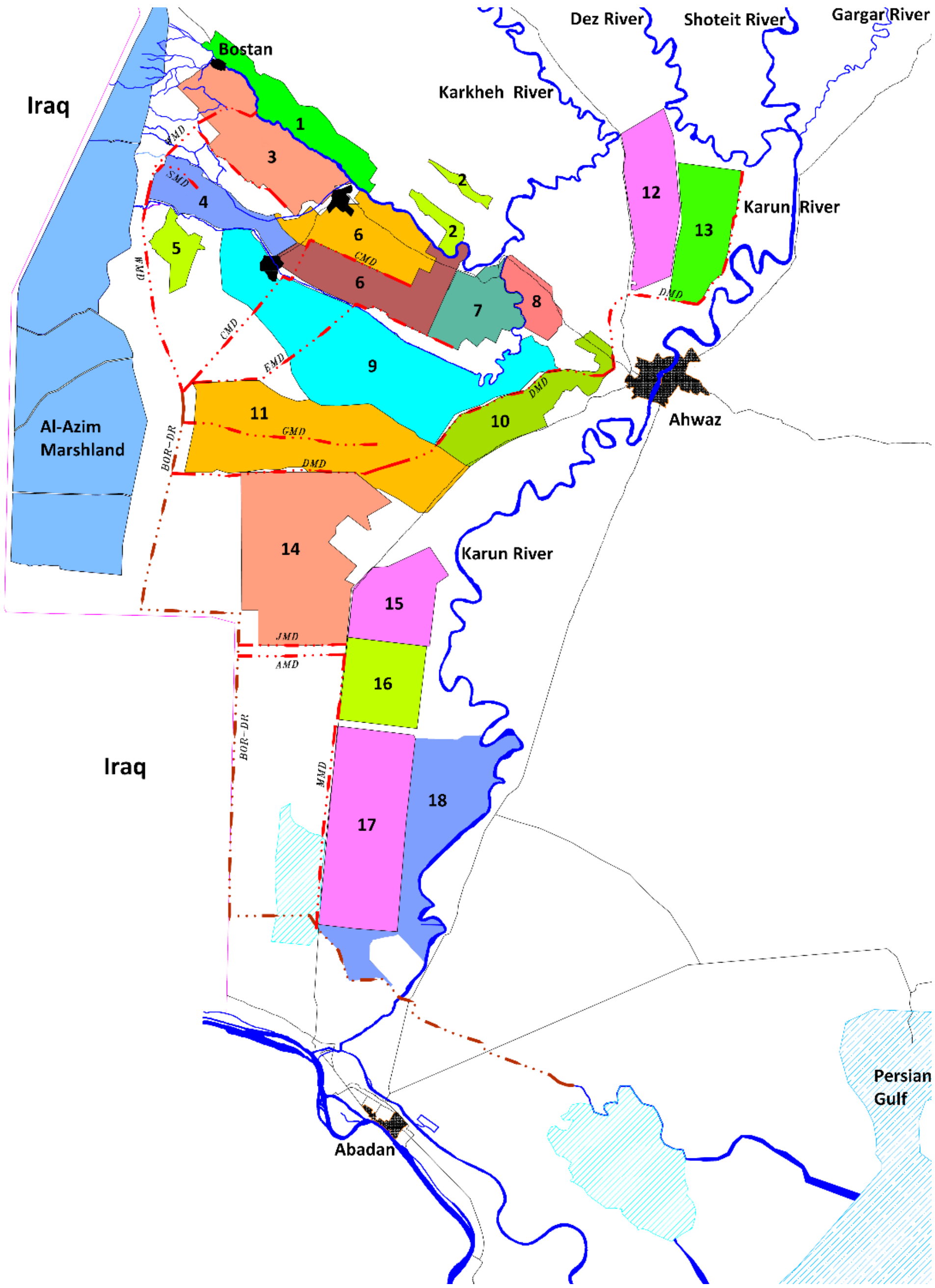

Figure 1. irrigation and drainage projects in the studied are and their main drains

WMD: Civil District 3, Azadegan plain, Civil District 4, Azadegan plain, New Yazd, Ghods and Zamzam, North of Hoofel
CMD: Civil Districts 1 and 2, Azadegan plain
EMD: Right Hamidiye, Left Hamidiye, The south of Karkhe Noor
GMD: Shahid Chamran, Development of Shahid Chamran
DMD: Dehkhoda sugarcane Agro-Industry, Kowsar
JMD: Jofeir
AMD: Amir Kabir sugarcane Agro-Industry
MMD: Mirza Kouchak Khan sugarcane Agro-Industry
KMD: Eucalyptus Agro-Industry
WKD: Western of Karun

Table 2. General information of irrigation and drainage projects in study area

Row	Project's name	Area (ha)	Row	Project's name	Area (ha)
1	North of Hoofel	10,000	10	Shahid Chamran	11,200
2	Ghods and Zamzam	4,750	11	Development of Shahid Chamran	53,805
3	Civil District 4, Azadegan plain	18,700	12	Kowsar	12,880
4	Civil District 3, Azadegan plain	13,000	13	Dehkhoda sugarcane Agro-Industry	12,000
5	New Yazd	4,580	14	Jofeir	39,645
6	Civil Districts 1 and 2, Azadegan plain	24,649	15	Amir Kabir sugarcane Agro-Industry	12,000
7	Right Hamidiye	8,502	16	Mirza Kouchak Khan sugarcane Agro-Industry	12,000
8	Left Hamidiye	6,158	17	Eucalyptus Agro-Industry	18,415
9	The south of Karkhe Noor	44,795	18	Western of Karun	40,000

Drainage water quantity and salinity simulation model

Jury et al. (2003) simulated the quality of drainage water of agricultural lands in San Joaquin Valley, California. They concluded that the salinity of discharged drainage water is in relation to the salinity of groundwater. They showed that the depth of the impermeable layer has a significant effect on the equilibrium time of the salinity of drainage water. In other words, if the impermeable layer is deep then more time is needed to reach the equilibrium time. On the other hand, the distance between drainage pipes has a significant effect on the discharge volume taken from the bottom of the drainage pipes. It means that closer drainage pipes tend to withdraw less amount of groundwater from the bottom of pipes. Therefore, the quantity and quality of discharged drainage water is a function of the depth and distance of the drainage pipes as well as the salinity profile in soil above and under drainage pipes (Wahba and Christen, 2006). In conclusion, it can be stated that if the groundwater under the drainage pipes has a high salinity level, the discharged drainage water suffers from high salinity as well.

The simulation model enjoys the benefits of system dynamics. The most important feature of system dynamics is that it helps to elucidate the endogenous structure of the system under consideration, and to demonstrate how different elements of a system actually relate to each other. This facilitates experimentation as relations within the system are changed to reflect different decisions (Elmahdi et al. 2005). Agricultural systems and their environmental effects, like many other environmental problems, constitute complex systems, the study of which requires a systemic approaches capable of explicitly managing the temporal dimension, sustainability conditions, uncertainty, and externalities (Bergh 1996). Therefore, system dynamics is a good approach to simulate such a system.

In order to simulate soil water movement and solute transport in saturated and unsaturated conditions of a drainage system the model applied the aforementioned technique. The system dynamics tool, Vensim, was used because it provides a fully integrated simulation system to conceptualize, document, simulate, and analyze models of dynamic systems. The prediction variables were drain discharge, drain water salinity, and ground water salinity behavior for different drainage densities (the depth of the drain and the drain spacing), soils, and climate.

The quantity and quality simulation model of this study consisted of two zones: a saturated zone and an unsaturated zone. The unsaturated zone was divided into four different layers ; each of them considered as a state variable. The inputs to the first layer were precipitation, irrigation water, groundwater upward flux from the sub-layer and the outputs are evapotranspiration and deep percolation. The inputs of the lower layer include deep percolation from the upper layer and upward groundwater flux and the outputs are evapotranspiration, deep percolation and the discharged amount of water from this layer to upper layers. In other words, the model traces the portion of the irrigation water that evapotranspires,and the portion that infiltrates through each layer, and finally the portion that recharges the groundwater.

The saturated layer is placed below the groundwater level. In this layer, drainage water enters the pipe drains from its entire perimeter. In saturated conditions, Hooghoudt's equation is used to calculate the drainage outflow. Hooghoudt's equation consists of two terms; the first term corresponds to the layer under the drain pipe and the second term corresponds to the layer above the drain pipe. Solute transport is often simulated by applying the convection-dispersion equation to field conditions. In this research, the dispersive flux is assumed to be the combination of molecular diffusion and dispersion mixing.

The concept of system dynamics is based on quantifying feedbacks and delays in the system. Therefore, the future state of the system can be calculated using a system structure and the initial value of state variables. The structure of the system is built using casual loops. There are two different casual loops in system thinking, reinforcing loops and balancing loops. Reinforcing loops represent a situation which an increase in the cause encourages an increase in the effect while balancing loops show that with an increase in the cause will result into the effect decreasing. For example, with an increase in soil moisture, deep percolation from the root zone increases and with an increase in deep percolation, moisture in the upper layer decreases and in the lower layer it increased. The causal loop diagrams are shown in Figures 2–4.

The presented simulation model uses meteorological, pedological, irrigation, groundwater, crop pattern and drainage design in order to forecast drainage water salinity and quantity.

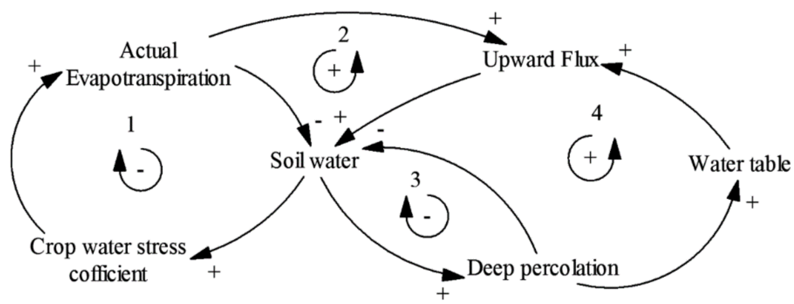

Figure 2. Unsaturated zone causal loop diagram (Nozary and Liaghat 2014)

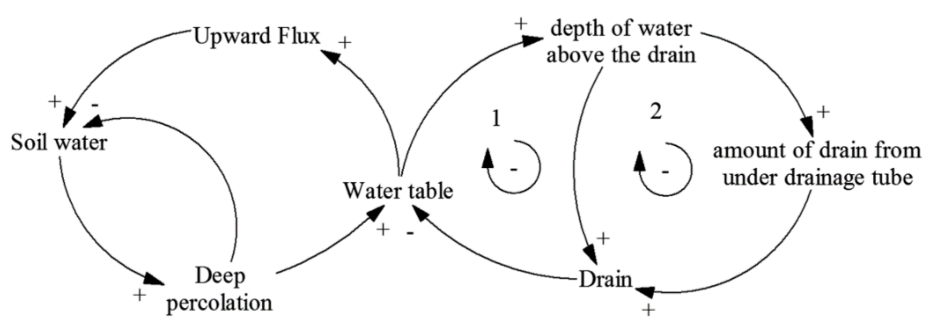

Figure 3. Drainage performance causal loop diagram (Nozary and Liaghat 2014)

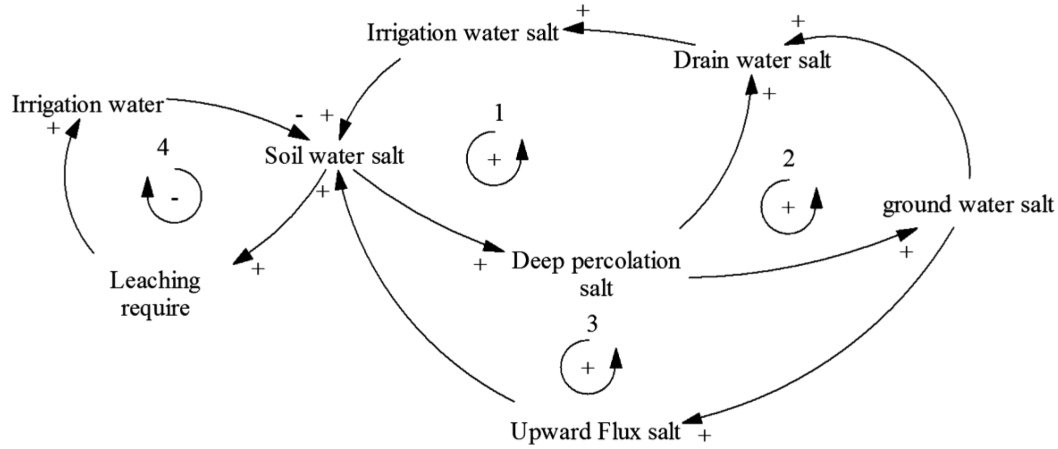

Figure 4. Causal loop diagram for dynamic salinization model (Nozary and Liaghat 2014)

The simulation model results were validated using a dataset taken from a 25 hectare field placed in the center of the sugarcane research institute of the Amir Kabir agro-industry. Three sets of piezometers were established 100, 250 and 375 meters from the collectors in order to capture the groundwater fluctuations. During the irrigation period (from March to September), fluctuations of the groundwater level, drains discharge, irrigation water salinity, groundwater salinity and drainage water salinity were measured on a daily basis.

Executing the model using the field conditions, groundwater fluctuation, drainage water discharge, drainage water salinity and groundwater salinity on a daily basis were simulated. The standard error (SE) and root square error (RSE) were calculated and the accuracy of the model was evaluated. The calculated SEs for groundwater fluctuations, drainage water discharge, and drainage water salinity were 14.4 cm, 0.43 l/s, 2.8 dS/m, respectively. The SEs of groundwater salinity in three different depths were 0.49, 0.29 and 0.36 dS/m from the surface to depths, respectively. These measures indicate relatively high accuracy. The RSEs for the mentioned variables in the same order were 8, 20, 19, 12.9, 7.5 and 8.2 percent which also indicate relatively high accuracy. The detailed description on the model development has been given by the developers (Nozary and Liaghat 2014).

On-farm techniques to reduce the quantity and enhance the quality of drainage water

Although this study was conducted in order to arrange official actions, some on-farm and project level suggestions were proposed. The Khuzestan Water and Power Authority, which is in charge of water resources and drainage water in the Khuzestan Province, has offered some design manuals for consulting engineers, and has offered some on-farm techniques for the farmers. The aim of these documents and techniques is to reduce the quantity of drainage water as well as enhancing the quality of drainage water (especially a reduction in fertilizers and pesticides concentration). These recommendations are summarized as below:

- Decreasing the depth of the subsurface drain pipes in order to reduce the groundwater proportion in drainage water salinity, especially in regions with highly saline shallow groundwater resources.
- Designing closed-end furrows, laser leveling and optimal irrigation management in the field to increase irrigation efficiency.
- Optimizing the usages of fertilizers and pesticides and replacing biological control instead of chemical control.
- Using drainage water for leaching and reclamation of saline soils (Sharifipour et al., 2015a, b).

Results and discussion

Drainage water planning and management: Dispose or Re-use?

Choosing whether drainage water should be disposed or re-used depends on the basis of its quality. In areas with shalow saline groundwater, and in which drainage water is too saline, in the first years of the operation of the irrigation and drianage network, it is necessary that drainage water is disposed of in evaporation ponds or the sea. When the quality of drainage water improves it can be used for the agriculture of salt tolerant plants, mixed with freshwater or it can be used as a replenishment source for water bodies.

In the region under study, irrigation and drainage projects are in the developmental stage. Therefore, drainage water will be produced as the projects finish and leaching begins. In other words, the speed of completing irrigation and drainage network projects shows rapid addition to the quantity of drainage water. Construction speed depends on many criteria, and thus different scenarios were developed. The results of this study are based on the most widely acceptable scenario, which indicates that 10,000 hectares of land will be added to the network annually. This study was about official practice and drainage water managements at official level usually in vicinity of the main drains. The Quantity and quality of drainage water in main drains in the study area during the operational time since the start of the project was simulated based on the aformetntioned scenario.

The simulated results of the model for WMD main drain are given in this study as an example. Figures 5 and 6 show discharge variability and salinity of the drainage water in WMD main drain, respectively. As it can be observed from these figures, the quantity of drainage increases while the salinity of drainage water decreases over months by maximizing irrigation, which is in April in the region. On the other hand, in months with no irrigation, the lowest amount of drainage water with the highest amount of salinity is disposed of . The Long-term trend shows that the quality of drainage water is getting better as the duration of operations continues. The model has been calibrated with the quantity and quality of drainage water data during the operational time span, should such data be available.

The Maximum calculated discharge using the model will be used for the hydraulic design of drains. For instance, a maximum discharge of drainage water in WMD main drain will occur in April 2057. The annually weighted average salinity of drainage water determines which management options (dispose or re-use) will be used. It is of note that as the drainage water quality increases during the operational time span, management options will adapt. The threshold of drainage water salinity at which it should be disposed or re-used is 8 dS/m for annually weighted average. For example, the annually weighted average of salinity on a WMD main drain is above 8 dS/m up to 2040, so it must be disposed of.

In this study the following receiving sources for drainage water disposal were considered.

- Evaporative ponds
- Evaporative ponds in dried parts of marshes of the region
- The Persian Gulf

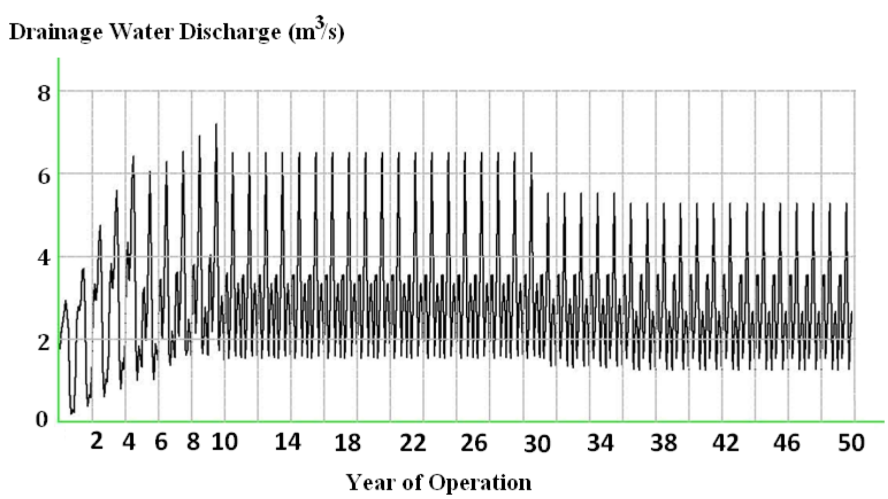

Figure 5. Drainage water discharge during the operational time in WMD main drain

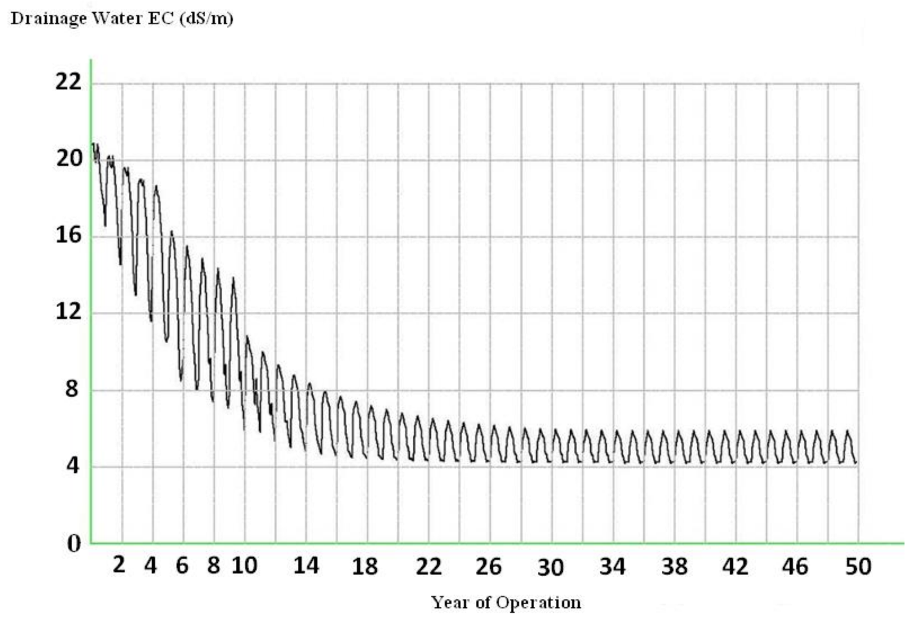

Figure 6. Drainage water Salinity during the operational time in WMD main drain

After sufficient time (approximately 20 years) since operations began, the following options are considered as the quality of drainage water which will allow the re-use of such water.

- Recharge marshes in the region
- Using drainage water for leaching and land reclamation
- Using drainage water for cultivating salt tolerant plants
- Using drainage water for natural resources conservation and desert degradation
- Recharging Arvand River
- Recharging the downstream region of the Karun River

According to the model results, the annually weighted average salinity of the CMD in the main drain will reach 7.98 dS/m in 2035 and will further reach 6 dS/m in 2050. A similar simulation for the EMD main drain shows that it will be 8 dS/m in 2047, and for the GMD main drain will be 9 dS/m in 2078 and for the DMD main drain it will be 7.34 dS/m in 2068. The Salinity of the MMD and AMD main drains are already below 7.5 dS/m, therefore it can be used for Eucalyptus agro-industry in northern Khoramshahr. The annually weighted average salinity in the JMD, WKD, and KMD main drains will never be better than 14.66 dS/m. Thisis due to the fact that the drainage water of the Eucalyptus agro-industry is highly saline because it is irrigated using the drainage water of the Amir Kabir and Mirza Kouchak Khan projects. Thus, it is obvious that, at least up to the next 20 years, the salinity of drainage water from projects placed in the South of the Karkheh river and West of the Karun river, except for the sugarcane fields of Amir Kabir and Mirza Kouchak Khan, will be high and needs to be disposed of.

The most suitable disposal method: Disposal to the sea and evaporative ponds

Disposal into the sea and evaporative ponds has the least effect on the environment. The regions main drain collects drainage water from the farthest northern end (e.g. WMD main drain) to the farthest south end of the study area (e.g. WKD main drain) to the south which there is a disposal point into the Persian Gulf and evaporative ponds. Evaporative ponds can not cope with the huge amount of the areas drainage water, but they can act as reducers for the drainage water discharge; the salt load; and the pollution.

In some main drains, drain water already has a suitable EC for re-use. Some drain water in some project will reach 8dS/m in different years. Beside the general long term trend in the quality changes of drain waters, which is inclined to salinity reduction, there is some monthly changes. For example, it is predicted that in 2030 drainage water salinity of DMD main drains, which transfer drainage water of the Kowsar project and the Dehkhoda sugarcane fields, will be more than 8 dS/m in November, December, January and February. These months are when no irrigation is applied for sugarcane. During the rest of the year, DMD's salinity is less than 8 dS/m and can be re-used. Therefore, a dual main drain is designed for transporting the areas drainage water; one to dispose saline drain water; and another one for transporting drain water with less salinity to re-use sites.

As per the results of the study, drainage water quality in main drains will be higher than 8 dS/m (except in MMD and AMD main drains) up to 2035, therefore, the drainage water in these drains must be disposed through the regional main drain (BOR-DR main drain). The final discharge for the regional main drain at the end of 2042 will reach approximately 90.07 m^3/s, but the salinity of some of the main drains will be suitable enough to be considered for the re-use. Considering the re-use, the final disposal of drainage water discharge will be 67 m^3/s, which will be disposed into the Persian Gulf.

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WATER MANAGEMENT AND FARMING SYSTEM TECHNOLOGIES WITHIN THE INDONESIAN RECLAIMED LOWLANDS FOR FOOD SECURITY OF THE NATION

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Abstract

Indonesians have been using lowlands nearby the rivers for food production for decades. Local indigenous people had developed paddy field with shallow intensive drainage systems within the tidal range. Paddy and coconut were planted. The Government of Indonesia since 1970 has been developing additional new settlement area for food production and transmigration up to 1.8 million ha mostly in Sumatera and Kalimantan islands. The total paddy field in combination of other crops within the lowlands of Indonesia so far is around 4.2 million ha. This paper will focus mainly on the reclaimed lowlands within the transmigration areas in South Sumatera, Jambi, South Kalimantan, West Kalimantan, East Kalimantan and North Kalimantan provinces. Water management consideration and farming systems technologies for paddy, corn and soy bean production have improved the yield. Rainfall, drainage, water retention and supplemental tidal irrigation are able to fulfill paddy water requirements at the farm level in November to March (first planting season of the year). Application of farming systems technologies have improved yield of paddy from 3-4 tons grain/ ha to 5-6 tons/ ha. In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha. Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. Prospective uses of this approach has been implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process.

KEY WORDS: Integrated lowland development, Water management, Farming system technology, Propagation development tdal lowland.

Introduction

The Government's economic development strategy places strong emphasis on rural and regional development. It includes interventions on key areas of the agricultural sector. The objective of this

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strategy has been to enchance food production especially rice, corn, and soybean; to meet increasing domestic demand; to provide rural employment; and to achieve balanced regional development. Direct Government interventions in the food sector has included :

1. Large investment in, and control and operation of, physical infrastructure for irrigation, drainage and flood control;
2. Massive farm input and farm support progress, including expansion of institutional credit arrangements, to promote the adoption of new production technology and assure farmers an acceptable income;
3. Expansion of research and extension networks, including the training program for human resources development: and
4. Establishment and operation of BULOG (the agency for national logistic administration) to co – ordinate and implement policies aimed at maintaining a nation – wide balance between the supply and demand of major food crops ensuring food security.

The Food Crop Sector has had a high priority since REPELITA I, and the government has achieved remarkable success in this regard. With the recent – on going economic crisis and recovery, the food security is one of the important issue. There is increasing awareness that the principal needs are :

1. To put strong emphasis on production of primary food crop to support food security;
2. To continue to improve the return from economic efficiency of the previous investment in irrigation and drainage, by rationalizing and strengthening system operation and maintenance, and increasing the level of cost recovery with regard to cultivation of secondary crops;
3. To continue exploitation of the currently untapped potential for major increases in land productivity by prudent expansion of the irrigation and drainage base, with special emphasis on small to medium – scale, quick – return investment;
4. To continue in improving the effectiveness of agricultural support program

Problem Definition

Indonesia avails over large lowland areas with an estimated acreage of about 33.4 million ha, out of which about 20 million ha is tidal lowland. About 8 million ha of the tidal lowlands is suitable for food crop production, implying that 12 million ha is not suitable (Figure 1). The other 13.4 million ha concern predominantly non-tidal lowlands along rivers and inland swamp areas. This discussion focuses on the about 4 million ha of the tidal lowlands that have been reclaimed, partly by spontaneous settlers (about 2.5 million ha) and partly by the Central Government (about 1.8 million ha). While the reclaimed areas mainly consist of clay and especially the government schemes have a rational lay out. These areas generally have a good potential for agriculture. Dependent on the local topographic situation, in the wet season the conditions are suitable for a rice crop and in the dry season for a second rice crop, or a dry food crop (Suryadi, 1996). However, production levels are generally low in many areas (1.5 – 2.0 tons/ha) with exceptions, especially in South Sumatra (4 – 5 tons/ha). The low production levels are caused by a variety of limitations but a major cause is the absence of an adequate water management infrastructure. For successful tidal lowland development and management there is a need for an integrated approach, based on effective water management in combination with the application of adequate farming systems technology and post harvest activities (Hartoyo Suprianto et al., 2009).

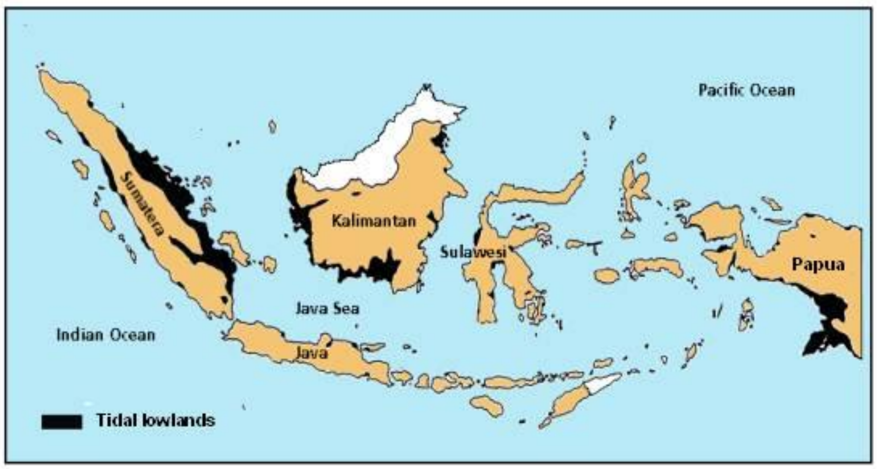

Figure 1. Tidal lowlands in Indonesia

Materials and Methods

Water management strategy which determined by the cropping pattern does not operate fully at the field even though the implementation has been anticipated. Cropping pattern which is an input to the water management action depends on the water availability and other agricultural inputs such as seed, fertilizer, labor and mechanization. Improvement of the water availability does not guarantee that the water will uniformly available at a tertiary block. And more importantly, the other agricultural inputs should be made available under the farmer's capacity. Water related issues on the tidal land can not be used to motivate farmers to start working on their farms as it is on a technically irrigated dry lands. Water management approach at the tidal land should be conducted differently as it is on a technically irrigated areas. Farmers would not be willing to work at the farm level unless the agricultural inputs also be made available. Integrated approach on food production in the reclaimed lowlands need to be done (Susanto, 2010)

Tidal Reclamation Scheme. The reclamation started with the introduction of primary canals connection two nearby bordering rivers. In addition, pairs of secondary canals known as village canal (SPD) and main drainage canals (SDU) were excavated. Farmers home lots and village roads situated along pairs of village secondary canals (SPD) (Figure 1 and 2). Tertiary canals bordering on tertiary block of 16 ha. One tertiary block designated 8 farmers having 2 ha of farm lots, first and second holding.

Water management units. As limited by the structures (canals and water gates) and actual field condition, a water management unit can be considered as 'secondary water management unit (SWMU)', 256 ha (128 farmers' households), and 'tertiary water management unit (TWMU)', 16 ha (8 farmers' households). A secondary block is bordered by secondary, tertiary canals and equipped with secondary gates as water in-outlets. Within a SWMU there are 16 TWMUs of 16 ha. A tertiary water management unit is bordered by secondary canals (part of SPD and part of SDU) and pair of tertiary canals equipped with tertiary gates. The TWMU is 8 ha for 8 farmers family (see Figures 1 and 2).

Approach. Water management will be conducted at secondary unit ('meso-level') by operating the secondary gates and at tertiary unit (micro level) by operating the tertiary structures, digging the quartenary canals and on farm water and soil management. Since the agricultural activities strongly depends on these water management units, the integrated agricultural development has to considered these water management approach. Agricultural development unit which covers 4 SWMU's 94 x 256 ha = 1024 ha) consists of at least 512 families. This family size is within the ratio of one field extension worker.

Scenarios. Cropping system development and management within the secondary or tertiary blocks level will consider several different water management strategies as flood protection, tidal irrigation, free drainage and quality or hydro-topography of the areas. First of all, quantity and quality of yield within a unit of cropping intensity from one crop to two or more crops per year need to be achieved. Project's components and sub components for the integrated development as shown on Table 1 and 2. There are three key factors to start with: Water management improvement, farming system technologies, and empowerment of the communities. During the first year of project, at least one cycle of the season, dry season, soybean-corn crops, and wet (rainy) season, rice crop, has to be achieved. In addition to the on-farm activities, the related off-farm activities will also be conducted. The outcomes will be evaluated for the following year's plan of works.

Results and Discussion

Experiences in the pilot areas integrated approach to tidal lowland development

As said, for successful tidal lowland management there is a need for an integrated approach, based on effective water management in combination with adequate farm inputs, farming systems technology and post harvest activities. In order to develop, analyze and promote such an integrated approach the project Land and Water Management Tidal Lowlands (LWMTL) was implemented from 2004 to 2006. The project aimed at improvement of the existing agricultural exploitation to increase cropping intensity and yields, in order to obtain indicators on the potential of the tidal lowlands to contribute to governments' objective with respect to self-sufficiency in rice and to a certain extent in maize. It was a bilateral cooperation between Indonesia and the Netherlands that was based on three pillars: a) assessment needed water control infrastructure; b) familiarization and implementation of farming systems technology; c) operation and maintenance with water users associations.

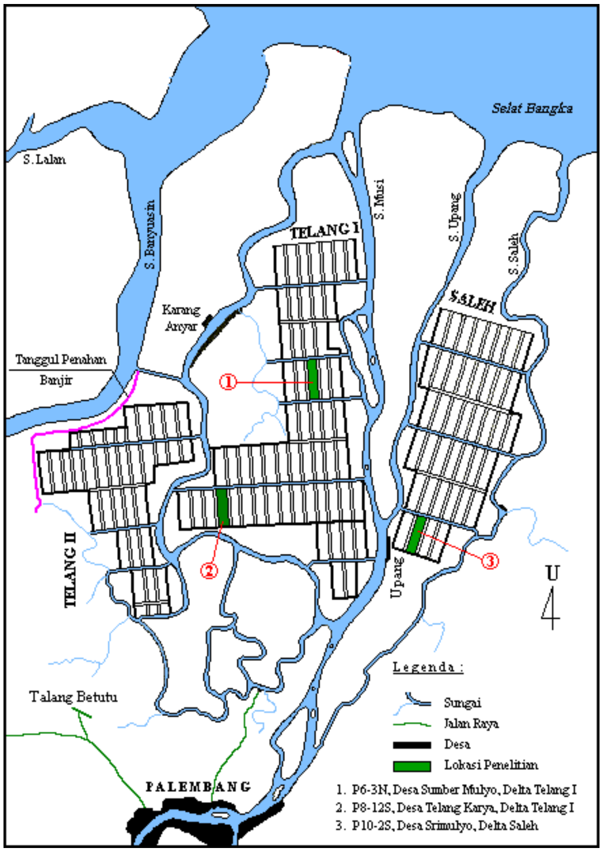

Figure 1. Telang and Saleh schemes, Musi delta, District Banyuasin, South Sumatra with the location of the three pilot areas (Hartoyo Suprianto et al, 2009)

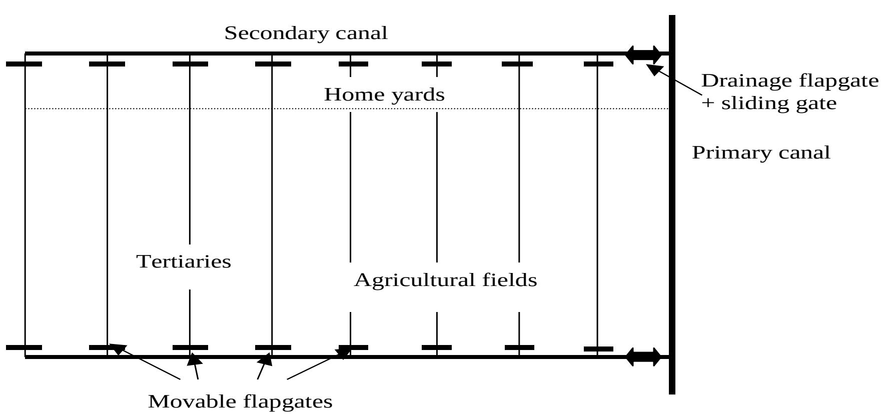

Figure 2. Example of a secondary block with water control structures

The approach that has been developed was applied in three pilot areas (representing category A, B and C areas) - each covering a secondary block of about 250 ha - in the Musi Delta, South Sumatra (Figures 1) (Hartoyo Suprianto et al., 2009).

In January 2007 the LWMTL project was followed up by the project Strengthening Tidal Lowland Development (STLD) where further experience has been obtained in the same three pilot areas in South Sumatra and their surrounding areas and in two new pilot areas in the Districts Pontianak and Sambas in West Kalimantan. In addition experience has been obtained with modern mechanized maintenance of secondary and tertiary canals. Completion of this project was by the end of July 2008. The proposed Propagation Development of Tidal Lowlands (PDTL)to disseminate the success of LWTL and PDTL results was then proposed.

Water management consideration and farming systems technologies for paddy, corn and soy bean production have improved the yield. Rainfall, drainage, water retention and supplemental tidal irrigation are able to fulfill paddy water requirements at the farm level in November to March (first planting season of the year) in Telang I and Telang II, Banyuasin areas. Application of farming systems technologies have improved yield of paddy in Telang I Banyuasin areas from 3-4 tons grain/ ha in 2003 to 5-6 tons/ ha in 2008 (Hartoyo Suprianto et al, 2009). In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period in Telang II in 2015. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha in Telang II area (Bappeda Banyuasin 2015). Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. The three key components: water management, farming system technologies, and empowerment of communities have given significant results of food production and farmers welfare. There are still a lot of components need to be considered and implemented (see Table 2). Related research and development are needed in this integrated approach (Direktorat Rawa dan Pantai 2009; Susanto, 2009, 2010, Sartika et al 2010, Rahmadi et al, 2010, Megawati et al 2012, Husin Adam et al 2013, Erry Korianti et al 2016).

Adoption and spreading over of the best practices to other provinces

Prospective uses of the integrated approach has been implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process. The selected interest local governments in 8 provinces to apply the integrated approach on lowland development are shown on Table 1.

Table 1. Selected Sites being used for an Integrated Lowland Development for Crops in 8 lowland provinces Indonesia

No	Name of provinces	**Districts** Sites	Hydro-topography	Present Yield and cropping pattern
1.	South Sumatera	**Banyuasin** Muara Sugihan	B/C	3-4 tons/ ha one crop per year
2.	Jambi	**Tanjung Jabung Timur** Berbak Delta	B	3-4 tons/ ha one crop per year
3.	Riau	**Indragiri Hilir** Pulau Palas	B	3-4 tons/ ha one crop per year
4.	South Kalimantan	**Barito Kuala** Danda Jaya	A/B	3-4 tons/ ha one crop per year
5.	West Kalimantan	**Kubu Raya** Bintang Mas	B/C	3-4 tons/ ha one crop per year
6	East Kalimantan	**Penajam Paser Utara** Sebakung	B/C	3-4 tons/ ha one crop per year
7.	North Kalimantan	**Bulungan** Tanjung Buka	A/B	3-4 tons/ ha one crop per year
8.	Central Kalimantan	**Seruyan**	A/B	3-4 tons/ ha one crop per year

Table 2. Integrated Lowland Development for Food Crops Components

No.	Project's component	Description
1.	Management Information System	Agro institutional profile, price information, market need assessment, data base, mapping, of soil-water constrains-farm-crops-yield-market-product, pest monitoring and control.
2.	Hydraulic Infrastructures Development and Improvement	Flood controls, river embankments, upgrading of the main and secondary canals, water retention structures, operation and maintenance
3.	On-Farm Soil-Water Management and Mechanization	Land clearing, ploughing, puddling, tertiary canals maintenance, on-farm quaternary canals and gates, field leveling, water distribution and uniformity, fertilization.
4.	Cropping System Management and Development	Crop selection, crop variety, seed, planting, crop protection and weed control, fertilization, cropping intensity, crop diversification, yield increase, technology demonstration.
5.	Harvest and Post-harvest Handling	Harvesting, threshing, seed sorting and screening, packing, transportation, drying, fumigation storage.
6.	Agroprocessing and Agroindustry Development	Sorting, washing, grinding, cooking, processing (home-industry), fermentation, quality assurance, marked oriented research, packing, labelling
7.	Agricultural Waste Management	Organic fertilizers (manures), utilization of agricultural waste for chicken-ducks pellet, composting, green fertilizer, mulching, ash for liming.
8.	Marketing	Market needs assessment, packing, and labeling, product and price information, KUD, credit system
9.	Agricultural Transportation System	On-farm road-bridge systems, earthen road compaction, motored-wheeled carts, water transport utilization, docking system
10.	Training-Extention and Community Development	Training for the trainer (TOT), training for the farmers, institutional integration, group activity studies, (mobile) training unit, brosur, booklet, comparative studies.
11.	Domestic Water Supply	Rainfall utilization and storage, communal water system, deep groundwater utilization, water treatment, water related desease extension and awareness
12.	On-Farm Farmers Oriented Research (Client Oriented Research)	Market information service, water management, soil improvement, vegetable research, cropping system development, fruit tree improvement, mechanization, seed production, pest monitoring and control, institutional affairs

The roles of multi stake holders. Implementation of integrated components need to be shared to multi stakeholders working on the same targeted areas. This will include the local government, academician/ researcher, private sector, community and politician. Continuous approaches and efforts have to be done.

Integrated Lowland Development Components for Welfare of the Community. The tree main components of integrated development as explained before is not sufficient and has to be coupled with a more comprehensive efforts as shown on Table 2 above. Role sharing and road maps are needed.

Conclusion

Application of farming systems technologies, water management practices, and community empowerment have improved yield of paddy at the first growing season from 3-4 tons grain/ ha to 5-6 tons/ ha. Other related suppoting factors are still needed simulatenously. In the second planting season of March-June, the use of ratton paddy and water melon for example will be benefited to adapt to the water regime during this period. In the drier months of June – September, corn is planted with the yield of 7-8 tons grain/ ha. Consideration of the water management and farming systems technologies has to be made depend on the site specific condition exits. Prospective uses of this approach has to be implemented to around 500.000 ha of reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan.

Implementation of integrated components need to be shared to multi stakeholders working on the same targeted areas. This will include the local government, academician/ researcher, private sector, community and politician. Continuous approaches and efforts have to be done.

Prospective use of the integrated approach has been implemented to the the reclaimed lowlands within the transmigration areas in Sumatera and Kalimantan with an estimate of cost around Rp 3-4 million/ ha. Knowledge transfer and empowering the local institutions have to be done simultaneously during this process.

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SIMULATION STUDY ON THE PERFORMANCE OF AN IMPROVED SUBSURFACE DRAINAGE SYSTEM

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Abstract

New requirements have been put forward for agricultural drainage systems due to frequent floods and shortage of cultivated land in China. The improved subsurface drainage is a more efficient drainage system due to the laying of high permeability materials as filters above the drains based on conventional subsurface drainage whose function is limited by soil hydraulic conductivity. The HYDRUS model was used to evaluate the impacts of the filters' hydraulic conductivity, in addition to the filter width and height, drain spacing and depth on improved subsurface and drainage discharge with constant ponding depth to support the subsequent design. In addition water table depths at different distances from the drain pipe for improved and conventional subsurface drainage were simulated under initial conditions of saturated soil and no surface ponding. The results indicated that the improved subsurface drainage had a real-time drainage function due to the fact that the cumulative outflow had increased by about 45% more than the conventional subsurface drainage within 12h after the beginning of the draining of the field soil. Improved subsurface drainage lowered the water table to an appropriate depth faster than conventional ones and provided a more favourable soil moisture condition for crop growth. Furthermore, through daily water balance analysis of improved and conventional subsurface drainage with different rainfalls and initial water table depths, the results showed that subsurface drainage could reduce surface runoff effectively, especially for improved subsurface drainage. Suitable drain ability of improved subsurface drainage was beneficial in the decreasing of the amount of soil water storage after rainfall and helped to shorten subsequent draining time during water table drawdown. The research results provide a scientific basis for improved subsurface drainage design and lay a good foundation for its application. Meanwhile, it would be beneficial to enrich agricultural drainage technologies and promote the development of agricultural drainage in China.

KEY WORDS: Hydrus, Improved subsurface drainage, Conventional subsurface drainage, Discharge, Water table, Runoff reduction.

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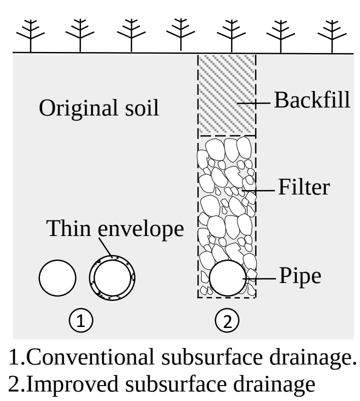
Introduction

Abnormal climate change increases the probability of heavy and intense rainfall events in some areas which causes floods frequently (Das et al., 2013; Groisman et al., 2005; Panagoulia, 2009). In China, most farmlands are in monsoon regions where floods happen more frequently influenced by monsoon climate (Loo et al., 2014). So there are higher demands for farmlands drainage facing flood threat.

Subsurface pipe drainage was widely used all over the world for the removal of excess water from soil profile to maintain favorable unsaturated condition in the root zone and improve the crop growth(Atfy et al., 1991; Darzi-Naftchali et al., 2013; Ghumman et al., 2013). Subsurface drainage systems not only reduce peak flows when compared with surface systems on similar soil, but also decrease soil erosion and sediment transport and improve agricultural water environment (Grazhdani et al., 1996). With the development of China's economy and technology, the issues of farmland shortage and agricultural pollution are getting more and more attention. Subsurface pipe drainage has great potential with characteristics of less land occupied and environmental friendly. Conventional subsurface drainage has limited discharge due to small soil hydraulic conductivity. The conventional subsurface drainage by increasing drain discharge and improving drainage efficiency will accelerate ponded surface water infiltration and removal effectively, which also will be beneficial for waterlogging control. Referring to the structure of conventional subsurface drainage and open ditches, Tao et al. (2016) proposed an improved subsurface drainage by using high permeability materials (gravels or wood chips or crop stalks et al.) as filter to replace the soil above the drains and backfilling 30~40cm original soil as a plow layer, shown in Figure 1. Larger discharge of improved subsurface drainage than conventional ones has been proved by soil column experiment, roughly. It might be difficult to evaluate the improved subsurface drainage performance comprehensively only by experiment. The numerical simulation could be a good



choice for more detailed study.

Fig.1 Sketch of two subsurface drainage patterns

Recently, DRAINMOD and SWAP (Soil-Water-Atmosphere-Plant) and HYDRUS have been widely used to simulate subsurface pipe drainage performence and its ability to control the water table. DRAINMOD and SWAP are one-dimension models based on hydrological process (Dam et al., 1997; Kroes et al., 2000). Skaggs et al. (2012) calibrated DRAINMOD with two years of field data for a sub-surface drained agricultural field in eastern North Carolina and validated the model by data of another two additional years to state the validity of DRAINMOD on predicting discharge and water table of subsurface drainage system. Wang et al. (2006) simulated the water table and surface runoff and subsurface drainage based on data of Eugene F.Whelan plots using DRAINMOD and demonstrated that DRAINMOD has a good simulation performance for hydrology and can be a useful tool for the design of the drainage system. Singh et al. (2006) designed subsurface drainage systems for Iowa' tile landscapes based on calibration and validation of DRAINMOD. Kelleners et al. (2000) predicted subsurface drainage water salinity for a long time using SWAP. Sarwar and Feddes (2000) applied SWAP model to compute the effects of land drainage (12 combinations of drain depth and spacing) on soil moisture conditions in the root zone and their effect on crop yield and soil salinization.

However, HYDRUS is a windows-based model, which can simulate two-dimensional and three-dimensional water flow situations. HYDRUS is used to simulate water, heat, and solute movement in variably saturated media. Especially, HYDRUS can handle flow domains delineated by irregular boundaries. The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy (Šimůnek et al., 2006). TEKİN (2002) has predicted the relationship of drain discharge and water table depth by simulating water flow into subsurface pipe drains for a layered soil profile based on HYDRUS-2D model. Ebrahimian and Noory (2014) have applied HYDRUS-2D model to simulate water flow under subsurface drainage in a paddy field for various drain depths and spacing, surface soil textures and crack conditions. Filipović et al. (2014) has used HYDRUS-2D/3D to evaluate three subsurface drainage systems of pipe drains, pipe drains with gravel trenches, pipe drains with gravel trenches and mole drains under a given high intensity rainfall and a real case scenario, and discussed the effects of three subsurface drainage systems on water table control. The results has demonstrated that pipe drains with gravel trenches and pipe drains with gravel trenches and mole drains were more efficient on waterlogging control, runoff reduction and drainage management than single pipe drains.

The main objective of this paper was to numerically evaluate the performance of improved subsurface drainage by HYDRUS-2D model based on calibration and verification by field experiment data. (ⅰ) The drainability of improved subsurface drainage was analyzed with variable factors of filter hydraulic conductivity, filter width and height, drain depth and drain spacing in saturated soil with constant ponding water depth. (ⅱ) Under initial saturated soil and no ponding water conditions, the water table dynamics under improved subsurface drainage was studied to explain the effect of water table control by comparing with conventional subsurface drainage. (ⅲ) Daily water balance was calculated to demonstrate the capacity of surface runoff reduction for improved subsurface drainage with variable initial water table depths and different rainfalls.

Materials and methods

Field experiment

The field experiment was conducted at Xinmaqiao experiment station in Huaibei plain, China(117°22′ E, 33°09′ N). The climate of Huaibei plain belongs to warm temperate and semi-humid monsoon climate with an average annual precipitation of 760mm~920mm(Qi, 2009), occuring mostly from June to September. It is prone to surface and subsurface waterlogging. Field experiments were carried out in 2015 and 2016. It consists two of conventional and improved subsurface drainage plots, each 18m wide by 17m long, with an area of 306 m^2. Each plot contained three 75mm diameter tile drains. Drains were installed at 0.80m depth and 6m spacing and the gravel filter width and height of the improved subsurface drainage were 0.4m and 0.5m. The drain outflows from each plot flowed directly into observation wells and cumulative discharges were recorded using digital water meters. Tests were conducted when surface ponding was generated or water table was close to the surface after rainfall. Furthermore, the hydraulic conductivities of soil in each plot had been measured by double loop infiltration experiment. The average values of conventional and subsurface drainage plot were 0.805m/d and 0.916m/d. The average saturated and residual water content were 0.31cm^3cm^{-3} and 0.05cm^3cm^{-3}, measured by laboratory test. Water table and the water contents in unsaturated soil were measured before testing (Table 1).

Due to the natural spatial heterogeneity of soils in the field, expected lack of uniformity of soil hydraulic properties, experimental data were used with the inverse option available in HYDRUS-2D to estimate the other effective soil hydraulic parameters characterizing (Kandelous and Šimůnek, 2010).

Table 1 Water table and content before drainage tests

Date	Ponding depth (cm)	Water table depth (cm)	Water content(cm^3cm^{-3})
August 12, 2015	7cm	-	-
August 13, 2015	-	25cm	0.25
October 18, 2015	1cm	-	-
June 5, 2016	-	5cm	0.28
June 7, 2016	-	5cm	0.28
June 24, 2016	-	20cm	0.255

Numerical modeling theory

The governing flow equation for two dimensional isothermal Darcian flow of water in variably saturated rigid porous medium is given by the following modified form of Richards equation:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) + \frac{\partial K_z}{\partial z} - S \quad (1)$$

Where θ is the volumetric water content [L^3L^{-3}], t is time [T], x and z are the spatial coordinates [L], h is the pressure head [L], S is a sink term [T^{-1}], K_x, K_z are components of K at x and z directions and K is the unsaturated hydraulic conductivity function [LT^{-1}] given by

$$K = K_s K_r \quad (2)$$

Where K_r is the relative hydraulic conductivity and K_s is the saturated hydraulic conductivity [LT^{-1}].

The van Genuchten(VG) model was used to describe soil hydraulic functions. The expressions of VG model were given by

$$\theta(h) = \begin{cases} \theta_r + \dfrac{\theta_s - \theta_r}{[1+|\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \quad (3)$$

$$K(h) = K_s S_e^l [1-(1-S_e^{1/m})^m]^2 \quad (4)$$

$$S_e = (\theta - \theta_r)/(\theta_s - \theta_r) \quad (5)$$

$$m = 1 - 1/n \qquad n > 1 \quad (6)$$

Where θ_r and θ_s denote the residual and saturated volumetric water contents [L^3L^{-3}], respectively; S_e is the effective saturation [-], α [L^{-1}] and n [-] are retention curve shape factors, and l is a pore connectivity parameter [-].

Model calibration and validation

The HYDRUS-2D was firstly used to calibrate unknown parameters of field soil according to observed drain process on August 13, 2015. The parameters of gravel describing filter hydraulic properties adopted the values suggested by (Filipović et al. (2014)). The final estimates of soil hydraulic parameters for soil and gravel were shown in Table2.

Table 2 Hydraulic parameters of soil and gravel for VG model

	θ_r(cm^3 cm^{-3})	θ_s(cm^3 cm^{-3})	a(cm^{-1})	n	K_s(cm min^{-1})	l
Soil in conventional plot	0.05	0.31	0.014	1.8	0.0560	0.5
Soil in improved plot	0.05	0.31	0.014	1.8	0.0636	0.5
Gravel in improved plot	0.005	0.42	0.1	2.1	2	0.5

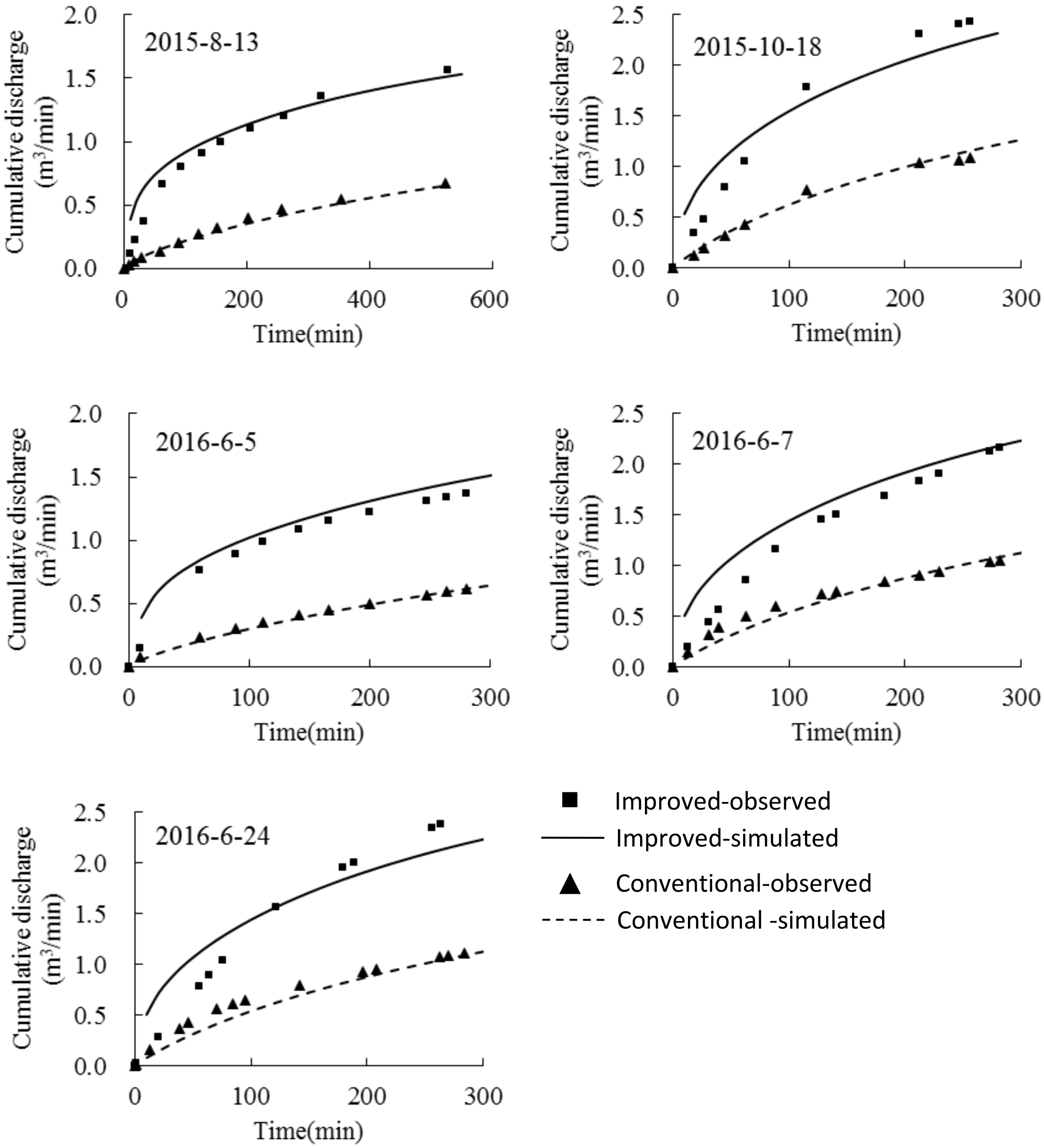


Fig.2 A comparison of observed and simulated drain process for the field experiment

On August 12, 2015, the drain test was conducted under the condition of surface ponding. The observed discharge were 0.0135cm^3 min^{-1} and 0.0116cm^{3}min^{-1} for conventional subsurface drainage and 0.0292cm^{3}min^{-1} and 0.0255cm^{3}min^{-1} for improved subsurface drainage with 7 and 1cm surface ponding depths, respectively. Correspondingly, the simulated discharge were 0.0131 cm^3 min^{-1} and 0.0121cm^{3}min^{-1}, 0.0296 cm^3 min^{-1} and 0.0262 cm^{3}min^{-1} for conventional and improved subsurface drainage. It could be easily seen that the observed and simulated discharge matched well under the condition of surface ponding. In addition, the improved subsurface drainage discharges were over 2 times of conventional ones with same ponding depth.

The comparison of observed and simulated cumulative discharge for conventional and improved subsurface drainage plot at other times were shown in figure 2. To evaluate the effect of calibration and validation, three statistical parameters of coefficient of determination (R^2), relative error (RE), and Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970; Saleh et al., 2000) were selected. Table 3 showed the evaluation of the model calibration and validation. In validation period, the statistical parameters R^2/RE/Nash-Sutcliffe efficiency coefficient were respectively 0.975/-4.6%/0.97 overall, which reflected an excellent performance of the model.

Table 3 Evaluation of the model calibration and validation

	Date	Coefficient of determination	Relative error (%)	Nash-Sutcliffe efficiency coefficient
calibration	August 13, 2015	0.948	8.7	0.93
	October 18, 2015	0.955	3.6	0.95
	June 5, 2016	0.985	6.1	0.97
validation	June 7, 2016	0.974	1.6	0.97
	June 24, 2016	0.977	-4.6	0.96
	Overall	0.975	-4.6	0.97

Simulated scenarios

The largest difference between improved and conventional subsurface drainage is that improved subsurface drainage uses high permeability material as filter laid from the drains to plough layer (seeing Figure 1). Gravels or rice husk or wood chips or crop stalks or cinders were commonly used as filter materials (Stuyt and Dierickx, 2006). These materials have different hydraulic conductivities. And even the permeability of a material will be changed after working for a long time. For an example, the hydraulic conductivity of rice husk will be reduced to half when pressure increases from 0kPa to 5kPa (Ebrahimian et al., 2011). In shallow groundwater areas, the water table can reach the ground surface within a short time after heavy and intense rainfall and surface ponding occurs subsequently, which will make the soil fully saturated. In this case, the effect of filter hydraulic conductivity on drainability of improved subsurface drainage in saturated soil with ponding water is worth to be discussed. Besides, filter width and height influence the drainability directly as well. Although the discharge of improved subsurface drainage with larger filter size will be larger, we also have to consider the installation cost of drains. Furthermore, drain depth and spacing are still the factors affecting the discharge of improved subsurface drainage. After surface ponding fading away, the main goal of drainage is to lower water table to an appropriate depth in a given number of days better for crop growth and yield (Claire et al., 2008; Jackson, 1990). So the ability of water table control was simulated to examine the function of the improved subsurface drainage.

Scenario 1 and 2 were developed to study the factors affecting the drainability of improved subsurface drainage with constant ponding depth in a saturated soil. In scenario 1, the effects of filter permeability on the removal of ponding water were discussed for improved subsurface drainage. Then in scenario 2, variable factors of filter width and height, drain depth and spacing were considered.

In scenario 3, the drain discharge and water table dynamics under improved subsurface drainage with initial saturated soil and no ponding water were studied. Compared with conventional subsurface drainage, water table depths at different distances away from the drain pipe were calculated to illustrate the function of lowering water table level by improved subsurface drainage.

In scenario 4, daily water balance for improved subsurface drainage was analyzed to explain the capacity of surface runoff reduction under rainfall of 25mm, 50mm and 100mm per day with initial water table depth of 0cm, 10cm and 30cm respectively.

Simulated scenario input

Drainage model using HYDRUS was built based on the above-mentioned four scenarios, showed in figure 2 in which S1 and S2 stand for hydraulic conductivities of the soil and filter, b_0 stands for filter width, h_0 is filter height, h is drain depth, B represents drain spacing and T represents the depth of impermeable layer. In the scenario 3 and 4, the geometric parameters were chosen by taking subsurface drainage practices of Huaibei plain as reference. Geometric parameters are assumed as follows: b_0=40cm, h_0=70cm, h=1m, B=40m, T=10m(Wen et al., 2000). Furthermore, the hydraulic conductivity of the soil and diameter of the pipe were assumed the same as that of improved plot in field experiment. For scenario 1 and 2, the parameters were varied as showed in table 4 based on aforementioned ones.

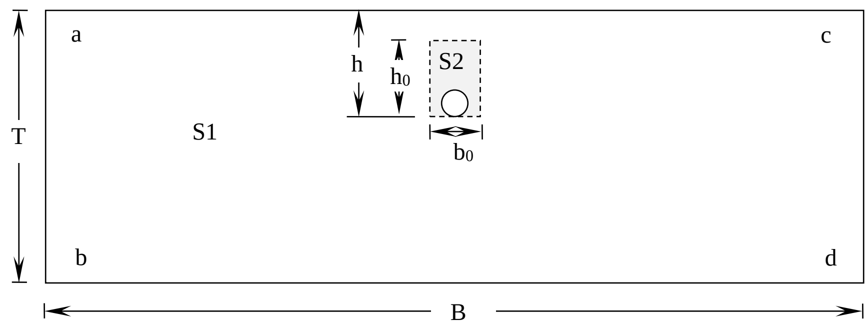


Fig.3 Sketch of improved subsurface drainage model

Table 4 Geometric parameters and filter hydraulic conductivity of scenario 1 and 2

Factors	Variable parameters
Filter hydraulic conductivity	$S2/S2_f$=0.1,0.3,0.5,0.8,1,1.2,1.5,1.8,2,3
Filter width	b_0=0,0.1,0.2,0.3,0.4,0.5,0.6m
Filter height	h_0=0,0.1,0.2,0.3,0.4,0.5,0.6,0.7m
Drain depth	h=0.8,0.9,1,1.1,1.2m, h_0=0.5m
Drain spacing	B=5,10 ,20, 30, 40, 50, 60 m

$S2_f$ stands for hydraulic conductivity of the filter in the field abdc was a no-flux boundary (Figure 3), drain pipe was assigned seepage boundary, and surface boundary ac was variable in different scenarios. The boundary ac was set to be constant head boundary of 7cm in scenario 1 and 2, and seepage boundary in scenario 3. While in scenario 4, atmospheric boundary was used to describe surface boundary ac where evaporation was ignored and rainfall was 25mm, 50mm and 100mm per day respectively. Besides, the pressure head in unsaturated soil were assumed to be -100cm when initial water table was lower than ground surface. VG model was also used to describe the soil hydraulic properties.

Results and discussion

Removal of ponding water

Effect of filter hydraulic conductivity

Effects of filter hydraulic conductivity on improved subsurface drainage discharge per unit length were shown in Table 5. Generally speaking, the improved subsurface drainage discharge increased with the increasing filter hydraulic conductivity, while the increased percentage of per unit hydraulic conductivity decreased gradually. When the ratio of filter and soil hydraulic conductivity was about 10 which was the minimum allowed ratio in usual filter design criteria, the discharge was about 1.9 times of that in conventional subsurface drainage. Next, when hydraulic conductivity of improved subsurface drainage filter was about 30~40 times of the soil's, the improved subsurface drainage discharge could be increased about 10% again based on the minimum allowed ratio aforementioned. However, the subsequently increased hydraulic conductivity of the filter would have small impacts on the increase of discharge.

In another words, there will be little influence on improved subsurface drainage discharge until filter hydraulic conductivity reduces to about 30~40 times of the soil after filters of gravels or rice husk or wood chips or crop stalks working for a long time in practice. Fortunately, there were still obvious larger discharge of improved subsurface drainage than conventional ones even when the ratio of filter and soil hydraulic conductivity reduced to 10.

Table 5 Discharges per unit length with different filter hydraulic conductivities

S2(m/d)	0.916	2.88	8.64	14.40	23.04	28.80	34.56	43.20	51.84	57.60	86.40
$S2/S2_f$	0.03	0.1	0.3	0.5	0.8	1.0	1.2	1.5	1.8	2.0	3.0
S2/S1	1.0	3.1	9.4	15.7	25.2	31.4	37.7	47.2	56.6	62.9	94.3
discharge(m^2/d)	1.51	2.40	2.87	2.95	3.01	3.04	3.06	3.09	3.10	3.12	3.15
Times of conventional drain	1.00	1.59	1.90	1.95	1.99	2.01	2.03	2.05	2.05	2.07	2.09

Effect of filter width and height

Figure 4 showed the effects of filter width and height on improved subsurface drainage discharge per unit length. It could be seen that wider and higher filter size could obviously increase the drain discharge before filter width and height reached critical values. When filter height kept constant, the relationship between improved subsurface drainage discharge per unit length and filter width could be estimated as a second degree parabola. The discharge increased about 76% when filter width varied from 0 to 0.2m and subsequently the discharge only increased 10% on the basis of current value every 0.1m increase in width when filter width changed from 0.2 to 0.6m. Similarly, when filter width remained constant, the discharge increased about 67% when filter height increased from 0 to 0.2m, and only 7% every 0.1m increase in width when filter width changed from 0.2 to 0.6m. Additionally, filter size is an important factor for influencing improved subsurface drainage discharge, larger filter size usually means larger discharge but higher cost. Four types of improved subsurface drainage with the same filter cross sectional area were further simulated(b_0=0.2m/ h_0=0.6m, b_0=0.3m/ h_0=0.4m, b_0=0.4m/ h_0=0.3m, b_0=0.6m/ h_0=0.2m). The discharges were 2.555,2.559,2.699,2.751 m^2/d respectively in order. It could be seen that bigger filter width made larger drain discharge when filter sectional area was a constant. However, filter width usually affects engineering excavation quantity. No matter in design or practice, it is critical to optimize drain layout considering the relationship between investments and drain effect with maximum benefit as the target.

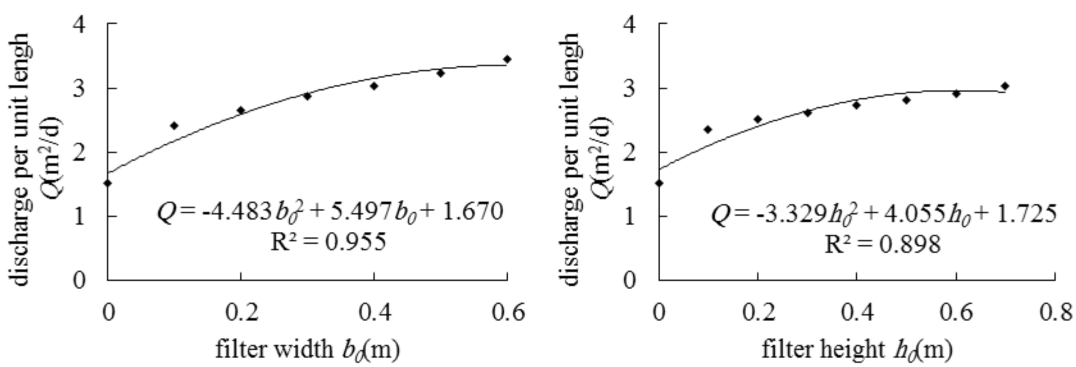


Fig.4 Effects of filter width and height on discharge per unit length

Effect of drain spacing and depth

With fixed filter size and drain depth, the total drain volume was close to be stable when drain spacing exceeded an effective control distance. For improved subsurface drainage, the discharge per unit length increased obviously with the increasing drain spacing within a drain spacing of 10m. After drain spacing exceeded 10m, the discharge changed slowly (left in figure 5). While for conventional subsurface drainage, the effective control distance was about 5m which was smaller than improved subsurface drainage. In another word, improved subsurface drainage could control larger drainage areas. Besides, the ratio of improved and conventional subsurface drainage discharge rose gradually within 10m drain spacing and was almost in a stable value 2.02 when drain spacing was larger than 10m. The effect of drain spacing on drainage discharge per unit area which is an important drainage index in design was also shown in figure 5 (right). We could easily found that the relationship between conventional and improved subsurface drainage discharge per unit area and drain spacing was power function distribution.

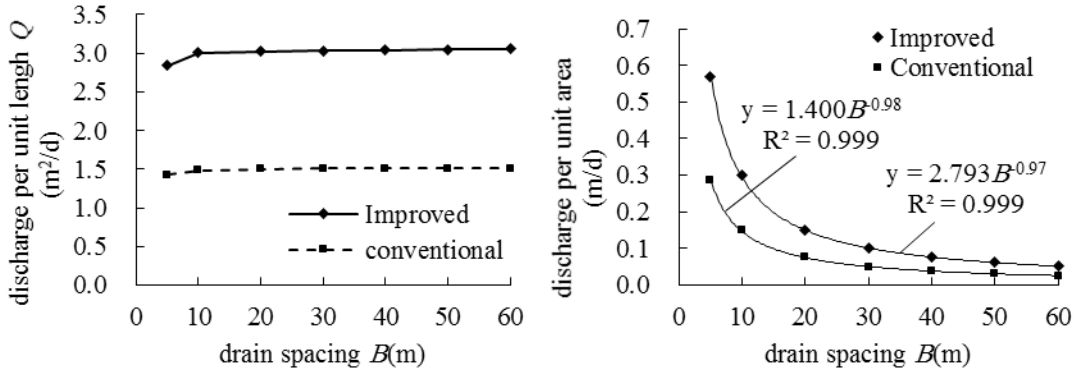


Fig.5 Effect of drain spacing on improved and conventional subsurface drainage discharge

In figure 6, the effect of drain depth on improved subsurface drainage discharge per unit length was given. The simulation results showed that the relationship between improved subsurface drainage discharge and drain depth satisfied linear positive correlation well when filter size and drain spacing kept constant. The variation trends of drain discharge with drain spacing and height were almost the same as that of conventional subsurface drainage obtained from Kirkham (1949) formula.

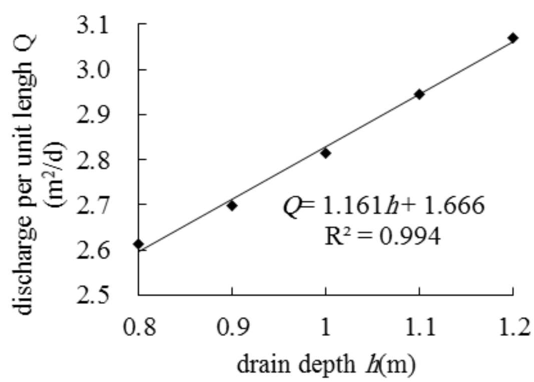


Fig.6 Effect of drain depth on improved subsurface drainage discharge

Water table control

Drain discharge and cumulative outflow

Figure 7 displayed improved and conventional subsurface drainage discharges and cumulative outflow per unit length within 72h after beginning drainage. With draining time going on, water table declined and discharge of improved and conventional subsurface drainage decreased gradually, but improved subsurface drainage discharge was larger than that of conventional subsurface drainage all the time. The improved subsurface drainage had a larger discharge as soon as the drainage began due to weak water holding capacity within the filter. Subsequently soil water around the filter was drained. As time continued, water table continuously decreased and contact zones between groundwater and filter narrowed gradually. Ultimately, the improved subsurface drainage discharge was close to conventional ones, as shown in the left side of figure 6. Meanwhile, it was easily found that the relationship between the discharge and draining time accorded with power function and presented a good correlation both for improved and conventional subsurface drainage.

For the right side in figure 7, conventional subsurface drainage had cumulative outflows of 2869, 4627, 7173 and 9028cm^2 per length at 12h, 24h, 48h and 72h after beginning drainage. While the cumulative outflows of improved subsurface drainage were 4173, 6205, 9053 and 11066cm^2 per length, resulting in a corresponding increase of 1303, 1578, 1880 and 2039 cm^2 than conventional ones respectively. From the view of cumulative outflow, the effect of improved subsurface drainage was remarkable within 12h after beginning drainage during which there was 45% cumulative outflow increasing than conventional subsurface drainage. That is to say, the improved subsurface drainage had obvious effect for real-time drainage and could lower water table to waterlogging tolerance more quickly to produce a more favourable soil moisture condition for crop growth.

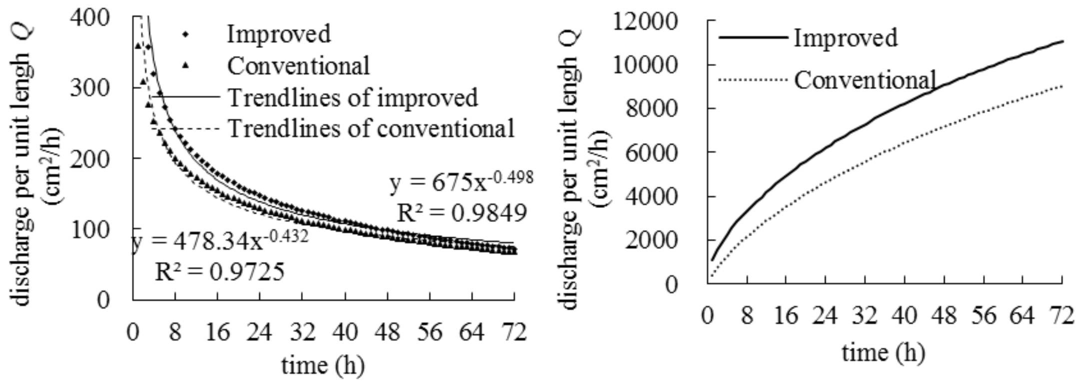


Fig.7 Dynamic processes of drain discharge and cumulative outflow

Water table dynamics

Under drain spacing of 40m, water table depths at distances of 20m(B/2), 10m(B/4) and 5m(B/8) away from the drain pipes under improved and conventional subsurface drainage respectively were shown in Figure 8.

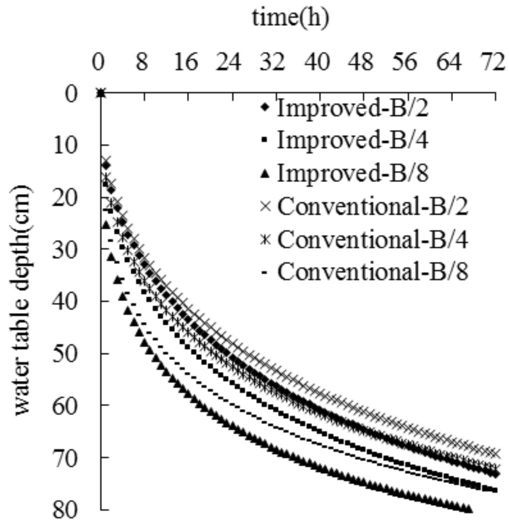


Fig.8 Water table depth in improved and conventional subsurface drainage

With the increase of draining time, water table declined and the ability of lowering water table of improved subsurface drainage was weakened because of decreasing discharges. In China, waterlogging control standard of agricultural drainage requires that water table should drop to 40~60cm below the soil surface within 3~4 days during waterlogging sensitive period for drought crops or within 3~5 days during drying period for paddy field. Hence, the time required to lower the water table to 50cm below the soil surface has been selected as a study target. Numerically, the times of water table drawdown at distances of 5m, 10m and 20m away from the drain pipes were 10h, 17h and 24h separately for improved subsurface drainage and 13h, 22h and 28h for conventional subsurface drainage. It could be seen that water table dropped more slowly at farther distance from drain pipes. In addition, the draining time of improved subsurface drainage lowing water table to 50cm below the soil surface decreased over 14% than conventional subsurface drainage. It was shown that improved subsurface drainage was more beneficial to control water table and helpful for drainage water management.

Drain process under high intense rainfall

Table 6 gave daily water balance of improved and conventional subsurface drainage corresponding to rainfall of 25mm, 50mm and 100mm per day under initial water table depth of 0cm, 10cm and 30cm respectively. The water contents in the unsaturated zone were set as 0.25 cm^3cm^{-3} and 0.28 cm^3cm^{-3} respectively with initial water table depth of 10 and 30cm according to field experiment. There were three ways to go for the rainfall: surface runoff, subsurface drainage and storage in soil. Generally, from table 6, we could see that surface runoff remarkably increased with the increasing rainfall when initial water table depths were equal, while the amount of subsurface drainage and soil water storage appeared small increase limited by soil hydraulic conductivity.

Under conditions of initial saturated soil, corresponding to 25mm, 50mm, 100mm rainfall per day, cumulative outflows were 19.4mm, 23.2mm and 27.5mm per length and the percentages of surface runoff reduction were 73%, 45% and 27% by infiltration for conventional subsurface drainage.

Depending on larger discharge, the cumulative outflows of improved subsurface drainage were 1.2, 1.2 and 1.3 times of conventional subsurface drainage discharge respectively and the percentages of surface runoff reduction also increased 12.6%, 16.4% and 21% than conventional ones, accordingly. It could be seen that the effect of improved subsurface drainage on surface runoff reduction was larger than conventional subsurface drainage, especially for large intense rainfall.

Table 6 Daily water Balance for high intense rainfall

	Water table depth (cm)	Rainfall (mm)	Infiltration (mm)	Runoff (mm)	Drain (mm)	Soil water variation (mm)
Improved subsurface drainage	0	25	20.6	4.4	24.1	-3.5
	0	50	26.3	23.7	28.9	-2.6
	0	100	32.9	67.2	34.9	-2.1
	10	25	21.5	3.5	23.3	-1.9
	10	50	27.3	22.7	28.2	-0.9
	10	100	34.6	65.4	34.8	-0.2
	30	25	24.3	0.7	18.0	6.3
	30	50	32.8	17.2	25.2	7.6
	30	100	41.0	59.0	32.8	8.2
Conventional subsurface drainage	0	25	18.3	6.7	19.4	-1.1
	0	50	22.6	27.4	23.2	-0.6
	0	100	27.2	72.9	27.5	-0.4
	10	25	19.3	5.7	18.9	0.4
	10	50	24.0	26.0	23.0	1.0
	10	100	28.5	71.5	27.2	1.3
	30	25	23.4	1.6	14.0	9.4
	30	50	29.9	20.1	19.9	10.0
	30	100	35.9	64.2	25.6	10.2

With the increasing of initial water table depth, less water were drained and more water were stored in soil which would accelerate the infiltration. The soil water storage in rainy day would directly influence the subsequent draining. For improved subsurface drainage, there was less increased soil water storage than conventional ones when other conditions were equal. Taking 50mm rainfall per day as an example, the soil water storages were 17.2 mm and 20.1mm for improved and conventional subsurface drainage separately when initial water table depth was 30cm. In addition, runoff decreased with the increasing of initial water table depth. Taking 50mm rainfall per day as an example, compared with conditions of initial saturated soil, there were 4.2%, 27.4% runoff reduction for improved subsurface drainage and 5.1%, 26.6% for conventional subsurface drainage under initial water table depth of 10cm and 30cm respectively.

To sum up, under same initial water table depth and rainfall, improved subsurface drainage had better drainability and more effect in reducing surface runoff than conventional subsurface drainage, which was better to satisfy agricultural drainage and waterlogging control requirement.

Conclusion

Numerical experiments have been performed for improved subsurface drainage, (ⅰ) the drainability of removing ponded surface water with variable filter hydraulic conductivity, filter height and width, drain spacing and depth, (ⅱ) the capacity of water table control, (ⅲ) drainability and surface runoff reduction under different rainfalls and initial water table depths. The main conclusions were as follows. Firstly, under saturated soil and constant ponding water depth conditions, the value of 30~40 was a transition ratio of filter and soil hydraulic conductivity. Improved subsurface drainage discharge increased obviously when the ratio was less than 30~40. But the increase of discharge tended to be small when the ratio exceeded 30~40. Fortunately, the discharge of improved subsurface drainage was significantly larger than conventional ones even when the ratio of filter and soil hydraulic conductivity reduced to 10. Filter width and height had a good relationship of second degree parabola with improved subsurface drainage discharge respectively. The effect of drain spacing and drain depth almost met the same rules as that in conventional subsurface drainage except for larger effective control distance. In practices, the factors aforementioned should be chosen carefully, considering the costs and benefits comprehensively. Secondly, improved subsurface drainage had better effect on water table control than conventional subsurface drainage. The draining time of improved subsurface drainage lowering water table to 50cm under surface decreased over 14% than conventional subsurface drainage. Finally, subsurface drainage could reduce runoff effectively, especially for improved ones under high intense rainfall. The effect of improved subsurface drainage was more significant with the increasing rainfall which also reduced more surface runoff. At the same time, the increase of soil water storage for improved subsurface drainage was smaller than conventional subsurface drainage, which alleviated subsurface waterlogging degree and was beneficial for subsequent water table control. In addition, the improved subsurface drainage played more advantage than conventional ones in shorten draining time for the selected soil texture.

Acknowledgement

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THE EFFECT OF CANAL WATER RETENTION ON THE FLUCTUATING WATER TABLE AT THE RECLAIMED LOWLANDS FARM AT TANJUNG LAGO, BANYUASIN, SOUTH SUMATERA

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Abstract

The reclaimed lowlands of Indonesia, respective of one 16 ha tertiary block within a 256 ha secondary block consisting of 16 tertiary blocks, are used for food production. The Paddy is planted during the rainy season of November to February followed by water melon cultivation in March to May, and corn in June to September. The fluctuation of the water table in the farm is very crusial in determining the cropping calender. Water management applying a free drainage approach is influenced by tidal water movement into the tertiary canals bordering the farmers fields. A constant water retention -10 cm below the canal bank increased the water table in the farm from -10 cm to +20 cm. Water retention (controlled drainage) mode was applied by farmers especially during the rice growing period. The release of water in the canal to a depth of -50 cm below the canal bank lowered the water table level to -20 cm. Over the 200 day experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The NO_3^-, NH_4^+, pH content of the water sample corresponded to the the fluctuating water table. Preliminary research results related to the water table fluctuation are discussed in this paper.

KEY WORDS: Water table fluctuation, Drainage, Reclaimded tidal lowland, Controlled drainage.

Introduction

Development of tidal lowland in South Sumatra has been conducted by government since 1969 through transmigration program. Conserved and improved tidal lowland land of South Sumatra are approximately covered 2.92 million ha (Euroconsult, 1995). It is reported that 60 percent rice production in South Sumatra of 2.8 million tons is currently produced from lowland areas (Prov. Agricultural Office of South Sumatra, 2015). The reclaimed lowland is frequently experience lack

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of fresh water supply due to low tidal irrigation that incapable reaching into the land and less rainfall. Moreover, porous soil condition results in high value of soil hydraulics conductivity caused in very high losses of water due to percolation and lateral seepage. It is caused that rainfall water is difficult to be retained. This made a sharp drawdown of the shallow water table in the farm (Susanto, 2007). The water table depth, especially in dry season, is lower than the depth of pyrite layer depth which results in oxidation process.

Water management is one of important factor for land management at reclaimed tidal lowland area (Suprianto et al. 2009). This management is not only to reduce or to add surface water availability, but also to reduce acidity, to minimize land acidity due to phyrite layer oxidation, to minimize salinity hazards and flooding risks, as well as to reduce toxic chemical compounds as a result of phyrite layer oxidation (Imanuddin and Susanto 2005). In order to establish the above conditions, water management operation is geared toward aspects of water table management that is always located above phyrite layer and land leaching through a controlled drainage systems (Skaggs, 1991).

In term of the above potential and constraint, tidal lowland development needs a proper planning, management, and utilization of land as well as proper technology application, especially water management aspect (Susanto, 2003). This soil has a good potential for agricultural development through proper management. Proper planning of water management is certainly need data of daily soil water status, thus yearly monitoring of that data is essential. Water table dynamics within the crop root zone has highly significant to influence water availability for crops. Therefore, a field study to monitor water status at tertiary blocks is needed in order to develop water management and land utilization planning. The study objective is to investigate the water table dynamics within tertiary blocks in order to determine correlation between water level in the canal and withn the soil at the farmers field during drainage. Daily water level fluctuation in the canal and water table fluctuation within the soil are observed

Materials and methods

Study and field investigation have been conducted at tidal lowland reclamation area. The demonstration plots (demplot) of 16 ha is located at Primer 17-6S, Banyu Urip, Tanjung Lago, Banyuasin District (Figure 1). Study and field monitoring are conducted within two growing seasons consisting of wet and dry seasons. Observation period (water table monitoring) in the field is carried out from January to June 2015. Soil and water samples were taken and analyzed 16 times during this periods.

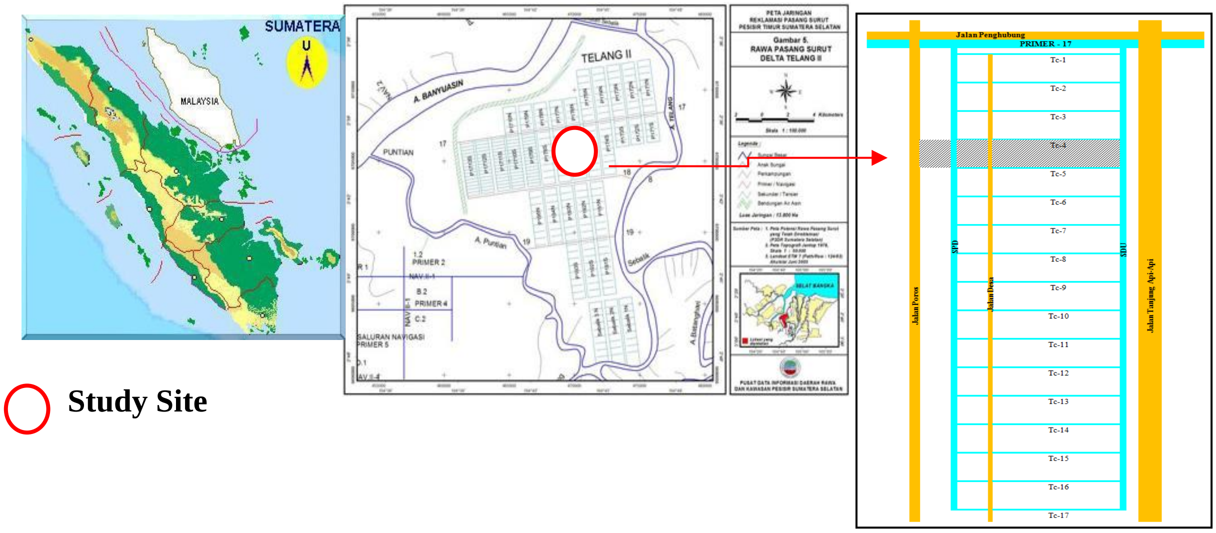

Figure 1. Study site at Primer 17-6S, Banyu Urip-Tanjung Lago, Banyuasin District

The water table fluctuation measurement at farmers field conducted by using observation wells made from perporated PVC pipes. Observation wells are placed midway between tertiary canals spacing of 200 m. The distance od the wells are 100 m, 50 m, 25 m, 12.5 m and 2.0 m from the tertiary canal. Water table fluctuations were observed daily as well as the water level at the tertiary canals. In addition, daily rainfall is observed by direct measurement from rainfall tipping buckets for every 07.00 a.m time. Soil survey is carried out to determine the physical characteristics of soil such as texture, bulk density, total pores volume, soil hydraulics conductivity, and acid sulphate layer depth. Potential of tidal water penetration within the canals and water table fluctuations at tertiary block are observed daily within two growing seasons (wet and dry seasons). Results of field observation data were analyzed and compared with observation of the critical value of soil water depth that is needed to grow the crops. The cropping pattern for this area is rice, ratton rice or water melon, and corn.

Results and discussion

General Condition for Study Site in Tanjung Lago, Banyuasin, South Sumatera

This reclaimed low land is classified into agroclimate type C1 based on Oldeman classification with monthly average temperature of 32^{0}C and yearly average rainfall of 2500-2800 mm. Rainy season is occured from November to April, whereas the dry season is occured from March to October (Figure 2). Rainfall is relatively low and ineffective to fulfill the crop water requirement at the dry season. This fresh water deficit problem is combined with the inflow of seawater or salt water during high tide. Based on high tide water that overflow into the land, Tanjung Lago lowland area in general is classified into B/C type overflow which means that it is not flooded during high tide or low tide. The land is not overflow by tide water, but the tide water penetrate into the primary, secondary and tertiary canals, affecting the fluctuating water table in the farm. The available water is mostly from rainfall water because tide water can not enter the land which results in rain-fed characteristics of the land. Quality of this land is characterized by unripe physical soil characteristics, high total pores volume (60-70 percents), low bulk density (0.90 – 1.0 grm/cm3), and light texture at the upper layer of 0-30 cm, and medium texture at the depth of 30-60 cm. Soil hydraulics conductivity is about 9-12 cm/h. This condition creates high water losses at this area. Hardpan layer is not develop in this land due to low intensity of soil tillage.

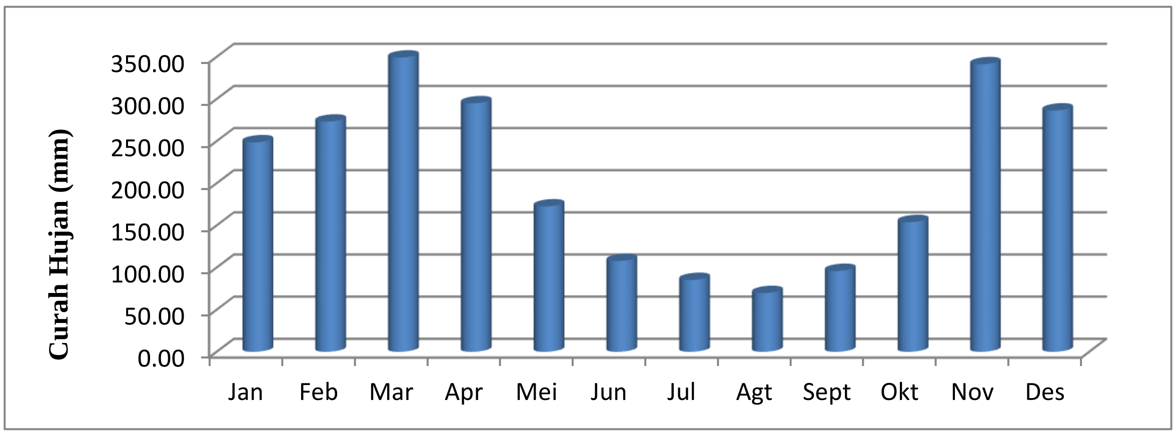

Figure 2. Average Monthly Rainfall in Tanjung Lago, Banyuasin, South Sumatera

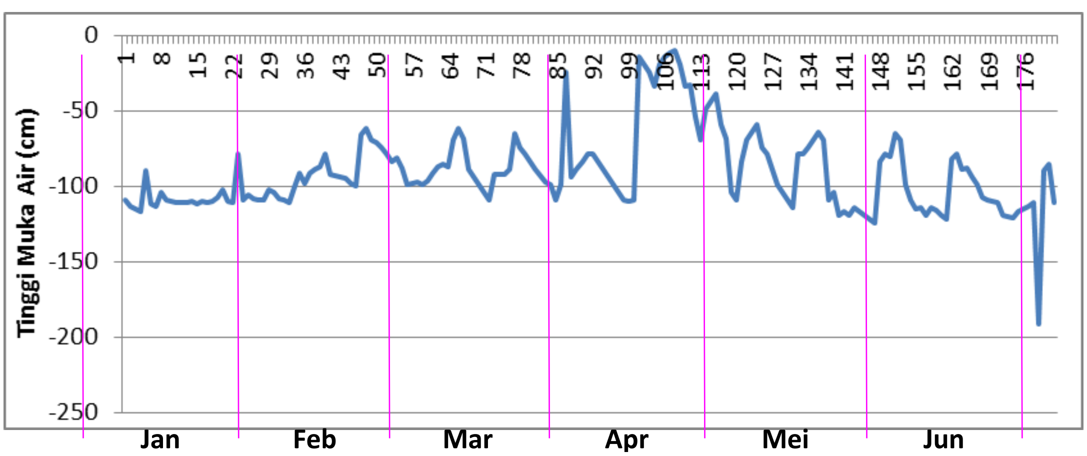

Figure 3. Water level fluctuation downstream of the tertiary canal Tc4 gate

Water level fluctuation downstream of the tertiary gate TC4

Observed water level downstream of the tertiary gate TC4 showed the effect of tidal water movement. The water level fluctuates according to the tidal water conditions. The water level downstream of the TC3 gates are always below the soil surface. It has several water level of peaks which varies during the rice growing season starting December up to April.

Water Level Fluctuation at Tertiary canal TC-4 upstream of the tertiary gate

Results of observation showed that yearly rainfall is 2500-2800 mm/year. This rainfall magnitude is actually sufficient to support paddy water needs. The effective rainfall is not optimal due to porous soil and high hydraulics conductivity as well as insufficient water management facilities. This condition is exaggerated by insufficient tidal water penetration. Free drainage mode applied by the farmers has to be changed to controlled drainage mode in this case as shown at Figure 4.

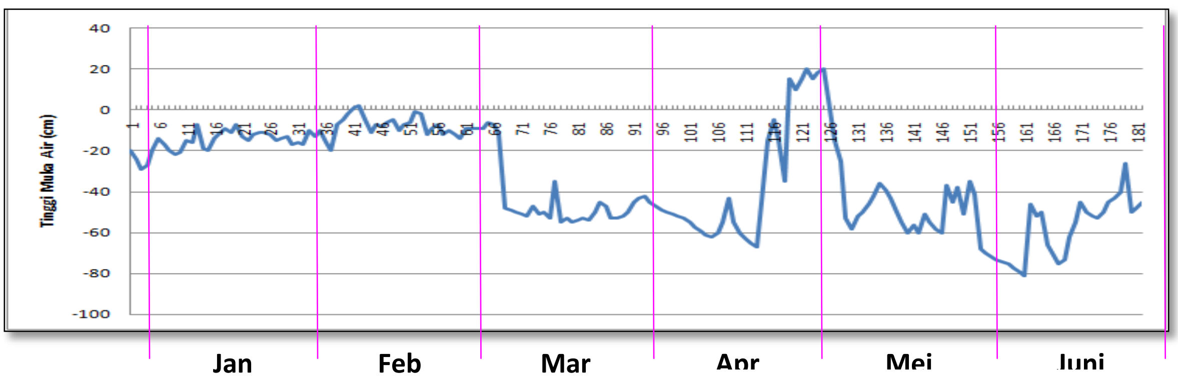

Figure 4. Water level fluctuation at tertiary canal (TC-4) with controlled drainage (water retention)

As shown on Figure 4, water is retained within the tertiary canal TC4 in January to February to almost 10-20 cm below the soil surface. This effort is to make full rainfall water retention in the paddy field during the vegetatif growth of rice planted at the end of Decmber 2015. Lateral seepage from the land into the tertiary canals as well as surface runoff will be reduced with a high water level position within the tertiary canals bordering the farm. Rainfall in January and February can be stored effectively with water retention at the TC4. The water at canal TC4 was release to average almost -50 cm during March and May to overcome the drying of farm land for rice harvest. Lowering the water level at TC4 will lower the water level in the farm. Another water retention at the end of April is due to land preparation for corn growing season. Free drainage mode applied at TC4 during May June onward for the corn growing season.

The Effect of TC4 water retention on Water table fluctuation within the soil at the observation Well 1 (near the tertiary canal TC4)

Results of daily water table analysis near the tertiary canal showed on Figure 5. Water table fluctuation within the soil near the canal TC-4 following the same trend with the fluctuating wate level inside the TC-4. In the months of January and February when the water was retained inside the TC-4, the water table at well 1 started to increase from less then 10 cm below the surface upto 3-7 cm above the soil in January and to about 10 cm above the soil in February and mid of March. The increased water table on the land with water retention in the TC4 follow the rainfall pattern during the same period. Lowering water level inside TC4 to -50 cm (Figure 4) has lowered the water level in the farm to -20 cm (Figure 5).

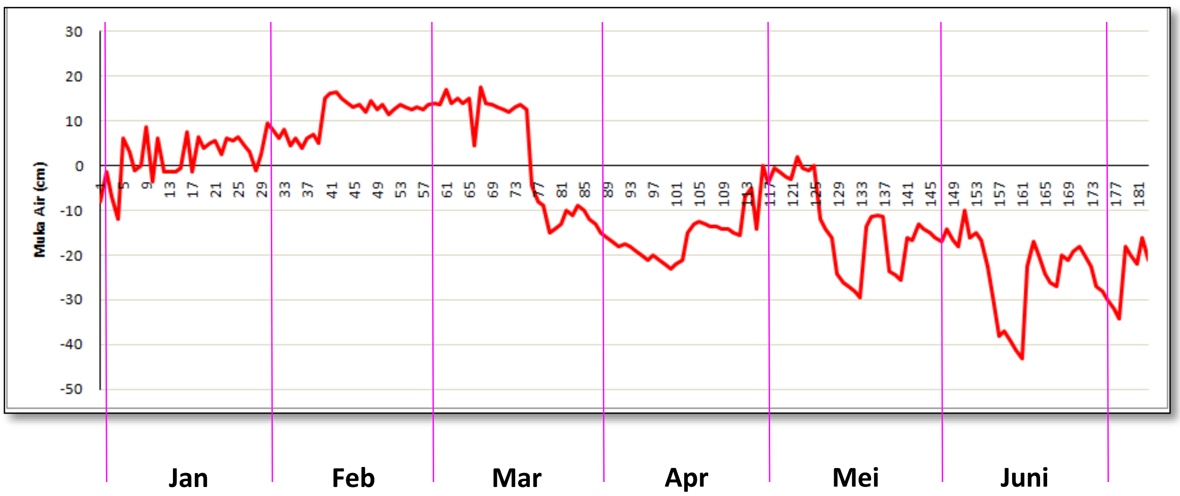

Figure 5. Water table fluctuation in well 1 during the observation periods (Well 1 is 2 m from the tertiary canal TC4)

Water table in Well 1 start to decrease with the release of water in the canal TC4 following the less rainfall in April. This water table fluctuated with free drainage applied following the rainfall in May onward.

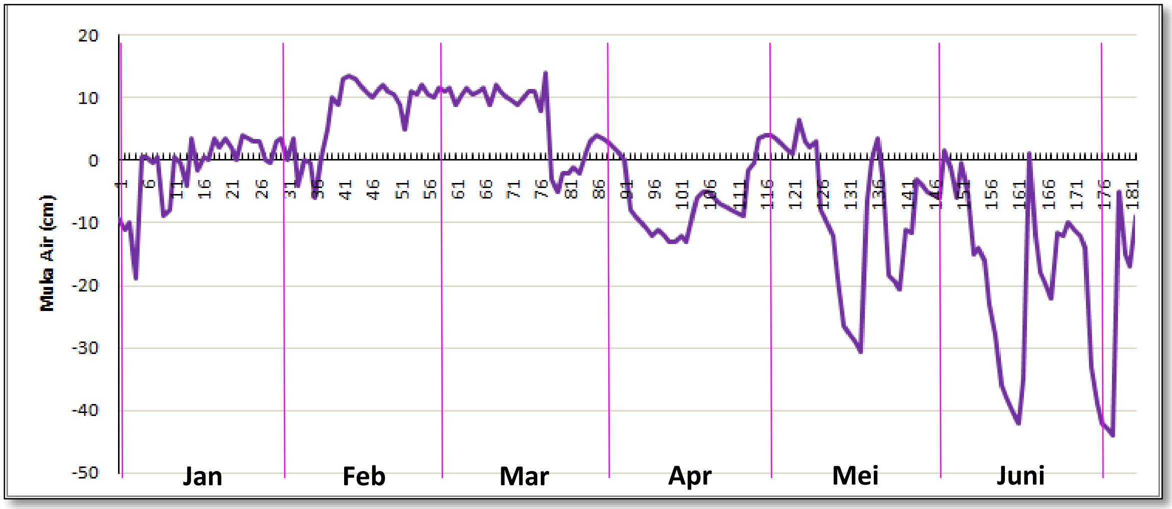

Figure 6. Water table fluctuation midway between tertiary canals, Wells-5, (100 m from the tertiary canals or midway between 2 tertiary canals)

Slightly difference respon observed at Well 5 about 100 m from the tertiary canal. Water table in January and February still just about at the soil surface while at Well 1 near the tertiary ist is about 10 cm above the ground. Water table near the filled tertiary canal will rise quickly compared to the area away from the tertiary canal. During March until Mid of April, the level of water table near (Well 1) and away (Well 5) from the canal TC4 is almost the same of 10 cm above the ground. It is clearly showed that water retention in the bordering tertiary canal with the existing rainfall, will help to retain water in the farmers fields. Paddy growing season in staring end of December 2015 until April 2016 will really need water retention in the tertiary to make the rainfall effective to support high water tabel at the farmers field

During almost 200 days experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The content of NO3-, NH4+, pH of the water sample will be related with the fluctuating water table.

Land and water management systems is a key factor in guarantee the success of food crops development at tidal lowland area. Agrophysical of land variations result in diversity of management systems within an area that need different approaches. Water management in tidal lowland is absolutely different than that of irrigated lands. Soil physical conditions, rainfall pattern, and tidal water effects are predominant factor in planning of the on farm water management. Some of important soil physical characteristics are total pores volume, texture, and soil hydraulic conductivity. Pore volume of soil layer within crop root zone varied in term of their forms, numbers, and sizes. The water availability within these pores are affected by soil, climate, crops, as well as land or water management practices.

Water management approach at the on farm level (free drainage, controlled drainage or water retention, and subirrigation) have to be applied differently depend the water regime needs at the on farm level. Cropping pattern of crops planted at the farmers field certainly related with the water table fluctuation. It is clearly show that paddy is best grwing when the water table near the soil surface. Corn is certainly need a lower water table for the development of depper root zone.

Conclusions

Characteristic of porous soil at the study site create relatively high water losses. Therefore, the main objective of water management for paddy field at this area is to hold rainfall water as much as possible. On the other side, during the corn growing season, is to release the water from the root zones.

A constant water retention -10 cm below the canal bank, in February and March 2016, has increased the water table in the farm from -10 cm in January 2016 to +20 cm at the end of February and beginning of March 2016. Water retention (controlled drainage) mode applied by the farmers especially during the rice growing period which need a high water table condition. The release of water in the canal to a depth of -50 cm below the canal bank lowered the ground water level in the farmers field to -20 cm. During almost 200 days experiment, soil and water samples are taken 16 times to be analyzed in relation to the fluctuating water table. The content of NO3-, NH4+, pH of the water sample will be related with the observed fluctuating water table.

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6

Topic 6:
Drainage
Special Issues

THE EFFECT OF LONG TERM TIDAL IRRIGATION AND DRAINAGE ON FORMATION OF IMPERMEABLE LAYER (CASE STUDY: ABADAN ISLAND, KHUZESTAN, IRAN)

Shahram Ashrafi[1,*], Fouad Tajik[2], Mojtaba Akram[3]

Abstract

Abadan palm date plantations have long been irrigated under tidal effects. Rivers flowing down to the sea have been and still are the water source for irrigation. During high tides, river water flows into the ditches and make subsurface irrigation possible while during low tides ditches act as the drains and water discharges out of the plant root-zone. Recently parts of the plantation has gone under traditional drainage due to rising of river water salinity and surprisingly failed to work efficiently. In order to find the cause, hydraulic conductivity of soil layers were measured using parallel ditch drains. Saturated hydraulic conductivity of the top soil (up to depth 95 cm) shows that, soil is very permeable up to 70 cm depth, but from the depth of 70 cm to 95 cm below the soil surface, it is impermeable. Piezometric measurements also have shown impermeability of the subsoil as well. Based on the piezometric measurements, soil layer located between depths of 70 to 130 cm is impermeable. Soil profile study showed three distinguishable layers in the experimental field. Although soil texture in the first layer (up to 75 cm depth) have been classified as a clayey texture, biological activities, mostly live and thick roots holes have changed the magnitude and the size of the pores in this texture. Value of saturated hydraulic conductivity of the top soil varies from 34 m/day at the top soil to a very low conductivity at the depth of around 70 cm. It was concluded that in tidal subsurface irrigation, only the upper part of the soil which has been under the root spread can be assumed permeable and deep drains laid below cannot work properly.

KEY WORDS: Date plantation, Drain ditch, Hydraulic conductivity, Piezometer, Recharge ditch.

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Introduction

Abadan Island was developed as a tidal mudflat formed by sedimentary deposition in the delta of the Karun and Arvand river systems. In the long past time, continuous and gradually sedimentation during the regularly occurred flooding along with tidal effects of the river and sea water, eventually raised the mudflat to the level where it became vegetated. The total date palm plantation area in the Abadan Island is around 28000 ha. The width of the orchard strips are between 1 and 3 kilometers along the Arvand and Bahmanshir rivers (Figure 1).

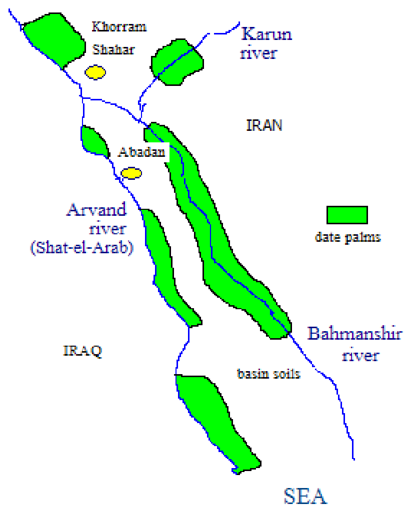

Figure 1. Sketch of the Abadan Island showing rivers and date palm plantations

The soil water condition in the palm date plantation of Abadan is controlled by tidal irrigation and drainage ditches in the neighboring Arvand and Bahmanshir rivers.
Tidal Irrigation is the subsurface irrigation of levee soils in coastal plains with river water under tidal influence. It is applied in (semi) arid zones at the mouth of a large river estuary or delta where a considerable tidal range (some 2 m) is present. The river discharge must be large enough to guarantee a sufficient flow of fresh water into the sea so that no salt water intrusion occurs in the river mouth. The irrigation is effectuated by digging tidal canals from the river shore into the main land that will guide the river water inland at high tide. At low tide, the canals and the soil drain out again, which promotes the aeration of the soil.

So far, the ditches were designed and constructed by farmers themselves, based on their experiences. The ditches with a depth of 70 to 80 cm and spacing of 10 to 12 meters, depending on the permeability of the top soil, receive their water from the tidal canals (Figure 2). In most cases tributary channels are also dug to ensure that the subirrigation is able to bring the whole area to the near saturation stage (Figure 3).

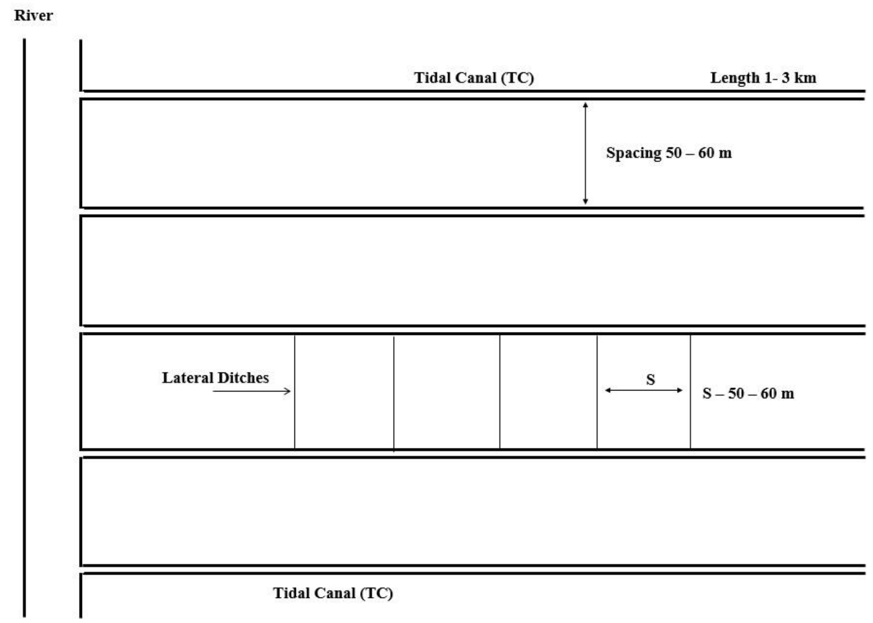

Figure 2. Sketch of the Abadan Island tidal canals and drains

The permeability of the top soil should be high enough to let the top soil between the parallel ditches becomes almost saturated during around 6 hours between high tide and normal water level, while it could drains out once in every near 6 hours between normal water level and low tide. In such a case trees have two times irrigation and two times drainage in a day.

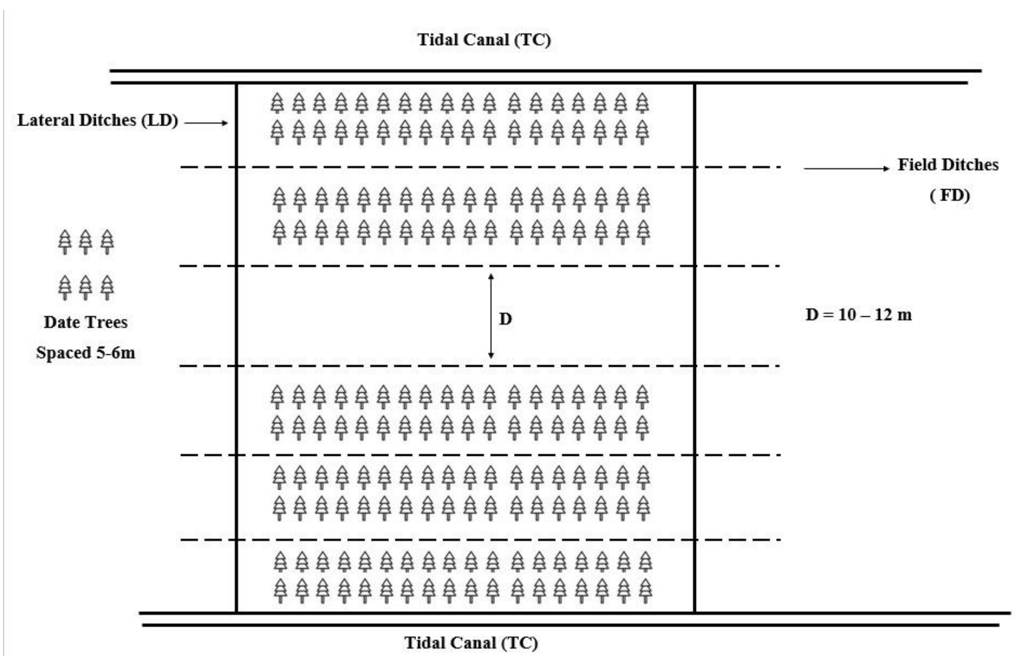

Figure 3. Sketch of the auxiliary field channels

Proper and efficient work of the system in the last few decades indicates the sustainability of the system. It also shows that farmers have been familiar with proper irrigation and drainage design of their orchards. They have also been well aware of the permeability of their topsoil.

Recently due to rising of river water salinity caused by reduction of river flows, parts of the plantations have gone under traditional drainage and surprisingly failed to work efficiently in some parts. The purpose of this research is to find the reasons behind and make the new drainage developments in tidal areas more effective, if possible. The hypothesis of this research is that drainage of the soils in this area is constrained by the impermeability of the subsoil.

Investigations conducted in last five decades by many researchers on the soil profile of Abadan Island showed that there are three distinguished soil layers in this area (Ashrafi et. al., 2015).
Soils of up to 75 cm depth are clayey textured brown colored with live roots and microorganisms without any sign of waterlogging. Soils between 75 and 180 cm are clayey textured brown colored with few roots, mostly narrow, with few mottles and gley with the signs of fluctuating to persistent water table. Soils below 180 cm are silty clay texture with many gley signs, brown mottles and few roots, green to grayish brown color which demonstrates mostly saturated soils.

Hydraulic conductivity

Hydraulic conductivity K-value in the soil profile can be highly variable from place to place and also can be variable with a different depth, what means spatial variability. Because of many factors such as uneven distribution of plant roots and agricultural activities, K-values can be variable not only in connection with different soil layers, but also within a one soil layer. Hydraulic conductivity is one of the most important factors in water management and design of subsurface drainage, while it is indispensable for the control of salinity in date palm orchard water regime. It must receive more attention in areas with tidal irrigation because of a long watering and dewatering time of the topsoil, while the other layers have much lower contribution, if any. Since the roots cannot stay alive in saturated zone, their spreading as well as their activities are limited to the topsoil, hence there is a significant difference between the hydraulic conductivity of the topsoil and other layers.
Hydraulic conductivity or K-values, is one of the principal and most important soil hydraulic characteristic parameter and it is an important factor in water transport in the soil profile and is used in all equations for subsurface water flow. Saturated hydraulic conductivity of Abadan Island soil had been investigated by many researchers but still there is a doubt on the location of impermeable layer in the soil profile (Ashrafi et. al., 2015).

There are many methods for measuring hydraulic conductivity of the soils. So far most of the measurements applied here have been based on small-scale field methods. Small scale field methods are not suitable for strongly layered soils or for soils with irregular pore space distribution. The Auger hole method has been the sole method used in previous studies. The depths of the holes have been between 1.5 and 2.0 meters. So, investigators have reached to an average hydraulic conductivity which could be much different from the hydraulic conductivity of each layer.
The large-scale fields' methods guarantee the representative K-values, where the problem of variation is eliminated as much as possible. But the large-scale field's methods are rather expensive and time-consuming, than the small scale methods. The advantage of the large-scale determinations is that the flow paths of the groundwater and the natural irregularities of the K-values along these paths are automatically taken into account in the overall K-value found with the method. It is then not necessary to determine the variations in the K-values from place to place, in horizontal and vertical direction, and the overall K-value found can be used directly as input into the drainage formulas. A second advantage is that the variation in K-values found is considerably less than those found with small-scale methods (Oosterbaan and Nijland, 1994). Among different methods of large scale field methods of hydraulic conductivity measurement, parallel drains ditch is more accurate as well as representative of the all area of groundwater flow to the drains (Ritzema, 2006).

Generalized table with the ranges of K-values for certain soil texture is presented in Table 1 (Ritzema 2006). The subsoil of Abadan is a poorly to nonstructured soil mostly with no cracks. So, one cannot expect a rather acceptable hydraulic conductivity to drain water.

Table1. K-value range by soil texture (Ritzema, 2006)

Texture	**Hydraulic conductivity K (m.day^{-1})**
Gravelly coarse sand	10 – 50
Medium sand	1 – 5
Sandy loam, fine sand	1 – 3
Loam, clay loam, clay (well structured)	0.5 – 2
Very fine sandy loam	0.2 – 0.5
Clay loam, clay (poorly structured)	0.002 – 0.2
Dense clay (no cracks, pores)	< 0.002

Preferential flow

Preferential flow may have drastic effect on the hydraulic conductivity of the soil and severely limits the applicability of standard flow models. Models are mostly based on Richards' equation (Gerke, 2006). The pore network, especially pore size distribution and connectivity, is believed to control soil hydraulic properties. Preferential flow pathways in this intact structured soil consist of a complex network of earthworm burrows, root channels, interaggregate macro pores, and meso pores or even micro pores in the soil matrix (Lou et al., 2008). Permeability problems on irrigated soils may be alleviated by root systems that increase water flow by creating macro pores. Infiltration rates have been shown to increase where plant roots decay and serve as preferential flow paths. Earthworm channels were also not stable. However, decaying roots of alfalfa produced stable macro pores, while wheat produced no such macro pores (Mitchell et al., 1995). Therefore, it depends on the shape and pattern of the roots. Root systems create networks of preferential flow and thus influence water pressures in soils which may alter subsurface flow. Preferential flow of water occurs in the following types of root channels: (a) channels formed by dead or decaying roots, (b) channels formed by decayed roots that are newly occupied by living roots, and (c) channels formed around live roots. Conceptual examples are presented to illustrate how root architecture and properties (e.g., diameter, length, orientation, topology, sinuosity, and decay rate) affect the creation of root channels and thus affect preferential flow (Ghestem et al., 2011). Furthermore, Bargues Tobella et al. (2014) demonstrated that trees have a positive impact on soil hydraulic properties influencing groundwater recharge. In order to model water flow through the soil, a relatively simple dual-porosity flow was introduced combining Richards' equation with composite (double-hump type) equations for the hydraulic properties to account for both soil textural (matrix) and soil structural (fractures, macro pores, peds) effects on flow (Simunek et al., 2003).

Material and Methods

In this study the saturated hydraulic conductivity of the different soil layers were measured using auger hole and inverse auger hole methods at 16 stations. At each site, a trench was dug to approximately 2 m depth to study the soil profile. Three points were chosen next to each profile in order to measure the saturated hydraulic conductivity of the soil layers each with three replications at the depths of 50, 100, 150 and 200 cm approximately. Results obtained from the study have shown, even soil layers at a specific depth in each station had different values of saturated hydraulic conductivity. Comparisons of the value of hydraulic conductivity in different sites at same soil layer showed significant differences in different places as well (Ashrafi et. al., 2015).

It seems that preferential flow is responsible for such a variation. Thus, the experiments continued in research date palm field of Shalheh with large scale field method named parallel drain ditches method in order to obtain more accurate and reliable values of saturated hydraulic conductivity of the soil layers in Abadan Island.

In order to combat shortcomings of small scale methods used in the past by engineers and researchers worked in Abadan which apparently reached to false values of hydraulic conductivity; it was decided to examine large scale method to reach to a hydraulic conductivity which could be representative of the region.

An experimental field was selected in the palm date plantations of Abadan, at Shalheh Haj Hossein village near to the Arvand river (approximately 500 meters far from Arvand). Soil description for 16 profiles distributed in the orchards was done in the summer 2015. In each profile, soil color and its layers were examined in the field and soil samples were taken to the laboratory to determine other soil properties. Profile no. 2 located in the experimental field was the representative profile of the region as shown in figure 4.

Figure 4. Location of the profile no 2 in Shalheh Haj Hossein

The experimental field was isolated in two sides by two open deep drains and the other two sides by using poly ethylene plastic rolls to a depth of around 1.5 meters. The irrigation water was recharged by a ditch laid in the middle of the two drains. Water surface was remained level both in irrigation and drainage ditches. Inflow and outflow was measured by WSC flumes.

Calculation of the value of hydraulic conductivity was measured from the ditch recharge rate and ground water table level (W.T.) midway between the middle ditch and drain ditch as shown in figure 5 from the readings of the observation well located there.

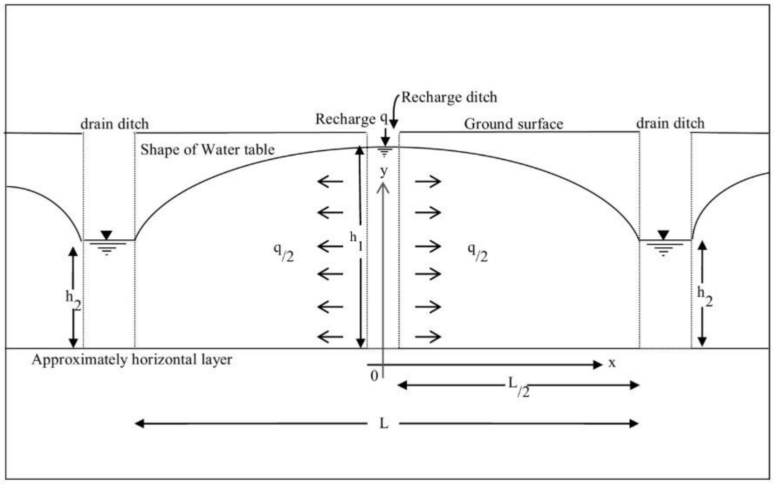

Figure 5. Schematic view of the steady state flow to the open ditches, placed on relatively horizontal layer

In the method used in this research, a system of open drain ditches, placed on relatively horizontal very low permeable layers, under the steady state drainage flow conditions, where recharge rate, q, was equal to drainage discharge q. Drain ditches spacing is L, free water level in the ditches is h_2 and the maximum of W.T. at the middle ditch between the drain ditches is h_1 as shown in Figure 2. Soil porous medium is assumed to be homogenous isotropic with one value of hydraulic conductivity K. The origin of x-y axis is selected to be on the middle of the bed of the irrigation ditch. Horizontal axis is positive to the right direction which extends on the very low permeable, approximately horizontal layer. Vertical axis is positive to the upward direction. All the process of steady state drainage flow is symmetrical with axis of symmetry, y-axis, placed at the midway between the drain ditches. Based on the Darcy's Law and Dupuit- Forcheheimer's assumptions, equation 1 is used for the calculation of saturated hydraulic conductivity of the soil at different water levels of the drain ditches.

$$q = \frac{\left(h_1^2 - h_2^2\right)}{2L} * K \quad (1)$$

Available ditch drain in the experimental field was excavated to the depth of 100 cm. The distance between the two drain ditches was 12 meters, equal to the width of the experimental field. The width of the experimental field was divided to two equal parts (each 6 m) and a ditch excavated to the depth of 100 cm at this point. This ditch was called recharge ditch in this study as shown in figure 5. The width of the recharge ditch was 40 cm with a length of 16 m which is equal to the length of the drain ditches. For measurement of the recharge rate during the experiments, WSC flumes (Washington State College Flume, type II) were installed at the upper and lower ends of the recharge ditch in the soil surface. For measuring the water table (W. T.) at the all ditches (drain ditches and recharge ditch) a scaled indicator was installed in the midpoint of the each ditch.

Small water tight dam was constructed at the lower end of each drain ditch as shown in figure 6. In order to maintain required water level at each drain ditch, 10 PVC pipes (approximately 0.7 meter long and 10 cm diameter) was installed horizontally in the body of the dams with a 10 cm incremental steps from bottom to the top of the dams.

Figure 6. Small water tight dams at lower ends of the drain ditches

For measuring the W.T. in the field, 6 observation wells in the right, and 6 in the left side of the recharge ditch were placed (at the midpoint of the field) to a depth of 130 cm. All of the observation wells were equipped with perforated 10 cm PVC pipe. Experimental field also was equipped with 8 piezometer batteries at the midpoint of the field with different distances from the recharge ditch. The depth of each piezometer battery in the soil was 40, 50, 60, 70, 90 and 130 cm from the soil surface. Piezometer batteries were installed parallel to the ditches.

Initial W. T. in observation wells and piezometers were measured before starting the experiment. Required level of the W.T. for measuring the saturated hydraulic conductivity of the each soil layer was maintained by plugging of the lower PVC pipes at the body of the dams. Experiment for each level of the W.T. (at the drain ditches) was started by recharging the middle ditch. Inflow and outflow from the middle ditch were measured by WSC flumes. Each experiment continued until reaching to equilibrium condition. This condition was obtained when water level or outflow from the lower end flume became a constant rate. In this condition, W.T. at each observation well reaches to a constant value. Reading the W.T. in the observation wells and piezometers were done approximately at 1 hour time interval. W.T. in the recharge ditch was kept at a constant level in all experiments and different levels of W.T at the drain ditches were examined. In each experiment, W.Ts at the drain ditches was approximately identical. In order to have a description from current situation of the soil layers at the experimental field, a profile was excavated to the depth of approximately 2 m. Soil color and layering examined in the field and soil properties determined in laboratory. Soil sampling was done with auger and soil properties determined at the soil laboratory of the Agricultural Engineering Research Institute (AERI) in Karaj.

Results and discussions

Soil description

The description of profile excavated adjacent to experimental field (UTM coordinates: 245750N; 3350537 E) is given in table 2.

Table 2. Soil description of profile 2, located adjacent to the experimental field

Depth (cm)	Soil description
0 - 20	Clayey texture with live roots, brown color.
20 - 75	Porous clayey texture with many live and thick roots and macro organisms, brown color.
75 - 100	Clayey texture with a few gley signs, few brown mottles, few live roots, hard digging.
100 - 140	Clayey texture with a few gley signs, few brown and black mottles, thin live roots, and fine sand lode.
140 - 160	Clayey texture with a few gley signs, many brown and black mottles, few live roots
160 - 180	Clayey texture with many gley signs and many brown mottles, few roots
180 - 200	Silty clay texture with many gley signs, brown mottles and few roots, green to grayish brown color

The results showed that the soil could be classified as Gleysols with 3 distinct layers. The first brown layer with less than 80 cm thickness is distinguished with plant root and biological activity, and has relatively high hydraulic conductivity and salinity in some regions. This layer is sensitive to soil management and must be regarded carefully in any development project. The second 100 cm layer has redoximorphic properties with visible mottling signs and slaking behavior. This layer needs special attention for drainage systems planning and design. Laying drains in this thick very low permeable reduced soil may result in a total failure. The third layer is permanently saturated and has green to grey color which behaves as sticky gley.

The soils of Abadan are mostly similar and classified as Typic Aquicambids (USDA, 2014) but better method of classification is the World Reference base for Soil Resource (FAO, 2014) which serves the best definition of characteristic and behavior of Abadan soils. Considering this classification, the soils could be classified as Gleysols. To determine the principal and supplementary qualifiers, detailed land classification and evaluation of Abadan soils must be done in the near future.

As other 15 profiles studied by Tajik et al. (2015) which showed that all have more or less the same characteristics, the first layer with less than 80 cm thickness is clayey textured, ML in US NRCS classification, EC = 12 dS/m; SAR = 14 (meq/lit)^0.5; pH = 8, calcium carbonate = 47.2 percent, and organic carbon = 1.3 percent. This layer with perceptible biologic activity is important in crop management and must be protected carefully.

The second layer has less than 110 cm thickness with clay texture, CL in US NRCS classification, redoximorphic properties and mottling, EC = 12 dS/m; SAR = 13(meq/lit)^0.5; pH = 7.9, calcium carbonate = 44.7 percent and organic carbon = 0.8 percent. This layer is important because installation of drainage lateral in many regions might ends in a total failure. It also has a very important role in sea water transmission to the land in moderate to high tides. The vertical cracks and slaking after wetting can be observed almost everywhere. This again brings preferential flow into consideration.

The third layer begins in 190 cm with clay texture and green to grayish color, CL in US NRCS classification, EC = 19 dS/m; SAR = 21(meq/lit)^0.5; pH = 8, calcium carbonate = 40 percent and organic carbon = 0.5 percent. This layer is permanently saturated and very sticky in top and slimy in bottom. The roots of reed were observed.

Determination of the location of impermeable layer in the soil profile

In the first step of experiment, it was required to determine the location of impermeable layer in the soil profile. For this purpose, W.T. in the drain ditches was kept at the lowest elevation until subsurface drain flow reached to the steady state condition. This experiment was repeated for different levels of W.T. in the drain ditches, up to the level of about 9 cm to the soil surface. Results of this experiment showed that, maximum rate of recharge/discharge is happening when W.T. in the drain ditches is at the lowest elevation (96.5 cm below the soil surface). This rate of recharge/discharge remains constant for other levels of 81 and 68 cm. This clearly shows that the flow contribution of this soil layer is almost zero. From the depth of 68 cm, as the elevation of the W.T. in the drain ditches increased, the value of recharge/discharge decreased as shown in figure 7. The equation obtained from the fitted line to the measured data was used and relationship between the recharge/discharge and W.T. in the ditches was calculated for different W.T.s in the ditches. Table 3 represents the role of different soil layers of depth increments in drainage rate.

Again it shows that the contribution of the upper depths are much more than the lower ones. It also demonstrates that the hydraulic conductivity of the lower strata (lower than 68 cm) is almost zero and could be assumed a real barrier to flow.

Table 3. The role of different soil layers of depth increments in drainage rate

Depth to ground surface (cm)	Discharge rate (L/S)	Layer depth (cm)	Contribution of the layer in drainage (L/S)	
			Based on data	Based on best fit
96.5	0.55198	96.5	0.000	-0.01434
81	0.55198	81-96.5	0.000	0.01391
68	0.55198	68-81	0.000	0.04751
52.5	0.46425	52.5-68	0.087735	0.05129
42	0.43343	42-52.5	0.030816	0.05283
33.5	0.40324	33.5-42	0.030198	0.09180
21.5	0.31903	21.5-33.5	0.084208	0.11706
9	0.18913	9-21.5	0.129895	0.17713

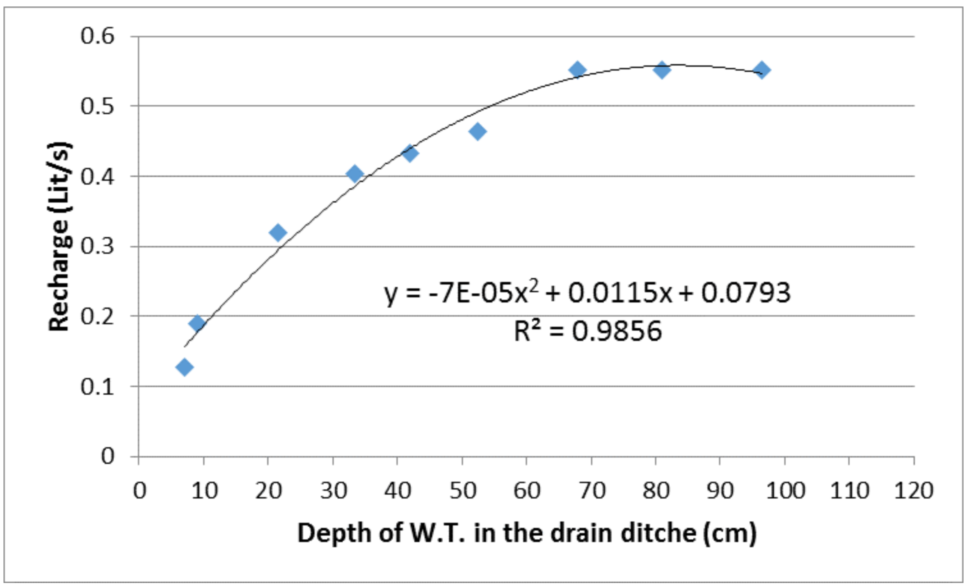

Figure 7. Relationship between the recharge/discharge and depth of W.T. in the drain ditches.

In this study, recharge measurements showed that, subsurface flow to the drain ditches remains constant when W.T. in the drain ditches being at the depths of 96.5, 81 and 68 cm. In this condition, it is very difficult to determine exact location of the impermeable layer in the soil profile. Therefore, lots of field experiments required for different levels of W.T., as well as accurate measuring instruments. The foregoing field data based on the subsurface flow or recharge measurement in this study showed that, top of the impermeable layer in the experimental field at Shalheh Haj-hossein should be around the depths of 65 to 70 cm and it extends at least to the depth of 96.5 cm which the data is collected from.

Piezometric study

Piezometers were used for measuring the potential of water in different soil layers. In order to have completely saturated condition of the soil profile from top to deep soil in the experimental field, the highest W.T. in the drain ditches was used for piezometric study. Before starting the experiments for any W.T.in the ditches, it was required to measure initial condition of the W.T.in the experimental field. As experiments were conducted continuously every day early morning and lasted to evening, soil layers had approximately 12 hours to discharge the water which had been remained from the previous experiment.

Before starting the experiment, initial condition of the W.T., which was measured in the 12 observation wells were more or less at the same elevation of 145 cm as shown in figures 8 to 13. At the end of experiment, final condition of the W. T. in the soil profile (between drain ditches) varies between depths of 21 and 6 cm in the vicinity of the drain ditch and in the recharge ditch, respectively as shown in figures 8 to 13. Results obtained for different depths of piezometers installed in soil profile (40, 50, 60, 70, 90 and 130 cm) are shown in figures 8, 9, 10, 11, 12 and 13 respectively.

Initial condition of the W. T. in the piezometers installed at the depths of 40 and 50 cm, showed that, there is no saturated water in soil profile, but initial W.T. in the observation wells, were approximately at the elevation of 145 cm as shown in figures 8 and 9. At the end of experiments, W.T. in the piezometers 40 and 50 cm are approximately identical with levels of the W.T. in the field at each point.

Initial condition of W.T.s in the 60 cm piezometers showed that, out of 8 piezometers, 3 piezometers still having water from the last experiment (12 hours before), but the other 5 piezometers are empty. Elevation of the W.T. in these 3 piezometers had not been significantly changed at the end of experiment as shown in figure 10. Initial condition of W.T.in the 70 cm piezometers showed that, all 8 piezometers still have water at the average depth of 65 cm which had been remaining from the last experiment (12 hour before), but the final condition of the W.T. in these piezometers have not been significantly changed at the end of experiment. Although average W.T. in the field at the end of experiment is 14 cm below the soil surface, but the average depth of W.T. in these piezometers has been remained at 62 cm below the soil surface at the same time, as shown in figure 11. Comparing average elevation of the W. T. in the field with the final elevation of the W. T. in the piezometers installed at the depth of 70 cm indicate that, movement of water from the soil to these piezometers is very slow. The average change of W.T. in these piezometers was only 3 cm during the experimental time. This indicates that, compare to upper layers, the permeability of the soil at the depth of 70 cm is very very low.

Initial and final conditions of the W.T. in the piezometers installed at the depths 90 and 130 cm are shown in figures 12 and 13. Almost all initial and final conditions of the W.T. have not been changed during the experimental time. This means that, soil layer located between 90 and 130 cm depth is not permeable at all.

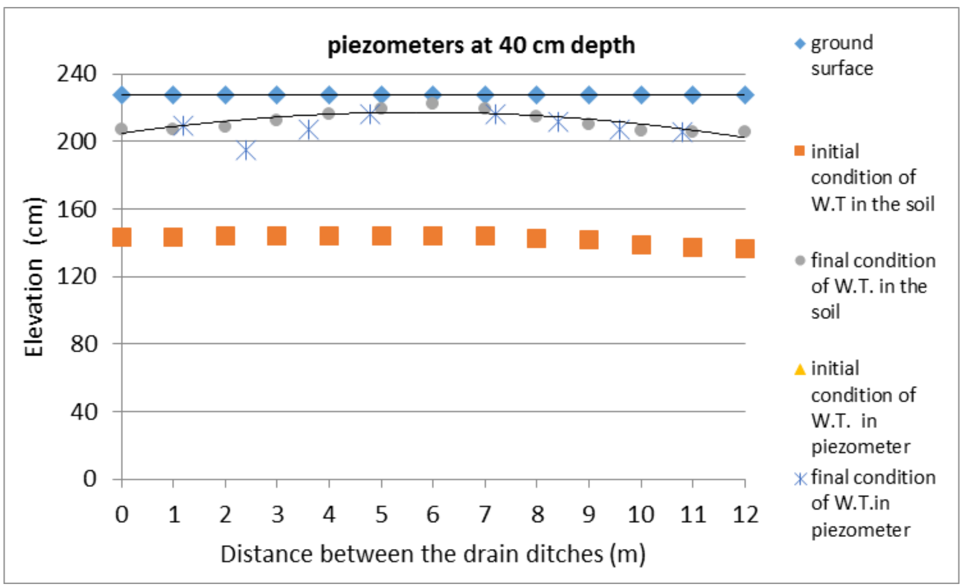

Figure 8. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 40 cm

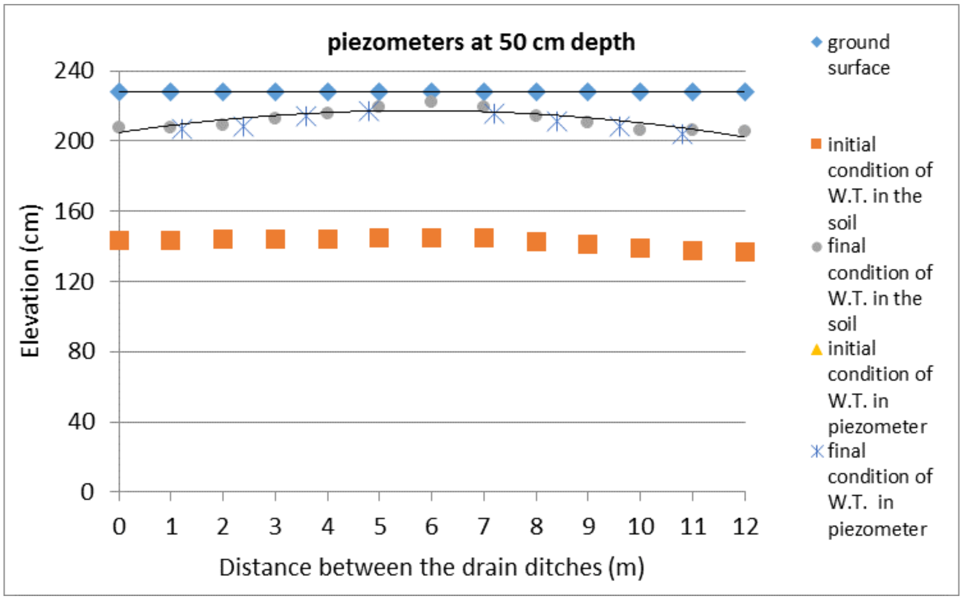

Figure 9. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 50 cm

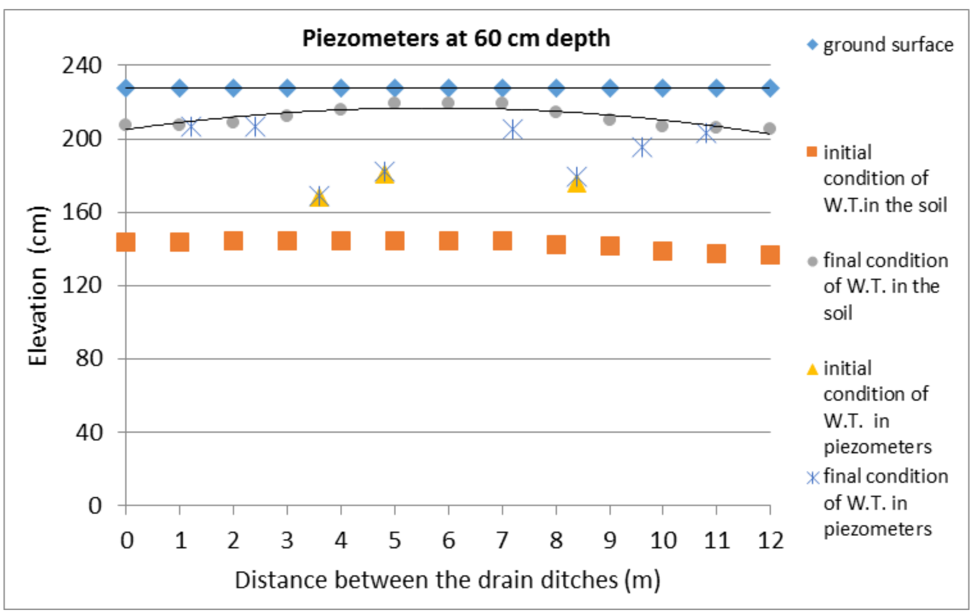

Figure 10. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 60 cm

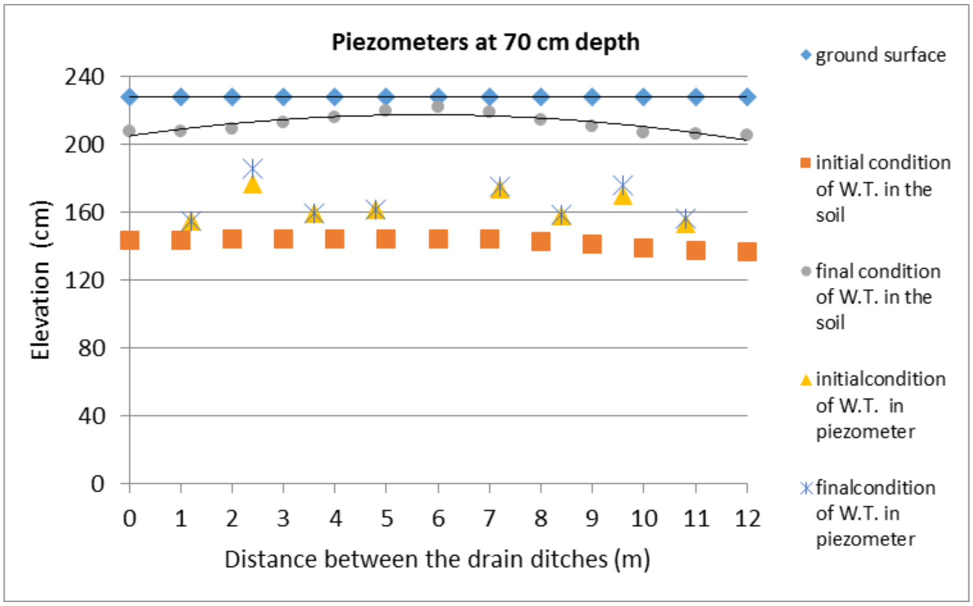

Figure 11. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 70 cm

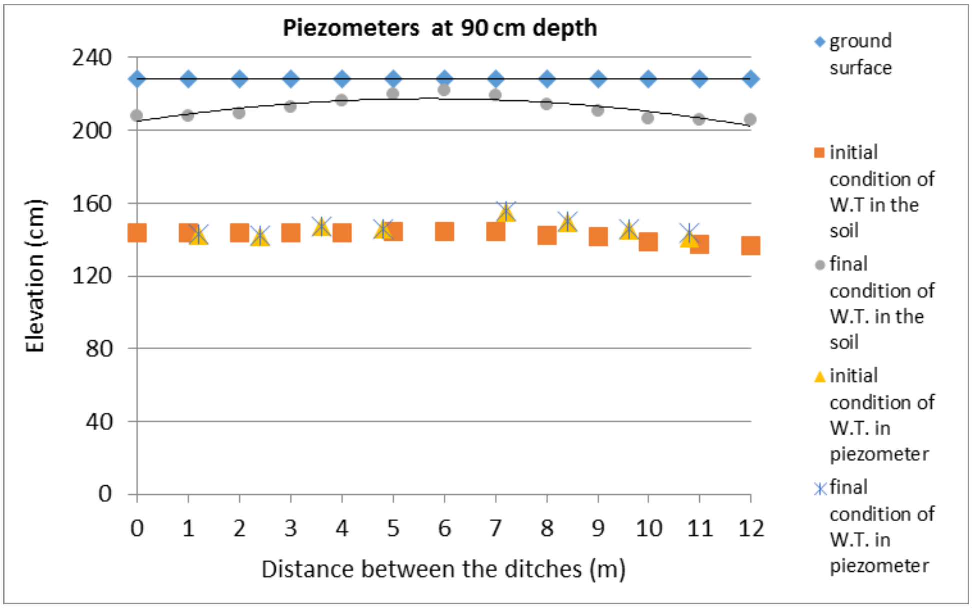

Figure 12. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 90 cm

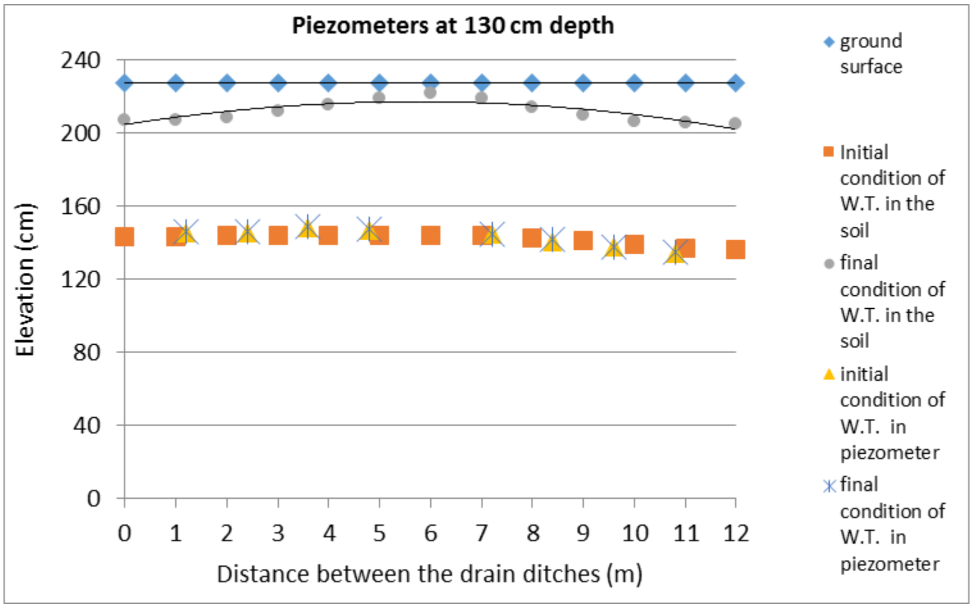

Figure 13. Initial and final conditions of the W.T. in the soil profile and piezometers istalled at the depth of 130 cm

Hydraulic conductivity calculation

Results achieved from measurements of recharge flow in this study have shown that, soil layer which is located at the depths of 68 to 96.5 cm is not permeable. This means soil layer located between elevations of 131.5 and 160 has no contribution to the drainage flow. Also, results which were taken from piezometric study have shown that, impermeability of the soil in the experimental field starts from elevation 158 cm (70 cm below the soil surface) and it extends to elevation 98 cm (130 cm below the soil surface) in soil profile. So, the foregoing results and equation 4 were used for hydraulic conductivity calculation. The K-value was calculated based on the concerning boundary condition of the flow in the field and ditches for each soil thickness. Then, the value of the hydraulic conductivity of the soil at each point in the soil profile was calculated using primary K-value which was calculated for each water table in the drain ditches and shown in figure 14. The equation obtained from the fitted line to the measured data was used and relationship between the soil depth and its hydraulic conductivity was calculated and shown in figure 15.

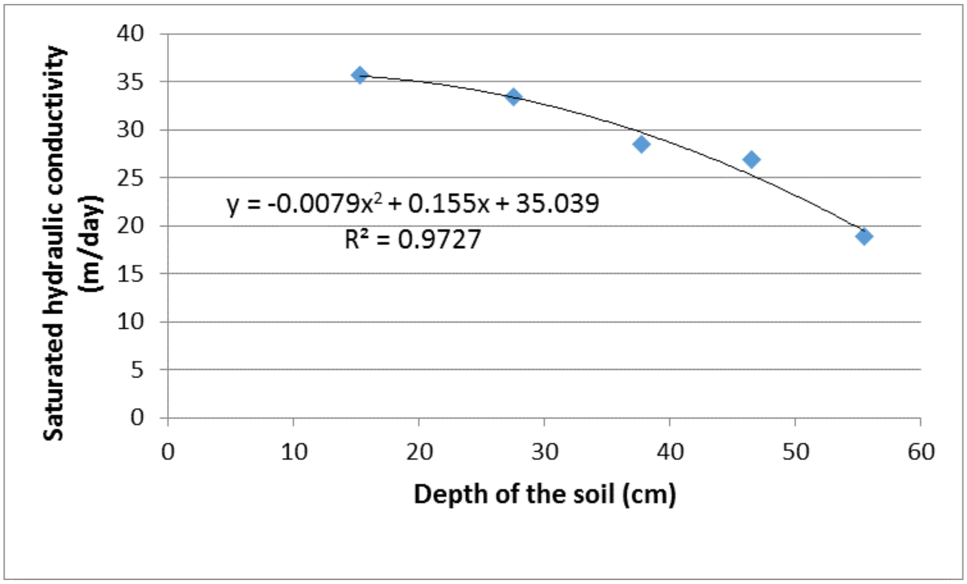

Figure 14. Relationship between depth of the soil and its hydraulic conductivity (Based on field measurements)

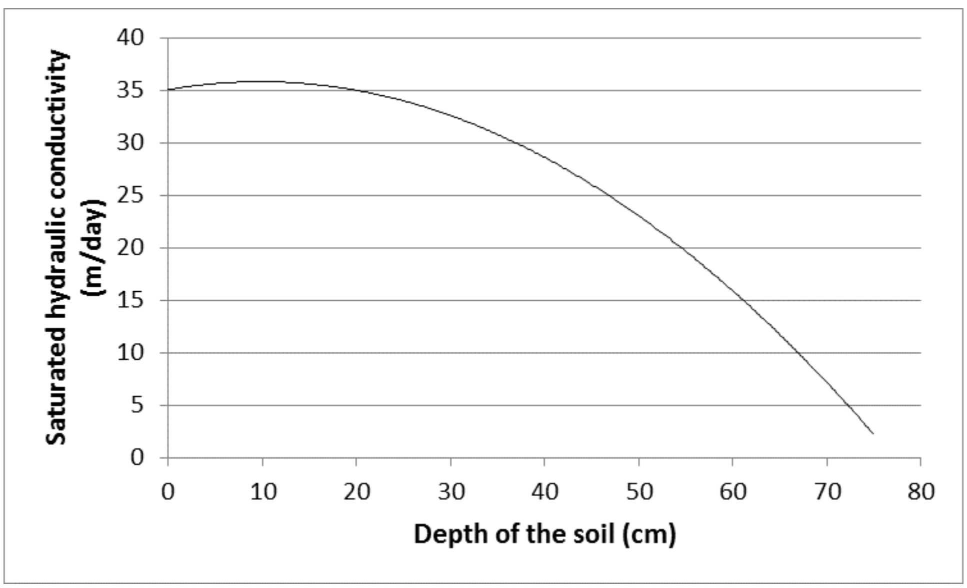

Figure 15. Relationship between depth of the soil and its hydraulic conductivity (Based on equation obtained from the fitted line to field data)

Soil profile description in this study have shown, out of three distinguished layers, most of the biological activities concentrated in the first layer which thickness is less than 80 cm. the results which was taken from hydraulic measurements completely matches with the soil description specially for the first 75 cm depth. Although soil texture in the first layer have been classified as a clayey texture in the first 75 cm layer, but biological activities mostly live and thick roots have changed the magnitude of the pores. The value of the saturated hydraulic conductivity of the experimental field shows that, in the first 60 cm layer, soil is very permeable and based on the classification in table 1 soils behaves like a gravelly coarse sand. As presented in table 2, texture of the this soil is porous clayey texture, so its saturated hydraulic conductivity should be less than 0.2 m/day, based on the classification presented in table 1. This diversity in saturated hydraulic conductivity can be interpreted only by addressing to the description of soil profile in table 2. As presented in table 2, live and thick roots and macro organisms (all biological activities) are concentrated in the first 75 cm depth of the experimental soil. As mentioned by different researchers like Lou et al., 2008 and Mitchell et al., 1995, preferential flow pathways consist of a complex network of earthworm burrows, root channels, inter aggregate macro pores, and meso pores or even micro pores in the soil matrix that increase water flow of the soil. Also, decaying roots of different plants makes preferential pathways and consequently causes high hydraulic conductivity of such a soil.

Acknowledgment

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A NEW DRAIN PIPE-ENVELOPE CONCEPT FOR SUBSURFACE DRAINAGE SYSTEMS IN IRRIGATED AGRICULTURE

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Abstract

In irrigated lands, drain pipes are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: high flow resistance in the vicinity of the drain, siltation, and root growth inside the pipe. A wide variety of materials are used as envelopes, ranging from mineral and synthetic materials to mineral fibres. The challenge is to match the envelope specifications with the soil type. As soils are rather variable, the design of envelopes is not straightforward as illustrated by the numerous norms and criteria that have been developed worldwide. These norms and criteria have been mainly developed in Western Europe and the USA and often lead to disappointing results when applied in other countries where their specifications and effectiveness have not been proven in field trials. In irrigated lands, problematical factors which are evident are that as compared to rainfed agriculture, the hydraulic function of an envelope is less important than the filter function moreover, the root growth inside the drain pipe is a major problem. To tackle these problems, an innovative envelope design concept, based on optimizing the geometry of the pipe and the envelope, has been tested in a 50 ha pilot area in Haran Province, Turkey. The new concept, Hydroluis®, consists of a corrugated inner pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the bottom part of the inner pipe in contact with the soil. The main advantage of the new concept is that it is less dependent on the soil type than the existing envelope materials. The new concept was tested and compared with a geotextile, a sand-gravel envelope and a control with no envelope material. All three envelope types had a lower sediment load as compared to the control and the sand-gravel and Hydroluis® envelopes had a considerable lower entrance resistance as compared to the geo-textile, which showed the best drain performance and showed no signs of root growth. It can be concluded that the Hydroluis® envelope is a good alternative for a sand/gravel or synthetic envelope in irrigated lands.

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KEY WORDS: Subsurface drainage, Envelope materials, Entrance resistance, Drain performance.

Introduction

Pipe drains are equipped with envelopes to safeguard the subsurface drainage system against the three main hazards of poor drain-line performance: siltation, high flow resistance in the vicinity of the drain pipe and root growth inside the pipe. A wide variety of materials are used as envelopes for drain pipes, ranging from organic and mineral material, to synthetic material and mineral fibres (Cavelaars et al., 2006). Organic material is mostly fibrous, and includes peat - the classical material used in Western Europe - coconut fibre, and various organic waste products like straw, chaff, heather, and sawdust. Mineral materials are mostly used in a granular form; they may be gravel, slag of various kinds (industrial waste products), or fired clay granules. Synthetic materials may be in a granular form (e.g. polystyrene) or in a fibrous form (e.g. nylon, acryl, and polypropylene). Glass fibre, glass wool, and rock wool, which all are mineral fibres, are also used. A drain envelope has three functions (Ritzema et al., 2006):

- Filter function: to prevent or restrict soil particles from entering the pipe where they may settle and eventually clog the pipe;
- Hydraulic function: to constitute a medium of good permeability around the pipe and thus reduce entrance resistance;
- Bedding function: to provide all-round support to the pipe in order to prevent damage due to the soil load. Note that large diameter plastic pipes are embedded in gravel especially for this purpose.

Apart from these conflicting filtering and hydraulic functions, the formulation of functional criteria for envelopes is complicated by a dependence on soil characteristics, mainly soil texture, and installation conditions (Stuyt and Dierickx, 2006; Stuyt and Willardson, 1999). Vlotman et al. (2001) reviewed the simultaneous development of theory and practical experience in Europe and North America. Traditionally, the required envelope around the drain pipe consisted of locally available materials like stones, gravel or straw. In arid areas, the technique of using gravel envelopes has been further developed to such a degree that effective gravel envelopes can be designed for most soils (United States Bureau of Reclamation, 1978). In practice, gravel envelopes are often expensive due to the high transport costs, while their installation is cumbersome and error prone, and requires almost perfect logistic management during installation (Ritzema et al., 2006). Moreover, gravel cannot be used when installation is done with trenchless equipment. Subsequently, pre-wrapped envelopes of synthetic material have been under development for some decades, but only limited research has been done on locally made synthetic envelopes for subsurface drainage in irrigated lands (El-Sadany Salem et al., 1995; Kumbhare and Ritzema, 2000). Specialized machines have been developed to pre-wrapped sheet and loose-fibre envelopes around the drain pipes, not in the field but in the factory, ensuring a better quality and easier quality control (Nijland et al., 2005). Pre-wrapped synthetic envelopes are presently used almost everywhere in Europe, in some areas of the United States, and in the countries in the Middle East. Since the specifications of envelopes are very soil specific and soils are rather variable, the specifications and effectiveness of envelopes have to be proven in field trials in the areas where they are to be applied (Vlotman et al., 2001).

The life of subsurface drainage systems can be hundred years if no blockage, deformation nor siltation occurs (Jahn et al., 2006; Stuyt et al., 2005). Blockage of the pipes generally occurs due to sanding, siltation, chemical and biological settlement, penetration of plant root into the pipe, accumulation of compressed filling soil in drainage trenches (in very wet environments) or improper installation of individual pipes (Eggelsmann, 1987). A common practice to prevent penetration of plant roots into the pipes is to increase installation depth. To prevent entry of sediments into drain pipes, pipes are wrapped with envelopes selected according to the characteristics of the soil in which they will be installed. In soils that are problematic in terms of siltation, it is important to prevent penetration of soil grains into the drain pipe (Zaslavsky, 1978). The envelope material wrapped around the pipes to prevent sediment penetration into pipes must have characteristics that does not increase entrance resistance (Wesseling and Homma, 1967). Head losses that occur due to the compression during the entering of water into the drains reduce efficiency of the systems. Increasing the size of the perforations and consequently the total area of holes in plastic drain pipes decrease entrance resistance (Cavelaars, 1965). In an experiment conducted in a horizontal sand tank with a fine sand loamy soil, Chiara and Ronnel (1987), who tested different envelope options, achieved the greatest flow rate and lowest siltation in the pipes wrapped with geotextiles.

Although there are many studies and publications that suggest that there is no need for envelopes in matured, structurally developed, stable soils that contain certain amount of clay (Vlotman, 1998), in Turkey drain pipes in these type of soils are generally equipped with envelopes (Bahçeci et al., 2001). The envelope material that has the best performance under these conditions is gravel obtained from natural sand gravel pits. These envelopes, however, are very expensive and often the particle-size distribution of these natural sand gravels doesn't match the design specifications. More recently geotextiles are used but they have the twin problem of clogging and root penetration.

A new concept, the **Hydroluis®** pipe-envelope system has been developed to overcome these shortcomings. It is designed in such a way that penetration of plant roots and soil particles into the pipe is prevented. The new concept consists of a corrugated inner corrugated pipe with two rows of perforations at the top and an unperforated outer pipe that covers about 2/3 of the inner pipe leaving the unperforated bottom part of the inner pipe in contact with the soil (Figure 1). The outer pipe has an egg-box profile to ensure that there is an open space between the two pipes through which the water can flow upward to the perforations in the inner pipe. The distance between the two pipes determines the flow velocity. The new concept has recently been certificated by the Turkish Bureau of Standardization (Türk Standardlari Enstitüsü, 2016). The two pipes are transported in roles to the field and put in place during installation using a specially developed extension on the trench box of the trencher. Another special punching device has been developed that is also mounted on the trench box to perforate the inner pipes during installation to ensure that the holes are in the correct position.

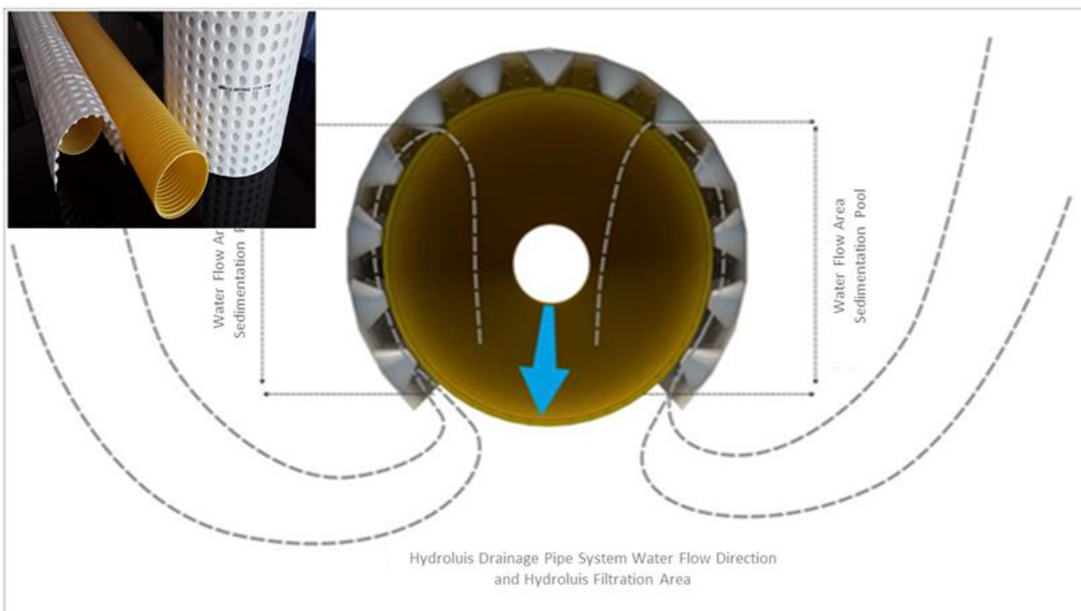

Figure 1. Hydroluis® pipe-envelope combination and working principle

The concept is based on the assumption that about 70% of water entering the drain pipes takes place with radial flow from underneath the pipes (Cavelaars et al., 2006). In a 'traditional' drain envelope system, water velocity increases when the water flows toward the perforations, increasing the risk of soil particle movement that results in either clogging of the envelope or sediment entering the pipe. In irrigated agriculture, this is particularly risky after irrigation when the water table rises well above drain level and consequently increases the hydraulic head. In the new concept, the velocity of the water decreases when it flows upward between the two pipes, significantly reducing the movement of the soil particles and thus the risk that these particles enter the inner drain pipe. The lighter and smaller particles that will stay in suspension during this upward movement, will stay in suspension when they enter the inner pipe eliminating or minimizing clogging and sedimentation.

A second problem for subsurface drains in irrigated agricultural lands is that root penetration is a major risk when the water table falls below drain level, because of the favourable humid conditions in the drain pipe (air & water). In the new concept, root penetration will be eliminated as the space between the inner and outer pipe is either saturated (when the water table is above drain level) or filled with air (when the water table is below drain level). Both conditions prevent root penetration. The objective of this study was to test the new concept under field conditions.

Materials and methods

The field study was conducted at the GAPTAEM research station (50 ha) near Harran (36° 56'44 N, 38° 54'44 E), located in south eastern Turkey 30 km south of city of Şanliurfa, at an altitude of about 400 m (Figure 2). The area is representative for the Şanliurfa Harran Plain, an area of about 150 000 ha that is already under irrigation. Water is mainly supplied from the Atatürk Dam with two tunnels (General Directorate of State Hydraulic Works, 2003).

Figure 2. Location of Harran pilot area

The climate in the Harran Plain is arid, hot in summer and cold and rainy in winter (Table 1). The average annual precipitation is 365 mm, the average temperature 17°C and open water surface evaporation 1849 mm. The distribution of the precipitation over the seasons is 56% in winter, 30% in spring, 1% in summer and 13% in autumn. The average number of rainy days is 70 and number of days covered with snow is 3.

Table 1. Meteorological data in the Harran plan (monthly averages).

	Precipitation (mm)	Temperature (°C)	Relative Humidity (%)	Evaporation (Class A - pan) (mm)	Wind speed (m/s)
Jan	66	5	69	-	1.6
Feb	63	6	64	-	1.7
Mar	60	10	58	52	1.6
Apr	27	15	58	117	1.6
May	23	22	42	199	1.9
Jun	4	28	33	315	2.4
Jul	0	31	34	376	2.3
Aug	0	30	40	338	1.9
Sep	1	25	38	250	1.5
Oct	20	18	45	152	1.0
Nov	42	10	60	51	0.9
Dec	61	6	72	-	1.2
Year	365	17	51	1849	1.6

The pilot area has a flat topography and deep alluvial soil profile with A and C horizons (Table 2). Soil texture is clayey with a clay content of more than 50–60%, the lime content is about 30% and the soil pH between 7.1–8.0. Soil samples were collected from different soil layers and their respective total porosity and effective porosity were determined in the laboratory by standard procedures (Braun and Kruijne, 2006).

Table 2. Soil properties in Harran Pilot Area

Treatment	Depth (cm)	Sat. Cap. (%)	Texture (%)			Class	pH	EC_e dS/m	Lime (%)
			Sand	Clay	Silt				
Control (no envelope)	0-30	78	24	56	20	Clay	7.6	0.7	30
	30-60	74	24	58	18	Clay	7.7	0.9	30
	60-90	70	22	58	20	Clay	7.8	1.2	30
	90-120	74	22	58	20	Clay	7.7	1.2	30
	120-150	68	32	44	24	Clay	7.8	0.9	30
	150-180	74	26	48	26	Clay	7.8	0.8	30
	180-210	77	24	54	22	Clay	7.8	0.7	30
Geotextile	0-30	71	24	66	20	Clay	7.6	0.8	31
	30-60	70	24	56	20	Clay	7.7	1.1	29
	60-90	71	20	58	22	Clay	7.7	1.4	30
	90-120	73	20	60	20	Clay	7.6	1.7	30
	120-150	74	22	58	20	Clay	7.6	1.6	32
	150-180	83	22	56	22	Clay	7.8	1.0	32
	180-210	79	22	58	20	Clay	7.9	0.8	29
Gravel	0-30	70	22	56	22	Clay	7.6	0.8	30
	30-60	71	24	56	20	Clay	7.7	0.9	29
	60-90	69	24	56	20	Clay	7.7	1.0	29
	90-120	70	22	58	20	Clay	7.7	1.0	35
	120-150	69	26	54	20	Clay	7.6	1.1	42
	150-180	74	24	56	20	Clay	7.7	0.9	43
	180-210	75	20	60	20	Clay	7.5	0.9	43
Hydroluis	0-30	72	22	60	18	Clay	7.7	0.9	30
	30-60	70	20	58	22	Clay	7.6	0.9	31
	60-90	70	20	60	20	Clay	7.6	0.9	32
	90-120	71	22	60	18	Clay	7.7	0.9	33
	120-150	72	18	60	22	Clay	7.6	1.0	35
	150-180	73	20	62	18	Clay	7.6	1.0	33
	180-210	78	22	56	22	Clay	7.6	0.8	44

Experimental site layout

In the test plot, plastic drain pipes were installed at an average depth of 1.50 m, with a 0.1% slope, with a length of 200-250 m and 25-60 m spacing. Four combinations were tested:

1) Sand-gravel filter envelope around the drain pipe
2) Pre-wrapped geotextile
3) Hydroluis® pipe-envelope combination
4) No envelope material (control)

For each combination, three field drains were connected to a collector drain through a manhole (Figure 3). Hydraulic heads were measured in three rows of observations wells: midway between the drains, adjacent to the drain pipe just outside the drain trench and inside the drain pipe (Figure 3 & 4). The head differences were used to assess the entrance resistances for the four drain/envelope combinations based on the classification proposed by (Cavelaars et al., 2006) (Table 3). Measurements were repeated 3-4 times a day to obtain data for different hydraulic heads. Water samples of the drain outflow were collected for pH, EC and silt-load analyses. The monitoring programme started in 2015, but only a limited number of data could be collected, thus the monitoring programme was repeated in 2016. At the end of each season, root growth was manually checked using a video system.

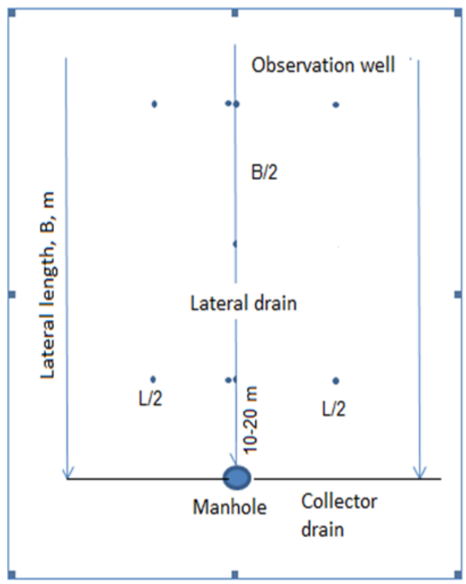

Figure 3. Measurement and observation network: each combination consists of three field drains connected to a collector drain through a manhole.

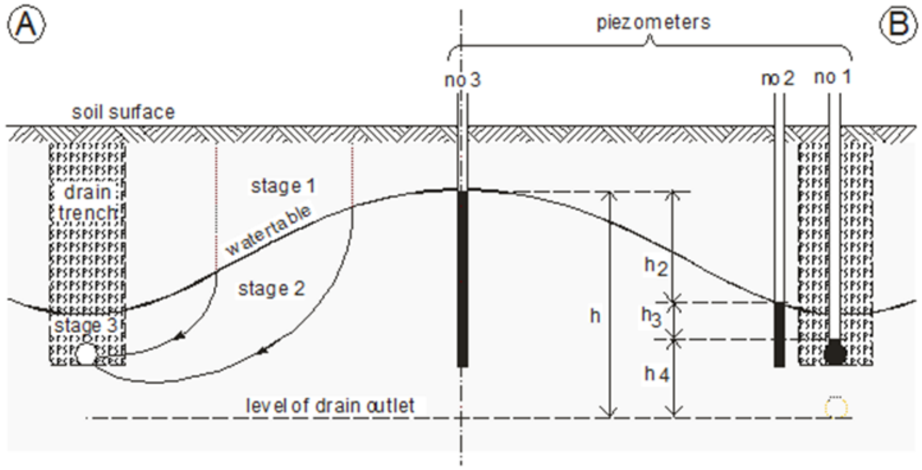

Figure 4. Principle of drainage testing: (A) Four stages of water flow towards and inside the drains; (B) Head losses in the four stages (Cavelaars et al., 2006).

Table 3. Drain performance criteria for different drain envelope combinations (Cavelaars et al., 2006)

$h_3/(h_2+h_3)$	Entre resistance	Drain performance
< 0.2-0.3	normal	good
0.3 – 0.6	high	moderate to poor
> 0.6	excessive	very poor

Results and discussion

The results of the monitoring programme in 2015 are presented in Table 4. The drain performance of the Hydroluis® pipe-envelope combination and the gravel envelope was good, but the performance of the geotextile was moderate to poor. The entrance resistance in the control plot was not measured, thus the drain performance could not be established. The sediment load was measure in all four combinations. The control plot had the highest sediment load (46 g m^{-3}), the sediment load in the drains with geotextile was 24% lower (35 g m^{-3}), the Hydroluis® combination had about the same reduction 26% (34 g m^{-3}), but the sediment load of the gravel envelope (26 g m^{-3}) was with 43% significant lower.

Table 4. Drain performance values for different drain envelope combinations (2015)

Envelope pipe combination	$h_3/(h_2+h_3)$ (-)	Drain performance	pH	EC (dS m^{-1})	Silt (g m^{-3})
Gravel	0.25	Good	7.2	0.96	26
Geotextile	0.38	Moderate to poor	7.5	0.99	35
Hydroluis®)	0.28	Good	7.0	0.97	34
Control	-	-	7.2	1.03	46

There is no significant difference between pH and EC values of drainage discharges and the siltation values are not high when they are evaluated in terms of irrigation water.

The results of the monitoring programme conducted in 2016 are presented in Table 5 to 8 for respectively the Hydroluis® pipe-envelop system, the gravel envelope, the geotextile and the control plot.

Table 5. Groundwater levels, hydraulic heads and entrance resistance for the Hydroluis® pipe-envelope system in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	h_{pipe} $(h-h_2-h_3)$ (cm)	h_{trench} $(h-h_2)$ (cm)	Entrance Resistance $h_3/(h_2+h_3)$ (-)
1	16.0	12.7	1.7	1.6	3.3	0.12
2	15.7	12.6	1.6	1.5	3.1	0.11
3	15.2	12.6	1.2	1.4	2.6	0.09
4	16.0	12.7	1.7	1.6	3.3	0.12
5	15.7	12.6	1.6	1.5	3.1	0.11
6	15.5	12.7	1.2	1.6	2.8	0.09
7	15.2	12.6	1.2	1.4	2.6	0.09
8	15.2	12.8	1.1	1.4	2.5	0.08
9	14.9	12.9	0.6	1.4	2.0	0.05
10	14.7	12.7	0.6	1.3	1.9	0.04
11	14.7	12.7	0.6	1.3	1.9	0.04
12	14.3	12.2	0.7	1.4	2.1	0.06
13	14.2	12.3	0.5	1.4	1.9	0.04
14	14.2	12.3	0.5	1.4	1.9	0.04
15	14.2	12.3	0.5	1.4	1.9	0.04
16	14.3	12.2	0.7	1.4	2.1	0.05
17	14.3	12.2	0.7	1.4	2.1	0.05
18	14.1	11.9	0.7	1.4	2.1	0.06
Average	14.9	12.5	1.0	1.4	2.4	0.07
St. Dev.						0.03

In the plot equipped with the Hydroluis® pipe-envelope system the average drain discharge was 0.062 l/s or 2 mm/day. This value is lower than the design drainage coefficient used in the project. The average hydraulic head midway between the drains was 14.9 cm, the head just outside the drain trench (h_{trench}) was 2.4 cm and the head just outside the pipe 1.4 cm (Figure 5). Based on the criteria presented in Table 3, the entrance resistance, with an average of 0.07 and a standard deviation of 0.03, can be classified as "normal" and the drain performance as "good".

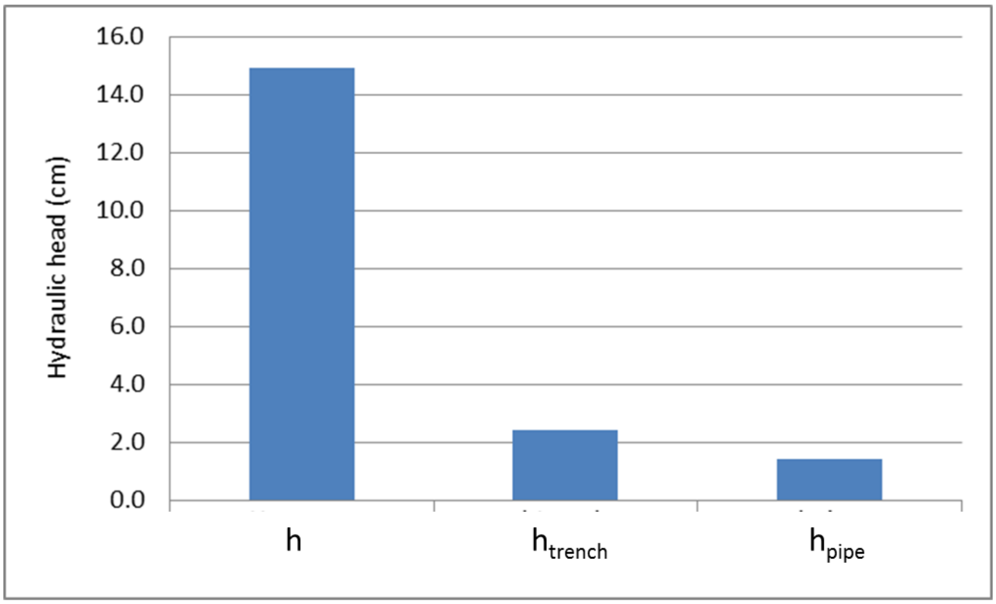

Figure 5. Average hydraulic head in the Hydroluis® pipe-envelope system

Table 6. Groundwater levels, hydraulic heads and entrance resistance for the sand gravel envelope in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance resistance $h_3/(h_2+h_3)$ (-)
1	17.7	8.4	4.4	0.34
2	13.7	9.4	6.4	0.41
3	11.7	8.4	4.4	0.34
4	12.2	7.4	5.9	0.44
Average	13.8	8.4	5.3	0.38
St. Dev.				0.04

The entrance resistance of the gravel envelope, with an average of 0.38 and a standard deviation of 0.04, can be classified as “high” and the drain performance as “moderate”.

Table 7. Groundwater levels, hydraulic heads and entrance resistance for the geotextile envelopes in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance Resistance $h_3/(h_2+h_3)$ (-)
1	19.8	9.3	5.9	0.39
1	8.6	3.6	7.0	0.66
2	8.0	4.0	6.0	0.60
3	7.1	7.1	4.0	0.36
6	17.3	4.4	13.0	0.75
7	8.1	3.8	6.5	0.63
8	13.8	3.4	11.0	0.76
9	9.6	2.6	6.5	0.71
10	8.6	3.1	5.0	0.61
11	8.6	3.6	7.0	0.66
Average				0.61
St. Dev.				0.14

The entrance resistance of the geotextile was significantly higher and with an average of 0.61 and a standard deviation of 0.14 can be classified as “excessive”, subsequently the drain performance is “very poor”.

Table 8. Groundwater levels, hydraulic heads and entrance resistance for pipes without envelopes (control plot) in 2016

No.	h (cm)	h_2 (cm)	h_3 (cm)	Entrance resistance $h_3/(h_2+h_3)$ (-)
1	8.5	2.0	2.0	0.49
2	12.2	-0.2	9.0	1.03
3	25.0	26.5	19.5	0.42
4	8.0	25.0	14.0	0.36
5	5.2	23.8	12.5	0.34
6	4.0	23.5	11.5	0.33
Average				0.49
St. Dev				0.27

In the control plot, the average entrance resistance was 0.49 and can thus be classified as "high" and the drain performance as "moderate to poor".

When we compare the four drain-envelope combination for both years, we can concluded the Hydroluis® drain-envelope combination had a normal entrance resistance and a good drain performance (Table 9). The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the geotextile and the drain without envelope in the control plot. The performance of the geotextile envelopes in 2016 was significantly poorer compared to 2015, suggesting a clogging problem of the envelope.

Table 9. Classification of the entrance resistance and drain performance for the four drain-envelope combinations

Pipe - Envelope combination	2015			2016		
	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance	$h_3/(h_2+h_3)$	Entrance resistance	Drain performance
Gravel	0.25	normal	good	0.38	normal	moderate
Geotextile	0.38	normal	moderate	0.64	high	very poor
Hydroluis®	0.28	normal	good	0.07	normal	good
Control	-		-	0.49	high	moderate to poor

The silt content was only measured in the plots with the Hydroluis® pipe-envelope system and the gravel envelopes (Table 10). In both plots the silt load of the drainage water is low and it will not create a risk of clogging the pipelines.

Table 10. Electric Conductivity (EC), pH and sediment load of the drainage effluents for the drains with Hydroluis® and geotextile in 2016

No.	Solid matter (%)	EC (dS/m)
Hydroluis:		
1	0.07	0.78
2	0.07	0.78
3	0.07	0.78
4	0.06	0.79
Average	0.07	0.79
Geotextile:		
1	0.07	1.01
2	0.07	1.00
3	0.08	0.95
4	0.07	1.03
Average	0.07	1.00

On 14 June, 2016 a visual inspection of the four drain-envelope combinations was done using a video camera (Figure 6). The drain pipes were also excavated for a visual inspection of root growth (Figure 7). Although root growth was limited, probable because the crops were still in their initial stage of development, it is clearly visible that the Hydroluis® combination didn't have any sedimentation inside the pipe nor any signs of root growth.

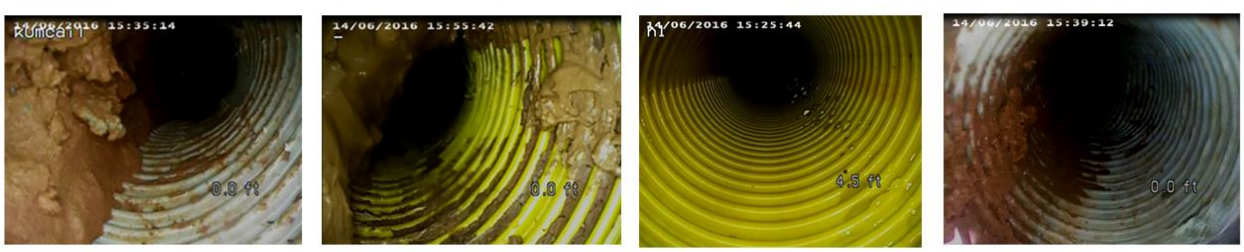

Figure 6. Visual inspection of the four drain-envelope combinations: from left to right: gravel – geotextile - Hydroluis® combination - control. (Note: vertical orientation of the photos is not correct because of the moving camera).

Figure 7. Visual inspection for root growth after excavation of the drain pipes with a geotextile (left), no envelope (middle) and Hydroluis® combination (right).

Conclusion

Three drain-envelope combinations of subsurface drainage systems were tested in a field plot and compared to a control plot with no envelope. Based on the two-year monitoring programme, it can be concluded that the Hydroluis® drain-envelope combination performed good with a normal entrance resistance and a good drain performance. The gravel envelope scored second with a normal entrance resistance and moderate to good drain performance. Both performed much better than the drains with a geotextile envelope and the drain without envelope in the control plot. The performance of the geotextile envelopes was significantly poorer in 2016 compared to 2015, suggesting a clogging problem of the envelope as the sediment load in the drainage water was comparable to the sediment load of the drainage water from the Hydroluis® plot. Another advantage of the Hydroluis® pipe envelope combination is that no sign of penetration of plant roots into the pipe were visible. Furthermore, the Hydroluis® pipe envelope combination has features that prevent or reduce deformation of the pipes by providing mechanical support through the egg-box profile of the outer pipe. The production costs are comparable to the cost of a pre-wrapped synthetic envelope (personal communication, PipeLife Nederland, 24-08-2016) and transportation and installation costs are lower than for a gravel envelope. Although the new concept looks promising, it is recommended to do more research to verify the long-term resistance to root growth and the performance under other soil, hydrological and agricultural conditions.

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CLOSED DRAINAGE ON HEAVY SOIL: THEORY AND PRACTICE IN RUSSIA

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Abstract

Maintaining, rehabilitation, and rational use of fertile agricultural lands are still urgent problems at present. High-quality improvement of agricultural land areas and natural agrolandscapes on the basis of multipurpose land reclamation is one of the quidelines of the activities of the Ministry of Agriculture, water management, designing and research organizations. One of the most important and effective methods of preventing lands from over wetting and bogging is closed drainage. Currently, there are 9.3 million ha of reclaimed lands in the Russian Federation, of which 4.8 million ha are drained; the balance cost of systems of all the forms of ownership totals 307 billion roubles. Out of the total area of drained lands 3.0 million ha, or 62 %, are represented with closed drainage systems, including 2.6 million ha in 29 subjects of the Russian Federation located within the Nonchernozem Zone, the remaining land areas are located in the regions of Siberia and Far East. The goal-oriented federal target program «Development of agricultural land reclamation of Russia for the period until 2020» was aimed at developing the system of rational agro-ameliorative practices for long-term operation of reclamation systems, in particular on heavy soils with the use of drainage and rehabilitation of the humid zone soils polluted as a result of human activities. This problem was successfully solved. The assessment of theoretical findings, experimental works and results of their practical use were carried out in some land reclamation project areas of the Nonchernozem Zone.

KEY WORDS: Close drainage, Land reclamation, Wetland, heavy soil, Adaptive landscape tillage.

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Introduction

According to the existing practice in the Russian Federation, in case of drainage of over wetted soils using the closed drainage system the recommended drain spacing varies within the limits of 15-40 m depending on the type of bogging and soil properties. As to the world practice of drainage construction, the closed drain spacing in slightly permeable soils varies from 6 to 15-17 m; this value varies from 20-25 to 50 m and more in well permeable soils. For example, the drain spacing in silty clay soils of Poland equals 8 m; it varies from 6 to 18 m in Germany, from 8 to 15 m in Austria and Switzerland, and averages 25 m in England.

The efficiency of heavy soil drainage is also achieved through regulation of the depth of drain laying. The depth of drain laying in heavy soils of the Russian Federation is assumed to be 1.0-1.2 m. The depth may be increased to 1.5-2.0 m under the condition of intense feeding with pressure water.

The efficiency of closed drainage operation depends not only on its parameters but also on constructional features of drainage pipes.

During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 1000 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Experimental site layout

The Nonchernozem Zone covers a vast area and is referred to the regions of low biological productivity of lands caused by the fact that the greater part of agricultural land areas is located in the regions of increased wetting and overwetting. In addition to this, pollution of soils, surface water and groundwater with chemicals exceeding the ultimate permissible concentrations is observed in some areas of this zone, the pollution being caused by the impact of industry, municipal utilities, and other factors.

Large-scale work related to the agrarian transformation in this zone was carried out over the period of 1974-1990. These transformations were based on multipurpose land reclamation. The lands of this zone needed drainage, removal of brush and stones, liming, cultivation; it was necessary to construct roads, dwelling facilities and to provide production and social infrastructure. Great volumes of works were implemented over the period in question. The Government was responsible for financing of transformations stipulated by the programme.

Drainage developments in the zone were mainly accomplished at that period; nearly all land reclamation systems currently used in agricultural production were constructed at that time. It was the period, when closed drainage was universally put into practice, main designs of drainage systems and conditions of their use were studied and developed, the technologies of all the main types of land reclamation operations were worked out.

The principal objects of drainage were overwetted boggy podzolic soils widely spread in the zone under study; the productivity of such soils could be rather rapidly increased through regulation of their water and air, nutritive and thermal regimes. Drainage complete with the system of cultivation and enrichment of soil with organic matter, liming of acidic soils and other measures permit the optimization of fertility of low-productive lands. Another, less topical and having limited spreading, object of land reclamation was peat soil of lowland type. Such soils are rich in organic matter and are referred to potentially fertile lands.

Results and discussion

Heavy soils of different degree of bogging referred to the podzolic and boggy podzolic types are widespread in northwest and central regions of the Nonchernozem Zone and in the Republic of Byelarus as well. The agricultural use of these soils is possible only after their drainage. However, it is worth mentioning that drainage of heavy soils is a complicated problem because of the specific physical properties of a soil profile. This is particularly true, when the object of drainage are dense, structure less and gleyed soils with a waterproof subsoil layer ($K_{seepage}$<0.1-0.01 m/day). The problem of drainage of such kind of soils is also observed in other countries.

The drainage of heavy soils is aimed at dropping the groundwater level and disposal of surface water. The main method of land drainage is closed drainage using tile or plastic pipes. The drains should be laid only with protective filtering envelope. The efficiency of the closed drainage system operation depends on the reliability of choosing the design parameters in the course of drainage system planning (depth of drain laying, drain spacing, etc.), which provide the necessary degree or rate of drainage according to crop demands for water regime.

Many famous scientists specialized in land reclamation (Kostyakov, Aver'yanov, Pisar'kov, Ivitskii, Dubenok, Volkonskii, Rozova, Shkinkis and other researchers) were involved in studying the theoretical principles of drainage operation and in engineering calculations of drainage in heavy mineral soils. Provision was made for substantiation of the impact of soil factors and human-induced (engineering) factors on the drainage capacity. In particular, the problem concerning the role of top soil and subsoil layers as well as drainage filling in formation of drainage runoff was discussed. Opinions differ in interpretation of these problems. For example, A.N. Kostyakov has revealed that in clayey slightly permeable soils groundwater runs to drains mainly along the plough sole of the top soil layer and the smaller part of it runs along the subsoil layer. Kh.A. Pisar'kov has found that the insignificant runoff through the subsoil layer is often more important than the greater runoff through the top soil, in other words, the runoff through the subsoil decreases the top soil overwetting. A.I. Klimko has revealed that under the condition of the Kaliningrad Region, where drains are laid at a depth of 0.85 m and spaced at 12-14 m, more that 40 % of water enters the drains through the top soil, 28 % of water runs along the surface of the top soil though the drainage filling, and 29 % of water comes from the subsoil layer. Ts. N. Shkinkis thinks that under the condition of deep drainage, less that 10 % of the total amount of excess water runs to drains through the heavy top soil layer. The studies carried out by I.M. Krivonosov in the Leningrad Region have shown that the runoff from drains is observed, when the level of groundwater is only in the top soil layer, i.e. the runoff is formed in the top soil layer and in more porous drainage filling. At the same time, the experiments performed by I. Dwob and R. Lamsodis did not reveal any difference in water permeability of trench filling material and intact ground. The efficiency of closed drainage operation in heavy, regularly overwetted soils was also studied by some other researchers.

The closed drainage is known to be more efficient under the condition of levelled surface, properly cultivated soils, and structural top soil rich in humus. The drainage effect of closed drainage systems depends on many natural and designing factors: permeability of soils and soil-forming rocks, meteorological conditions, relief of the area to be drained, depth of soil freezing, and drainage system parameters. In addition to this, the efficiency of tile drainage in loamy soils fed by atmospheric precipitation greatly depends on the location of drains on the surface to be drained, drain spacing, drain length, depth of drain laying, design of the conveying part of the system of structures.

According to the existing practice in the Russian Federation, in case of drainage of overwetted soils using the closed drainage system the recommended drain spacing varies within the limits of 15-40 m depending on the type of bogging and soil properties. As to the world practice of drainage construction, the closed drain spacing in slightly permeable soils varies from 6 to 15-17 m; this value varies from 20-25 to 50 m and more in well permeable soils. For example, the drain spacing in silty clay soils of Poland equals 8 m; it varies from 6 to 18 m in Germany, from 8 to 15 m in Austria and Switzerland, and averages 25 m in England.

The efficiency of heavy soil drainage is also achieved through regulation of the depth of drain laying. The depth of drain laying in heavy soils of the Russian Federation is assumed to be 1.0-1.2 m. The depth may be increased to 1.5-2.0 m under the condition of intense feeding with pressure water. In slightly permeable soils, when the line of seepage is not formed in subsoil layers, the depth of drain laying is decreased to 0.7-0.9 m and drain filling with filtering material is provided. As for the foreign experience, the following depth of drain laying is practiced in different countries depending on soil and climatic conditions: 0.8-1.6 m in arable lands and 0.7-1.3 m in grasslands of Austria, 1.2 m in Finland; at the rate of drainage equaling 0.6-0.9 m, the depth of drain laying varies from 0.75 to 1.37 m in the USA; it varies from 0.9 to 1.3 m in England and from 0.9 to 1.5 m in Poland.

The efficiency of closed drainage operation depends not only on its parameters but also on constructional features of drainage pipes.

Over a long period of time, drains for closed drainage systems were made of tile pipes in Russia. Beginning in 1975, corrugated PVC and polyethylene pipes 50 and 63 mm in diameter are used. Roll synthetic nonwoven materials are used as filtering materials. Drains in moderately and slightly permeable soils are also covered with local bulk filtering material (sand, wood chips, slag, etc.) and then backfill of trenches with excavated earth is performed.

To speed up water disposal from the top soil in very compacted heavy soils (the seepage factor being less than 0.1 m/day) it is recommended to practice permeable filling of drainage systems (up to the ground surface or up to the top soil) with the use of gravel and crushed stone or to supplement drainage with a complex of agro-ameliorative measures, which contributes to more rapid inflow of excess water into drains.

In draining lands of heavy mineralogical composition, the use is made of granulated material of high permeability (sand, gravel, ash and slag wastes, etc.) for filling trenches.

During the operation period, compacted layers are formed in the soil profile under the impact of agricultural machinery. Deep ameliorative soil loosening to the depth of occurrence of the compacted layer sole is capable to restore the soil profile permeability and design regime of drainage operation.

Thus, it can be concluded that only the application of a complex of agro-ameliorative measures can provide normal operation of drainage in heavy soils and enhance the efficiency of drained land use.

Land reclamation systems were constructed in the Russian Federation in the 1960s-1980s. Over the period of reforms, the insufficient financing from budgets of different levels and other sources resulted in dramatic decrease of volumes of works related to reconstruction and rehabilitation of land reclamation systems, the volume of necessary repair and maintenance operations also decreased. As a consequence, the technical level of these systems decreased along with the condition of reclaimed lands, particularly in farm systems belonging to agricultural commodity producers or assigned to them.

Currently, the condition of nearly 1.4 million ha of drained lands (29% of the total drained area) is unsatisfactory. High groundwater table and intolerable delay in surface water disposal are observed in this area. The total of 1.6 million ha of drained land systems need reconstruction and rehabilitation.

The condition of about 30% of areas under drainage systems with tile drains is unsatisfactory; secondary bogging is observed in some places. Silting of drains, collecting drains, and discharge canals is recorded as a result of long-term exploitation of these systems. Moreover, because of the lack of financing and special equipment, canals got overgrown with wood and brush vegetation. The cleaning of canals from vegetation and sediments goes on slowly.

To ensure long-term functioning and more efficient operation of drainage systems with the use of tile and other type of drainage the following measures are necessary: regular cleaning of drainage systems (particularly, outlets of discharge collecting drains) from sediments with application of up-to-date methods and use of drain-flushing machines; reconstruction, repair, and cleaning of canals from vegetation and sediments. This will need considerable enlargement of the fleet of excavators, cutters, and other special machines in water management organizations. Some steps in this direction have been already taken.

Scientific analysis of these data shows, that yield of agricultural crops on the heavy mineral soils drained by subsoil pipes, essentially raises at carrying out of agro- and land reclamation actions in different variations. On land improvement systems for efficiency of subsoil drainage it is offered to apply a complex of agro-technical and agro-ameliorative actions. On heavy soils the most effective reception of improvement of their fertility is application of subsoiling.

Efficiency of functioning of the close pipes also is defined by a technical condition of the drainage system including pipes, canals network and constructions. As it would be noticed, that with increase in period of validity of a drainage its working capacity worsens, in concerning to silting and ferrites deposits process.

It is necessary to understand, that the ecological substantiation of efficiency of drainage systems on heavy cespitose-podzolic soils in depending on term of its action and operation conditions is not enough elaborate. Also the question on change of soil conditions depending on period of validity of drainage system on the base of application of agronomy actions is insufficiently known.

In the conditions of the Central area of the Nonchernozem zone of the Russian Federation more than half of drained lands are used under forage crops (perennial and annual grasses, root crops). E.I.Lopukhin (1974) specifies, that on the drained lands expediently expansion of the areas under perennial grasses that promote increase of fertility of soils.

On heavy mineral drained soils It is possible to give a high yields of grain, a potato and root crops. However a high crop yields depends of drainage efficiency, its technological parameters and a design.

In the conditions of the Moscow and Vladimirovsky Districts it was estimated, that the yield of grain cultures and perennial grasses depends of drainage parameters: with reduction of distances between drains and increase in their depth. Deep subsoiling on the base of a drainage with spacing from 22 to 30 meters has allowed a grain yield increase in comparison with the control (a drainage without subsoiling) on 10-20 %.

Considerable volumes of work related to reconstruction and rehabilitation of drainage systems have to be fulfilled in accordance with the approved Federal target program «Development of agricultural land reclamation of Russia for the period until 2020». During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 100 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Conclusion

The Government of the Russian Federation accepted the federal target program «Development of agricultural land reclamation of Russia for the period until 2020». The purpose of the program is improvement of the competitiveness, profitability and stability of agricultural output. It requires to emplement complex land reclamation measures along with the methods of adaptive landscape tillage for ensuring food security and preserving future generations of natural resources. Federal target program for the development of land reclamation aimed to solving the problem of food security by means of sustainable innovation development of agriculture and the creation of mechanism for effective use of agricultural land and natural resources with methods of integrated land reclamation measures, irrespective of climate change and abnormalities.

During the period of 2014-2020, it is planned to reconstruct drainage systems covering the area of 1000 000 ha, to implement a large volume of other works aimed at improving drained land areas, soil fertility and enhancing the efficiency of drained land use.

Acknowledgement

The authors wish to express our sincere thanks and appreciation to the Ministry of agriculture of the Russian Federation for support the Program.

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DRAINAGE SYSTEM DESIGN FOR COASTAL POWER PLANT: OPTIMIZATION OF LIMITED RESOURCES

Chawalit Chanamai[1,*], Narin Phaowanich[2]

Abstract

The southern part of Thailand plays an important role in tourism and economic development; thus, growth in electricity demand increases steadily. To ensure stability of supply, it was decided that a base load power plant is to be developed to provide reliable and dependable electricity supply. Thepa Coal-fired Power Plant is located near the coastal area at Pak Bang Sub-district, Thepa District, Songkhla Province, Thailand. The project has an area of around 4.736 km^2. The Thepa Power Plant Project covers the construction of the power plant complex, bearth and jetty facilities, as well as the construction of high voltage 500 kV transmission line.

Geographically, the Thepa District deals with both floods and droughts every year. The Office of Disaster Prevention and Mitigation proposes a plan to prevent flood and drought in the area to reduce the impact of such events on residents and the local agricultural sector. The change in land use is one factor that increases flood risk by reducing water permeability and increasing water surface runoff. To minimize the environmental impacts of developed land area, Sustainable Urban Drainage System (SUDS) techniques have been used as a tool for integrated water resources and water management. SUDS techniques are internationally adopted as an effective tool for sustainable design philosophies aiming not only to protect natural resources, but also to maintain good public health. In addition, the SUDS technique also preserves biological diversity by minimizing environment impact from developed land area over the long term.

This study focuses primarily on the sustainable and environmental-friendly design of drainage system for the new coastal power plant. The drainage system has been design using the Storm and Sanitary Analysis (SSA) two dimensional mathematical model which is for hydrology and hydraulics in a project. The study quantifies the criteria of the drainage system of the Power Plant. After identifying a suitable area for constructing a power plant, hydrological data including flood area, temperature, rainfall, runoff, soil properties and geometry were collected to be used as the basis for drainage design preventing flood area problems. One of the key principals in the design is to try to avoid any conflicts with the local community. After examining all relevant aspects, the criteria of drainage design and the criteria of sustainability design are set up to fully utilize

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available resources, not only for drainage, but also for power plant usage during construction as well as operation.

Flood prevention of the power plant is mandatory for reliable plant operation. Accordingly, the flow velocity should be designed for self-cleaning velocity. The velocity is then defined as the rate between 0.6 to 3.0 m/s to prevent sedimentation and to prevent erosion of pipe, gutter and channel. The maximum flow velocity is then quantified by the return period of rainfall at the project area. The drainage system planning is considered based on (i) Rational Method, (ii) Time of Concentrate (TOC), and (iii) Flood Routing.

The results of the study through the application of SUDS techniques show that the drainage system is composed of a 5.00 x 3.65 m 1.50 km main drain channel ., 2 retention ponds of total capacity 6,900,000 m^3, and a run-off canal. This system will effectively utilize the surface runoff while providing a reliable flood prevention system to the power plant.

KEY WORDS: Drainage design, Power plant, SUDS, SSA, Storm Drainage, Sustain Urban Drainage System.

Introduction

Electricity Generating Authority of Thailand (EGAT) is a state enterprise of power sector under the supervision of the Ministry of Energy of Thailand. The main objectives of EGAT are production electricity for supplying the usages of all sectors. The southern part of Thailand is important area of economic activities and tourism, thus the electricity demand rate keep increasing steadily. Some power plants need to shut down for maintenance as power plant management plan. Moreover, some of power plants in the south did not operate to the maximum capacity. EGAT seriously concerns about electricity reserving and suppling power generation for the future. That is the reasons why EGAT need to construct new power plant (COT, 2015).

The main problems of Thepa District are flood and drought (Buenoi, 2016). Not only residents suffer from these problems, but also plants and wildlife are affected from flood and drought. Water is more difficult to percolate to ground because land area surface is covered by building materials. The effect of land developing increases of runoff surface. Therefore, EGAT's engineers shall consider both on environmental factors; pollution impact and preventing the flood and also engineering sector.

To reducing the environmental impact of developed land area, SUDS is introduced to design land area development (Zhou, 2014). Moreover, The study of Royal Haskoing illustrated that the capital cost of SUDS in terms of maintenance decrease around 2.5 – 8.0 percent from the traditional drainage system per property at UK (Royal Haskoing, 2012).

In this paper focuses primarily on how to design the drainage for new power plant near the coastal by sustaining water resources. The two mathematical dimensions of hydrology and hydraulics model is used to design drainage system by SSA in project. The study quantifies the criteria of drainage system of Power Plant.

Study Area

Thepa Coal-fired Power Plant which has capacity 1,100 MW is located near coastal area at Pak Bang Sub-district, Thepa District, Songkhla Province, Thailand. The project area is around 4.736 km^2. The Thepa Coal-fired Power Plant is going to construct birth and jetty for importation of bituminous coal and sub-bituminous coal. Moreover, the project includes the electrical line 500 kV around 70-80 km for connection with Hat Yai 3 high voltage power station (COT, 2015). The location of study area is showed in the Figure 1.

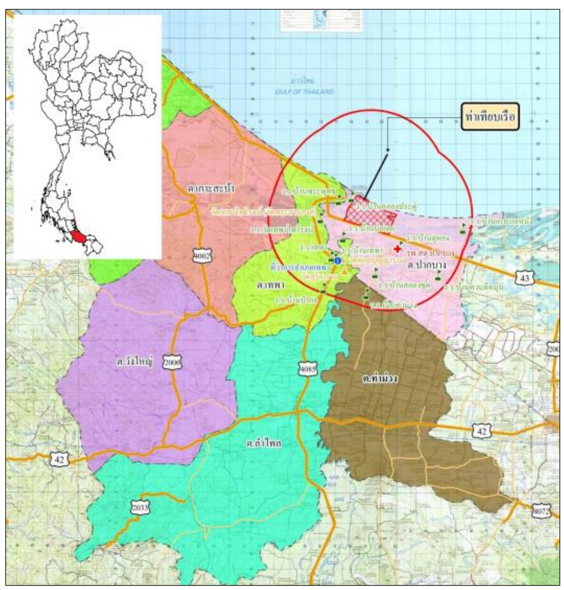

Figure 1. Thepa Coal-fired Power Plant

Previous Studies

In 2007, the European Flood Risk Directive presented the flood risk management plans by applied USDS method (Boogaard and Stockel, 2011). According SUDS, the drainage plan can reduce flood at the beach resort Egmond aan Zee in the north-west of the Netherland during extreme rainfall events.

Elliott and Trowsdale discuss about capability and relevance of 10 models to sustainable drainage systems. The paper presents insights into the advantages and disadvantages of the reviewed models in response to different requirements of the various SUDS devices (Elliott and Trowsdale, 2007).

According to Modelling of Sustainable Urban Drainage Measurement, Vergroesen et. al. found that the models for SUDS for green roofs, swale filter drainage system and infiltration transport drainage system are reasonable (Vergroesen et. al., 2014). The results from the mathematic model can present physical behavior of each system.

Methodology and Data

Methodology of Design

The overall methodology of drainage design for a new power plant is shown in Figure 2. After identify the proper area for construction of power plant. The designer shall collect data including flood area, temperature, rainfall, runoff, soil properties and geometry to prepare drainage design and prevent flood area problem. The local people shall allow to express their thoughts and have metting with designer team for reducing misunderstands about the project. Moreover, the designer shall understand their demand to reduce conflicts of community. After examining the engineering proposes, the criteria of drainage design and criteria of sustainability design are set up to design and analyze the drainage model for multi proposes. The submission of drainage of project will be considered by EHIA which is an indicator of the impact in environment and health. The agreement of city council is the final process for construction.

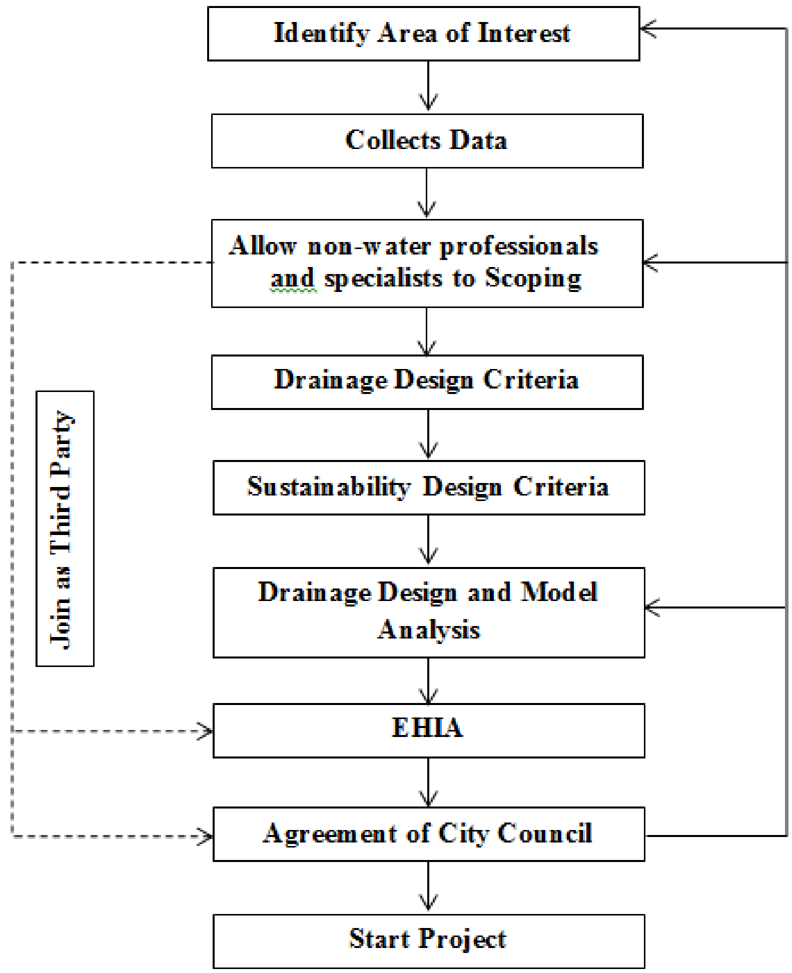

Figure 2. Framework of Drainage Design for Power Plant near Coastal

SUDS

Sustainable land development challenge engineer to improve amenity by balancing environment and health with changing land use. SUDS is techniques to manage runoff attenuation and mitigation with considering about pollutants reduction and amenity construction (Zhou, 2014). SUDS has approaches to manage water quantity (drought and flooding), water quality (pollution), amenity (new construction) and biodiversity (wildlife and plants) in a long term. The SUDS applied to the new project design has many techniques (Wilson et, al, 2011). There are many ways to present the components. This study focuses on only 4 elements of SUDS as follows:

Filter Strips

The filter strips refer to grass or other plant strips to collect mass of water or sheet flow and to remove pollution from it. The minimum length of covering plants and grass should be around 900-

1,200 mm with minimum top soil depth 150 mm. The filter strips prevent flood by infiltration and remove silt or small particular in water for preventing pollution.

Detention Basin

Generally, Detention basin refers to open and flat area covering with grass that are normally dry. If it rain heavily, these areas are used to store excess water in short term. Sometimes, they are used for multi proposes such as play areas.

Swale

Swale is a very shallow channel with side slope is not more than 1 in 3 for collecting runoff and removing pollution. Plants and grass can cover on both slope and bottom surface along the channels for preventing flood by infiltration. The flow rate for swale is not more than 1 – 2 m/s to prevent erosion. Normally, grass swales height should be 75 – 100 mm to prevent grass lodging and falling over due to the wind and runoff.

Retention Pond or wetland

The retention pond and wetlands are proposed to provide temporary storage for excess rainfall. They are designed as the open areas of shallow water. The water level will rise if it rain. Ponds and water land have the same concept that they provide the benefits of environment by removing pollution from surface water. The different between pond and wetland is that the pond consider to storing excess water, while wetlands focus on treatment pollution.

SSA

SSA is hydraulics, hydrology and water quality model which developed by Autodesk in 2010. Many projects and case study use SSA as a tool to design and analyze drainage system including stormwater, retention pond, outlet structure and water quality. The model is used worldwide because the results of model can be exported and analysized to AutoCAD and ArcGIS. SSA analysis is based on USEPA SWMM 5.0, NRSC (SCS) TR-55, NRSC (SCS) TR-20, HEC-1, rational method and unit hydrograph (Autodesk, 2013). SSA can quantify SUDS for storage volume requirement for the peak flow attenuation in project area, by determining the volume of runoff to extent storm durations for examining the critical storm duration. The model computes the volume of runoff by the storm duration time step method. The Figure 3 showed the software display the calculation of SUDS storage dialog box. The latest version of SSA is 2016. However, in this study use SSA version 2012 to design and analysis drainage system.

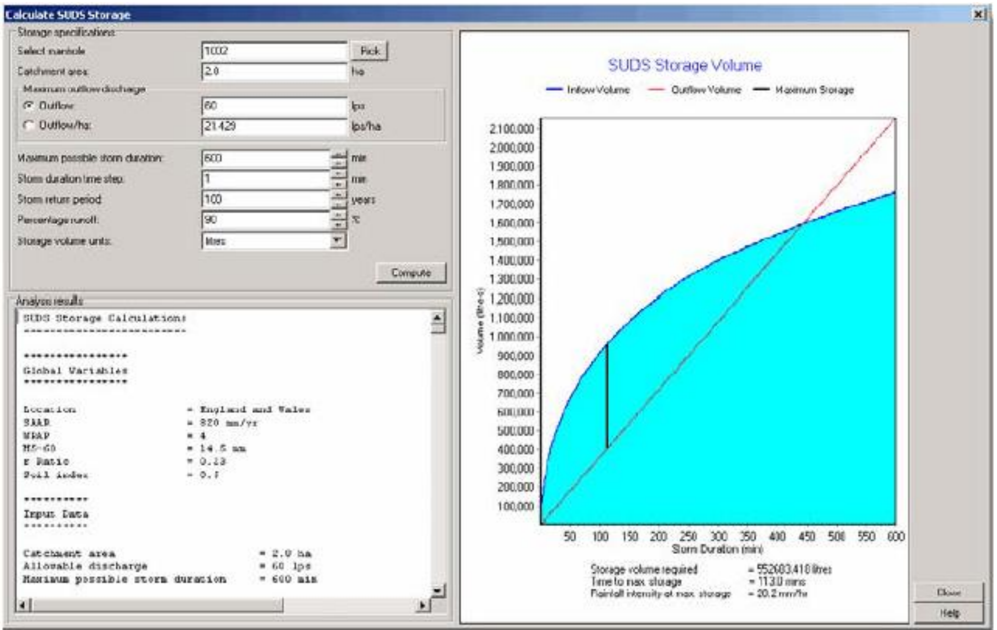

Figure 3. The example calculation SUDS storage (Autodesk, 2013)

Design Criteria

The new power plant needs a good drainage system design. The flow velocity should be designed with self-cleaning velocity. The velocity should be between 0.6 to 3.0 m3 for preventing sedimentation and preventing erosion of pipe, gutter and channel (NHI, 2001). The maximum flow velocity can be quantified by return period of rainfall at the project area. The drainage system plan based on following criteria:

Rational Method

The idea of Rational method is calculated from the maximum discharge by the rainfall excess in catchment area (NHI, 2001). The equation of rational method showed in Equation 1.

$$Q = 0.278CIA \qquad (1)$$

Where Q is the peak flow (m/s), C is the coefficient of runoff, I is intensity of precipitation (mm/hr) and A is drainage area or catchment area (km^2). The runoff coefficient is showed in Table 1.

Table 1 Runoff Coefficient (Autodesk, 2013)

Type of Drainage Area	Runoff Coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential:	
Sigle-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.10-0.30
Unimproved areas	
Street:	
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drive and walk	0.75-0.85
Roofs	0.75-0.95

Time of Concentrate (TOC)

TOC refers to the time from all area in drainage catchment flow through outlet. TOC shall be considered from the longest point of drainage system. According to SSA, TOC is consists of TOC of catchment area to drainage system and TOC of drainage system. The method is calculated by the equation 2 (NEH, 2010).

$$T = \frac{L}{V} \tag{2}$$

Where T is travel time (min.), L is the flow length (m.) and V is the average velocity (m/s).

Flood Routing

Flood routing of drainage system is determined by mass conservation and momentum equations in variety cases. There are three different models in SAA to solve these equations (Autodesk, 2013). Steady flow, kinematic wave and dynamic wave routing are selected to calculate flood routing depending on the purpose of the simulation. In this study, SSA must show a balance between preserving water and attenuating flooding risk. That is the reason why the kinematic wave model was selected to solve these equations.

Manning's Equation

The stromwater discharge of variety drainage shape of pipe, channel and culvert can be calculated by Manning's equation. SSA support to the calculation of any types of pipe and irregular natural cross-section. The Manning's equation (Equation 3) was select for this study (Autodesk, 2013).

$$Q = \frac{1}{n} A R^{2/3} \sqrt{S} \qquad (3)$$

Where Q is flow rate (m^3/s), n is Manning roughness coefficient, A is cross section area (m^2), R is hydraulic radius (m.) and S is energy slope. For Manning roughness coefficient is showed in Table 2 (Autodesk, 2013).

Table 2 Manning's Roughness Coefficient for Channels and Overland Flow (Autodesk, 2013)

Land Surface Type	Manning n
Concrete, Asphalt or Gravel	0.005-0.015
Rural Residential (1-10 acre lots, maintenance or grazing assumed)	0.40
1-3 building units/acre	0.30
3-10 building units/acre	0.20
>10 building units/acre	0.15
Commercial/Industrial (effects of landscaping, driveways, roofs included in combined value)	0.11
Average Grass Cover	0.40
Poor Grass Cover, Moderately Rough Surface	0.30-0.40
Light Turf	0.20
Dense Turf	0.17-0.80
Dense Grass	0.17-0.30
Bermuda Grass	0.30-0.48
Dense Shrubbery and Forest Litter	0.40

Data and Sources

SAA in this study is calculated using data from various sources. The list of data requirement is showed in Table 3.

Table 3. Data and sources in this study

Data	Sources	Period
Weather parameters (temperature, rainfall, humidity, Sun hour and wind speed)	Thai Meteorological Department (TMD)	๑๙๖๑-๒๐๑๐
Geology and soil properties	EGAT	2015-2016
Runoff and sea level	Royal Irrigation Department, Thailand (RID) and Marine Department of Thailand(MD)	1970-2010

Drainage Design and Discussion

The conceptual master plan of power plant is showed in Figure 4. The power plant zone is located at the west side of the project area. For the east side of the project, EGAT plans for providing the public area such as garden, observation, market, waterpark opening sport fields, community center and agricultural demonstration area. The drainage system in this zone is designed as swale flow to wetland which locates near waterpark. The water will be collected at a retention pond (capacity around 5,000 m3) for planting at agricultural demonstration area. Storm water from retention pond 1 (power plant zone) is preparing for waterpark. Stromwater is collected from green zone around market, garden and Java bird competition area to retention pond of public area (capacity around 8,000 m3) is located at observation. At the center of the sought east part of the project area, there is opened sport area (football, volleyball and cycling) which is designed as detention basin around 130,000 m2 to infiltration to the ground. In case of high rainfall excess, the excess of water will flow to waste water treatment tank checking and improving quality before release to Tu Yong Channel.

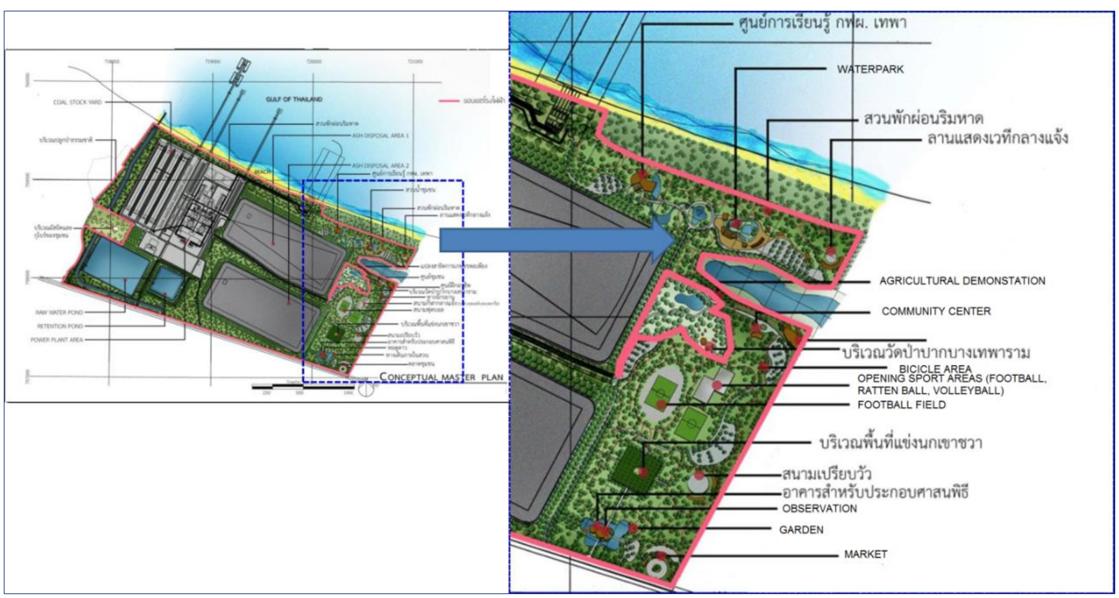

Figure 4. The Conceptual Master Plan

According to the project location, flood plain always across the main road to resident and project area in rainy season. The channel is improved by concrete lining and construction embankment for preventing flood event. The flood direction and channel were showed in the Figure 5. The trapezoid channel has 5 meters width with average slope 1:3. The capacity of this channel is 63 m^3/s, while the 100 years return period of flood plain is around 58.10 m^3/s.

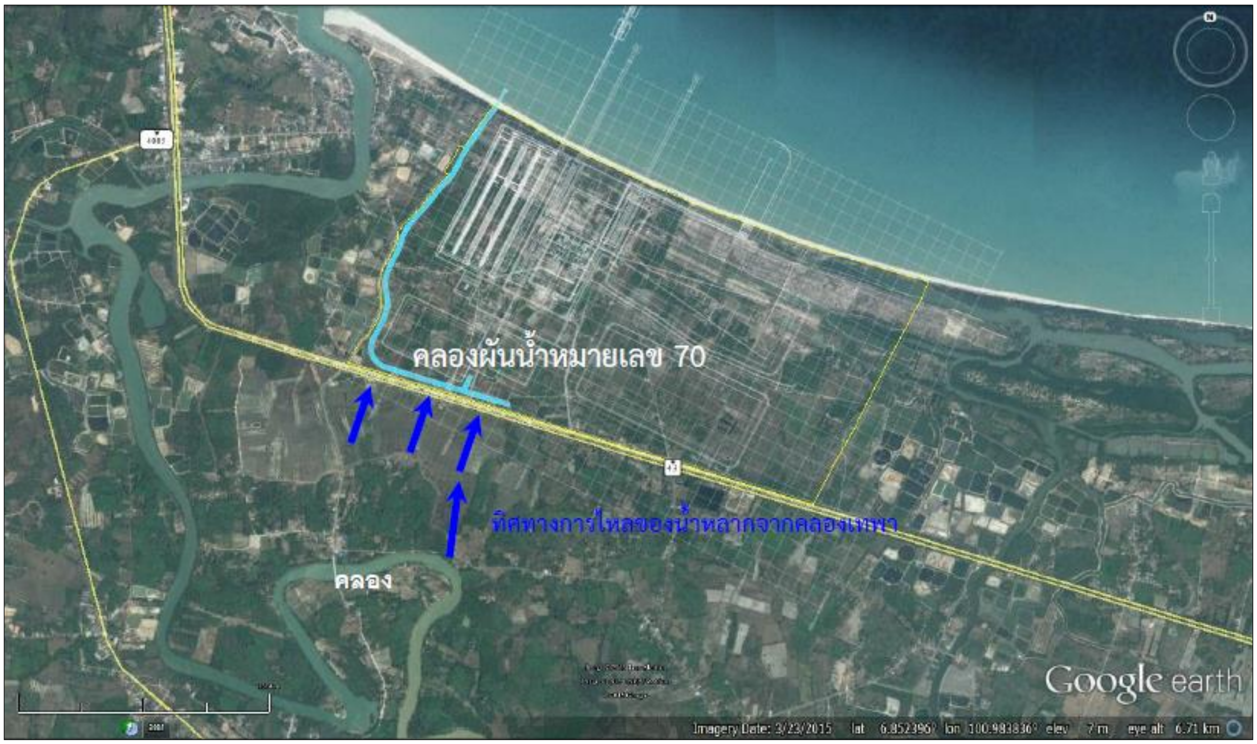

Figure 5. The Conceptual Master Plan

According to Table 2, the main drainage which has size of 5.00 x 3.65 meter is designed to collect stormwater base on 10 years return period of rainfall duration 15 minutes the safety factor 1.30. The capacity of this main drain is 35.25 m^3/s. There is clearance around 15 meters both sides of main drain with filter strips removing particles from water. All of stromwater is collected at the retention ponds with capacity 6,900,000 m^3 by main drainage system. The retention pond consists of clay blanket and HDPE sheet to prevent water infiltration and preventing sea water dissolve to water system. Water is prepared for gardening, washing equipment, spreading coal and public area.

Table 4 Calculation of Main Drain

From	To	Increment Length of Gutter m.	Total Length of Gutter m.	Total Catchment Area m².	Area for C 0.30	Area for C 0.80	I mm/hr	Qp m³/s	Drainage System Design: Bed Width m.	y m.	A m².	P m.	R m.	n Manning	Depth of Channel m.	Qmax m/s	vmax m/s	Safety Factor
1	2	3.25	3.25	193,619	0	193,619	150	6.45	5.00	0.80	7.50	8.00	0.94	0.015	2.35	15.15	2.02	2.35
2	3	212.80	216.05	280,170	0	280,170	150	9.34	5.00	1.03	8.63	8.45	1.02	0.015	2.35	18.43	2.14	1.97
3	4	178.46	394.51	297,650	4,980	292,670	150	9.82	5.00	1.06	8.80	8.52	1.03	0.015	2.56	18.96	2.15	1.93
4	5	21.53	416.04	428,320	4,980	423,340	150	14.17	5.00	1.37	10.33	9.13	1.13	0.015	2.74	23.63	2.29	1.67
5	6	114.07	530.11	445,200	9,790	435,410	150	14.64	5.00	1.40	10.48	9.19	1.14	0.015	2.76	24.10	2.30	1.65
6	7	85.89	616.00	526,987	9,790	517,197	150	17.36	5.00	1.58	11.38	9.55	1.19	0.015	2.88	26.95	2.37	1.55
7	8	49.77	665.77	556,037	20,200	535,837	150	18.11	5.00	1.62	11.61	9.64	1.20	0.015	2.96	27.70	2.39	1.53
8	9	222.64	888.41	573,257	37,420	535,837	150	18.33	5.00	1.64	11.68	9.67	1.21	0.015	3.01	27.91	2.39	1.52
9	10	13.50	901.91	584,417	48,580	535,837	150	18.47	5.00	1.65	11.73	9.69	1.21	0.015	3.23	28.07	2.39	1.52
10	11	14.00	915.91	766,027	48,580	717,447	150	24.52	5.00	2.02	13.60	10.44	1.30	0.015	3.25	34.20	2.51	1.39
11	12	103.65	1,019.56	788,197	48,580	739,617	150	25.26	5.00	2.06	13.82	10.53	1.31	0.015	3.26	34.91	2.53	1.38
12	13	150.00	1,169.56	900,917	48,580	852,337	150	29.02	5.00	2.29	14.95	10.98	1.36	0.015	3.36	38.72	2.59	1.33
13	14	306.80	1,476.36	1,007,867	112,170	895,697	150	31.26	5.00	2.42	15.58	11.23	1.39	0.015	3.51	40.84	2.62	1.31
14	15	42.35	1,518.71	1,007,867	112,170	895,697	150	31.26	5.00	2.415	15.575	11.23	1.38691	0.015	2.42	42.97	2.65	1.30

The ash disposal ponds are located at the center of project area. The cross-section of ash disposal pond is showed in Figure 6. The bottom of disposal pond is covered by sand layer and under drain system. The under drain collect water around 65 m^3/day from initial filter particles in sand layer to waste water treatment area. The HDPE sheet is used to prevent stormwater mixing with ash emit to environment. The waste water system will be treated and reused for electrical production process which is about 600 m^3/day. As a result of the simulation of water level in Figure 7, the capacity of ash disposal pond is available to store both stormwater and ash for 15 years.

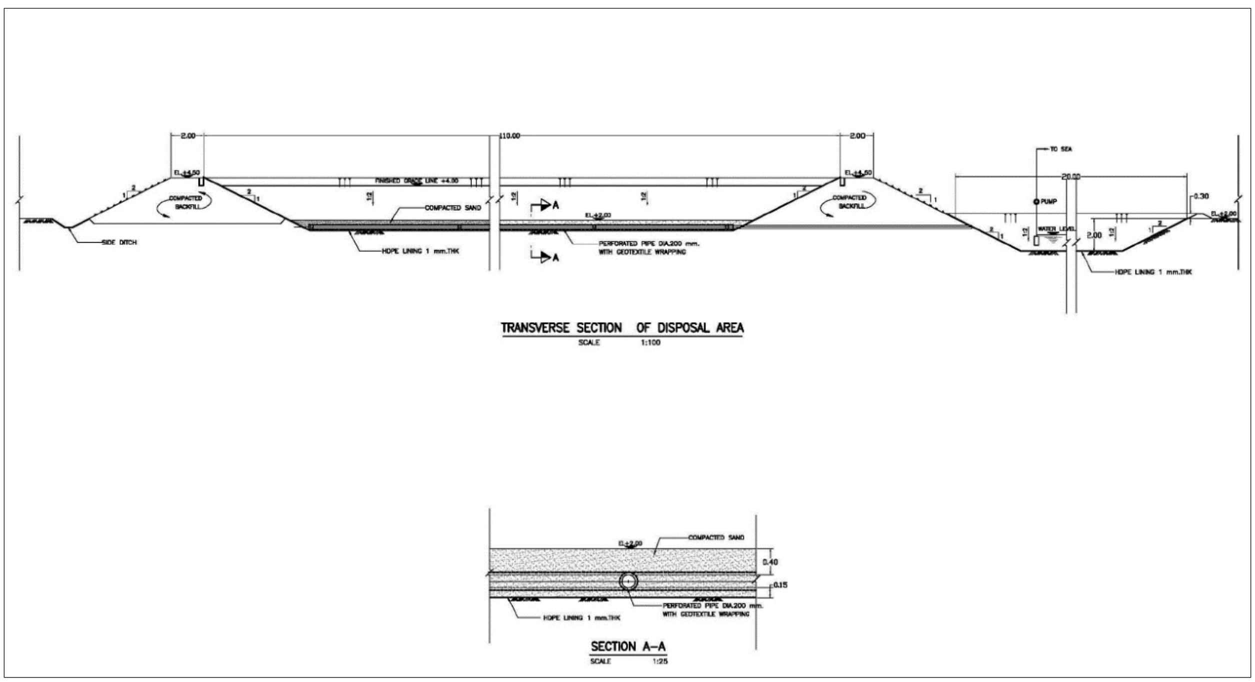

Figure 6. Ash Disposal Section

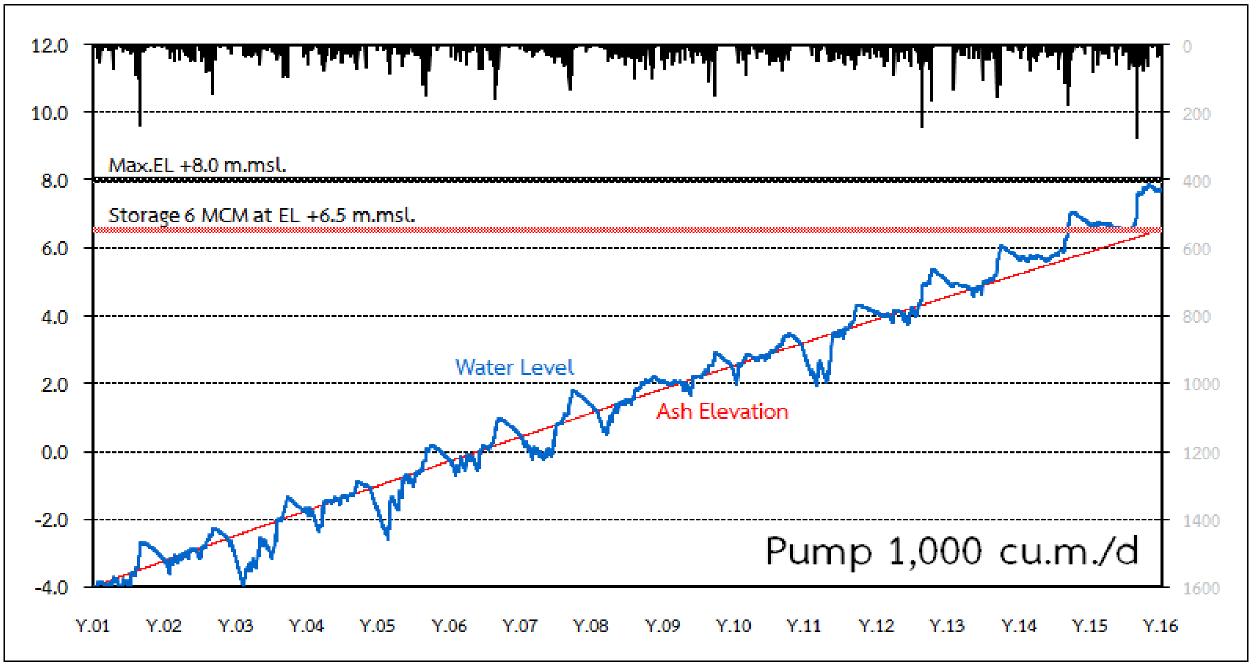

Figure 7. Water Management at Ash Disposal

Conclusion

This case study has shown that EGAT concerns about sustain water. The drainage system designed for coastal power plant in Thailand which gets along well with environment and community. According to SUDS techniques, the new power plant which is located near the coastal will effectively prevent 100 years return period of flood from the site project and out site project area for people around Thepa Power Plant. Swale, filter strips and detention pond are used as to improve water quality in drainage system. According to reusing water in power plant activities such as gardening (412 m^3/day), washing ash and equipment (200 m^3/day), and utilizing in the public area zone, rainfall in the project area is used up. It means that there isn't stromwater that mixes with pollutant such as sediment and oil releasing to public channel or river. The rainfall assess in rainy season shall store in retention ponds for using in dry season in both power plant project and public area.

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MODELING STORM WATER MANAGEMENT FOR WATER SENSITIVE URBAN DESIGN USING SUSTAIN

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Abstract

In an attempt to transit South Australia to a water sensitive State, a plan named Water for Good was launched in 2012 which is a guide for urban and regional development of South Australia. One of the main objectives of this plan is to reduce the negative impact of urbanization on the water cycle of the cities. In order to reduce the hydrological impact of urbanization, best management practices have been proposed. Determining the topology of such structures (number, size and placement) is the key element of any urban storm water management plans. Several models have been proposed which are based on hydrologic, hydraulic or combination of both properties of the catchments. This paper addresses some of the most important models and then introduces SUSTAIN as a suitable model for the optimization of best management practices in South Australia. The selection of the appropriate model was based on the desired condition of the study. In order to study the potential of SUSTAIN for storm water management, a part of the Paddocks area located in Para hills, South Australia was selected which is 15.95 acres in size and was broken into five sub- catchments. The hydrologic parameters of the model were derived from a calibrated model which was developed using EPA SWMM. Three types of BMPs i.e. rain garden (bioretention), rainwater tank (cistern) and detention tank (bioretention as a surrogate) were studied. After designing the study area, defining data layers, placement of BMPs, specifying routing network and the setting of parameters for each sub catchment and BMPs, SUSTAIN was run for a minimum of six months leading up to the 2 or 5 year ARI event. A total of 15 out of 50 scenarios result into an optimized solution which can be classified in three groups according to the type of used BMPs. SUSTAIN successfully produced results for preserving peak flow rate within the catchment, producing data regarding the least cost solution for the size and placement of

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retention or detention storages. In the retention scenario, levels of demand (or disposal) greater than 450 L/day of retained water were required to produce an optimum result for the 2 years ARI storm event, and greater than 5000 L/day flow to preserve the existing peak flow of the 5 year ARI storm event. For detention systems, an orifice 25 mm was successfully used for preserving both the 2 years ARI and 5 years ARI. However, there did not appear to be any clear pattern in the placement of retention or detention tanks, with results varying each time a successful scenario was rerun. Further optimization with multiple outcomes is recommended to produce a pattern of optimal tank arrangement.

KEY WORDS: Water Sensitive Urban Design, Storm Water Management, SUSTAIN, BMP.

Introduction

There have been recorded an increasing attempt to improve peak flood quantile estimation in the world over the recent decades (Jenkinson, 1955; Dalrymple, 1960;Benson, 1962; Greenwood et al., 1979; USWRC, 1981; Kuczera, 1982; Adamowski, 1985; Hosking et al., 1985; Hosking and Wallis, 1988; Jin and Stedinger, 1989; Burn, 1990; McKerchar and Pearson, 1990; Madsen et al., 1997; Penning-Rowsell et al., 2000; Handmer, 2001; Reiss and Thomass, 2001; Katz et al., 2002;Reis et al., 2004; Zhang and Singh, 2006;Borga et al., 2011; Chavoshi et al., 2012; Castellarin et al., 2012; Silva et al., 2012; Brodie, 2013; Yongfei et al., 2013; Chavoshi et al., 2013a,b; Bezak et al., 2014; Zhang et al., 2014; David and Davidova, 2014). One of the main goals of such studies is to provide reliable estimation of peak flood values with different return period for designing flood control structures.

Several studies have investigated the impact of WSUD features to manage flow rate, volume and flooding from developed catchments. The studies include a wide variety of techniques for simulating the impact of WSUD systems on the flow volume, peak flow rate and flood volume. The EPA SWMM was most widely applied for predicting flow rate, volume and flooding, however few studies assessed the impact of WSUD on peak flows over a truly continuous simulation period, which is required to capture the variability of rainfall and the impact of antecedent catchment conditions (which are influenced by the filling and emptying of storages).

In order to investigate the potential of SUSTAIN in WSUD projects, it was employed for a small urban catchment. The main objective of this study is to find the appropriate BMPs combination (type, size, number and location) to reduce overland flood peak with different ARI to a desired level according to the least cost.

Materials and methods

Case Study

To demonstrate the potential of SUSTAIN for the optimization of BMPs for storm water management, a case study was developed based on a sub-catchment of the Paddocks catchment area located in Para hills, South Australia (Figure 1). This catchment is 6.46 hectares in size and was broken into five sub- catchments (Table 1). It includes four landuse types, namely pervious area (45.39%), road (19.65%), roof (23.85%) and other impervious area (11.12%). Table 2 shows the ratio of current landuse types in each of the sub-areas

Figure 1. An aerial view of the study area and its sub-catchments

Table 1. Sub-catchments properties in the study area

Parameter	Sub-catchment				
	C1	C2	C3	C4	C5
Area (ha)	0.53	2.15	0.17	2.12	1.49
Slope (%)	7.5	7.5	7.5	7.5	6.25
Width (ft)	445.45	1800	141.52	1775.52	1250.25

shown in Figure 1. As this table shows, impervious area (directly connected and indirectly connected) covers almost 55.10 percent of the catchment.

Table 2. Landuse types and percent in each sub catchment

Sub-catchment	C1	C2	C3	C4	C5
Forest_Pervious	44.09	46.00	22.05	44.76	48.54
Road_Impervious	14.50	21.54	58.50	19.95	13.93
Rooftop_Impervious	30.96	23.79	0.00	23.96	23.93
Low Density Residential	10.46	8.67	19.45	11.34	13.61

The impervious condition in both predevelopment and post development scenarios are shown in Table 3.

Table 3. Distribution of impervious and pervious area in the region

Sub catchment	Area (hectare)	Pre development		Post development	
		Impervious (%)	Routed (%)	Impervious (%)	Routed (%)
C1	0.53	44.7	55	62.6	32.3
C2	2.15	47.4	39	70.5	18.8
C3	0.17	44.7	24	66.1	1.8
C4	2.12	44.7	41	63.7	19.2
C5	1.49	43	55	56.5	32.3

A total of 46 houses each with one rainwater tank exist in the study area. According to Australian Building Codes Board (2013) each new house to be build must have one rainwater tank. So, in order to simulate the post development condition, a total of 50% impervious surface increment due to new infill development was considered. It means that a total of 50% of new tanks were considered for post development scenario.

It was assumed that 1 in 3 houses was demolished and replaced with 2 new homes on the same allotment. Each allotment was assumed to be in accordance with Table 4. It was assumed that each new house was constructed with one LID unit. IN all cases, the connected roof area was assumed to be 100 m2 (Table 4).

Table 4. New allotment properties

Houses	2
Roof (m2)	400
Paving (m2)	70
New connected imp (m2)	470
new indirect imp (m2)	30
Total impervious (m2)	500
Connected impervious per allot (%)	54.20
Total (%)	0.57

Model Setup

The hydrologic parameters of the model were derived from a calibrated model which was developed using EPA SWMM. These parameters include soil infiltration characteristics (using the Horton infiltration model, including minimum and maximum infiltration rate, a decay constant, a maximum infiltration volume and drying time), Manning's coefficient for overland flow over the pervious and impervious part of the basin, depth of depression storage on the pervious and impervious part of the basin, percent of the impervious area with no depression storage, percent of routed runoff, pipe roughness coefficient, surface depression storage and monthly mean evapotranspiration. The values of the model parameters are listed in the Appendix 1 and 2. In the model, all runoff from indirectly connected impervious area was assumed to run over the pervious area before reaching the catchment outlet (drain). Other required information was collected including spatial data (GIS maps, catchment properties, landuse) and climate data (6-minutes precipitation and average monthly evaporation from the BOM gauge at Parafield Airport, 023013).

Water Sensitive Urban Design Measures

Three types of BMPs i.e. rain garden (bioretention), rainwater tank (cistern) and detention tank (bioretention as surrogate) were studied. Rainwater tanks were simulated using the 'cistern' node in SUSTAIN, while rain garden and detention tanks were studied by applying the bioretention node with different properties to suit (Figure 2).

The properties of assumed on site detention tanks (simulated by adapting the bioretention node as a surrogate), rain garden (simulated using the bioretention node) and on site rainwater tanks (simulated using the cistern node) are shown in Appendix 3 to 5.

In the first class of scenarios, each new house was equipped to one cistern and a uniform steady rate for water usage (cistern release) was considered. In this case, the size of the cistern was considered as a model variable while other parameters were pre-specified in SUSTAIN.

In the second class of scenarios, one rain garden was allocated to each new house and the length and width of tanks were considered as evaluation factors.

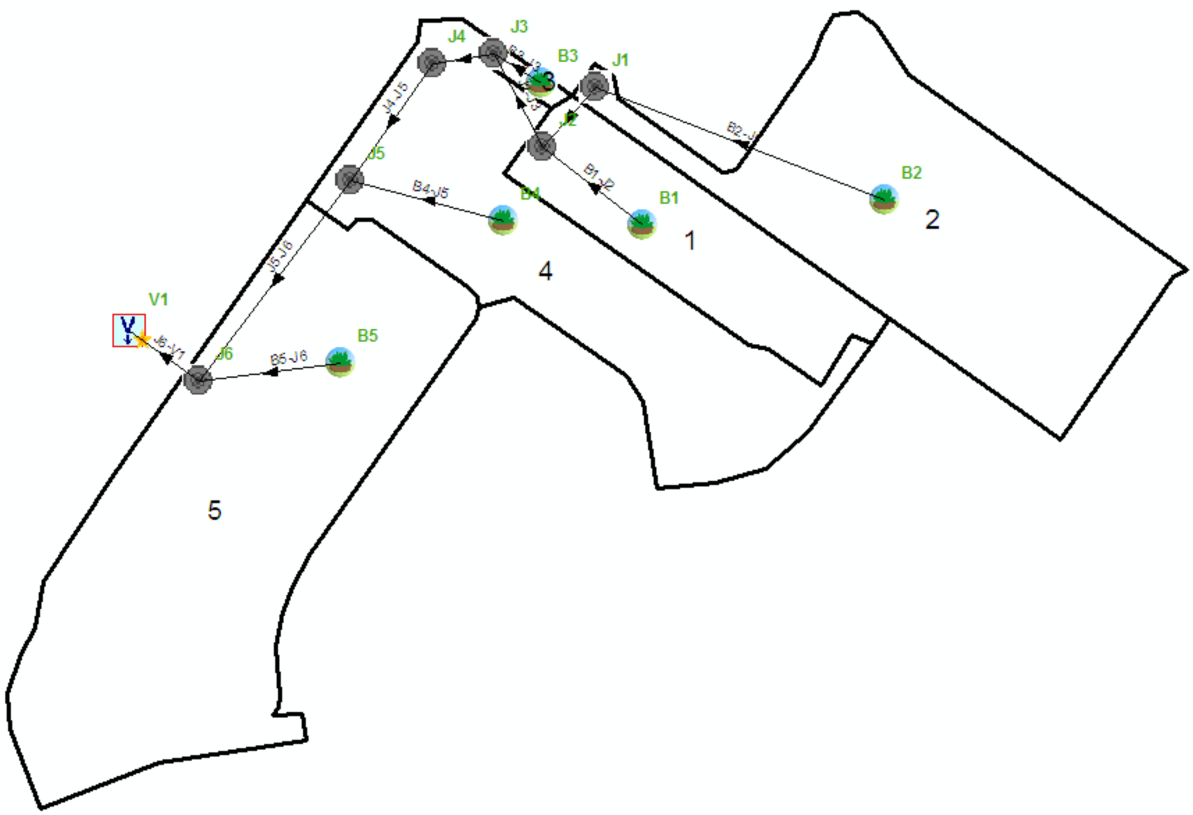

Figure 2. The schematic view of the sub-catchments and BMPs network in the study area

As the last class of scenarios, one detention tank was attributed to each new house and the size of tank (length and width) as well as orifice parameters (diameter and height) were selected as evaluation factors.

The cost of implementation

The assumed cost for rainwater tanks included a fixed cost of AUD$2546 for the purchase of each rainwater tank as well as AUD$3.34 for each cubic foot of tank storage (Marsden and Associates, 2007). Detention tank cost includes AUD$1907 as the fixed cost and AUD$3.34 per square feet of each bioretention system.

The cost of bioretention systems (rain garden and detention tank) was estimated by the following equation (EWATER, 2010):

$$\text{Cost} = 387.4 * A^{0.7673} \quad (1)$$

Where, A is the plan surface area (m2)

Determination of peak flow with different return interval

The methodology proposed by Ghafouri (1996) was used to estimate the peak flow of runoff from the catchment (Table 5).

Table 5. The estimated peak discharge with different return period in the study area

ARI	1	2	5	10	20
Pre-infill	5.67	7.89	10.84	13.06	15.29
Post-Infill	10.40	13.57	17.77	20.95	24.12

The recorded peak discharge events on 26 March 2004 and 15 January 1997 were selected as 2 and 5 ARI values, respectively, because these values have the closest value to estimated 2 and 5 ARI events in the pre-development flow time series at the end of the catchment. These values were selected to represent the threshold flows for optimization in SUSTAIN. Therefore a period of rainfall was selected for each threshold which included one of these events. This period was selected so as to not include any peak discharge events greater than the defined threshold. Table 6shows the selected 2 and 5 ARI peak discharge as well as their rainfall periods. The period was selected so that the simulation was less than one year to reduce model simulation times.

Table 6. Selected 2 and 5 ARI peak discharge

ARI	2	5
Threshold	5.71	6.8
Date and time of occurrence	26th March 1984, 12:12	15th January 1977, 17:30
Rainfall Period	1st April1983 to 28th March1984	15th January 1976 to 16th January 1977

Figures 3 and 4 show the comparison of pre-infill and post-infill scenarios in terms of 2 and 5 years ARI, respectively.

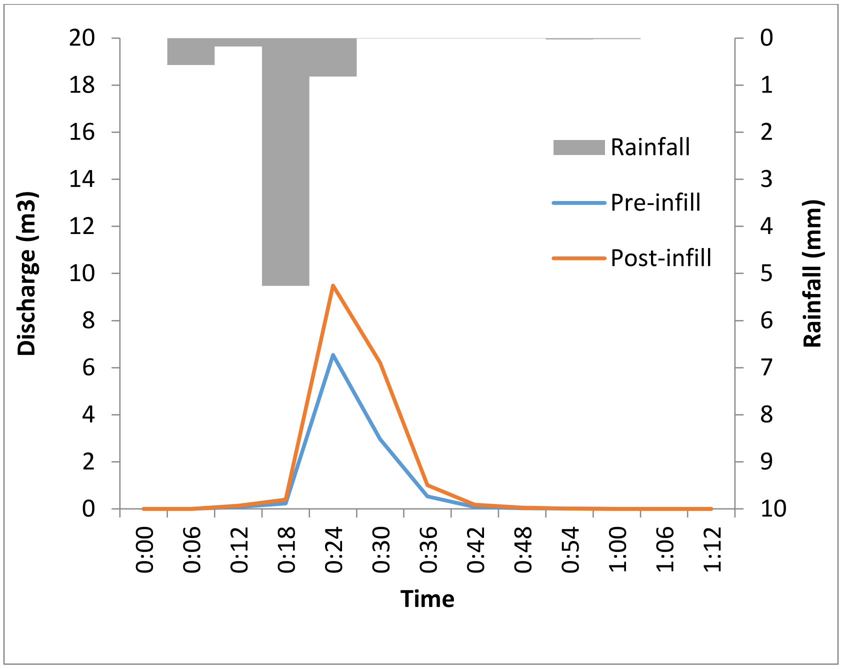

Figure 3. A sub-section of 2- years ARI flow hydrograph (26th March 1984)

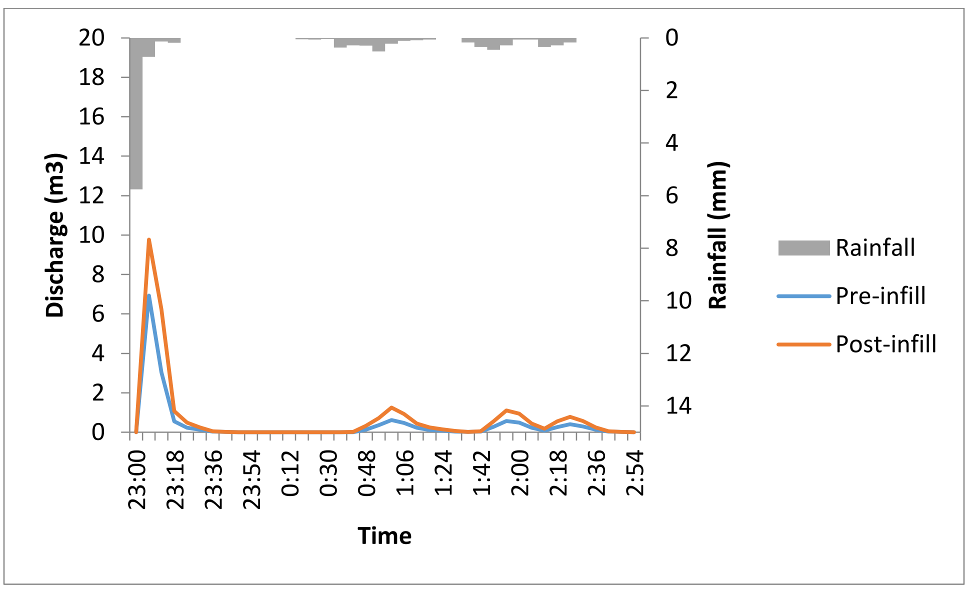

Figure 4. A section of 5- years ARI flow hydrograph (14th January 1977)

Defining scenarios

After designing the study area, defining data layers, placement of BMPs, specifying routing network and setting parameters of each sub catchment and BMPs, SUSTAIN was run for a minimum of six months leading up to the 2 or 5 year ARI event. As the first step, landuse was simulated using the internal simulation option to generate the runoff time series for each sub catchment. Then the assessment process was initiated by defining the assessment point where flow rates are used to measure the effects of WSUD. In this study the outlet of the catchment was selected as the assessment point for all of the scenarios. The assessment process was based on minimizing cost and the evaluation factor was the peak discharge at the assessment point. The peak discharge was set to equal the 2 or 5 Year ARI prior to infill development. The number of near optimal solutions for output was set to 1, and the model was instructed to stop searching when it could not optimize cost more than $2000. Depending on the catchment area, number of sub catchments, the complexity of BMPs network and assessment parameters, several iterations were calculated and compared by SUSTAIN to find the optimum solution. The following sections describe the modeling approach to optimize the placement of rainwater tanks, bioretention systems and detention tanks on redeveloped allotments in the model.

Results and discussion

A bar chart showing the evaluation factor values of four different conditions, i.e. pre-development, post-development, existing and best solutions was generated for each scenar-

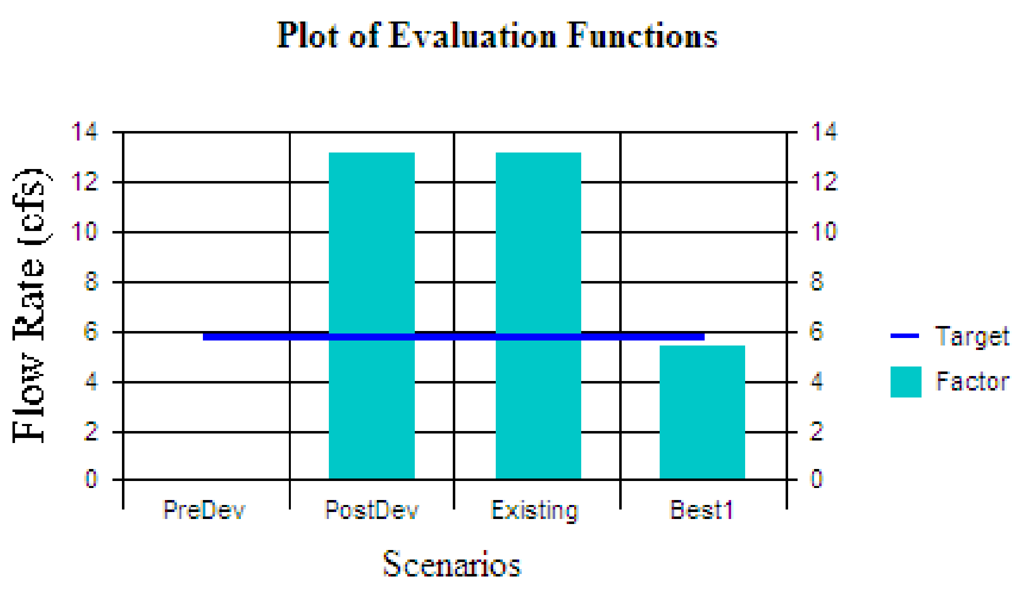

Figure 5. Results of evaluation in different condition

-io. An example of this output is shown in Figure 5 which corresponds to the results of scenario number 44. In this graph, pre-development refers to the condition prior to development; post-development and existing deal with developed condition without and with BMPs, respectively; and the best solutions show (e.g. Best1) shows the optimal solutions determined during the optimization process. Figure 5 shows fully optimized results as the solution Best1 is below the target flow rate. It should be noted that this may not always be possible. The solution Best1 may be above the target value if the WSUD options considered cannot be arranged to achieve the target flow rate (pre-infill development ARI).

To calculate the total volume of runoff intercepted by BMPs in each scenario, the volume of flow water was measured and multiplied by the number of BMPs in each sub catchment.

A total of 15 out of 50 scenarios tend to an optimized solution which can be classified in three groups according to the type of used BMPs. The topology (number and placement) of BMPs in the catchment which caused to a proper solution in both 2 and 5 ARI were studied. This result can help to program for a sustainable water resources management in the region. The effect of different BMPs on flood reduction can be seen in some scenarios (Figures 6 to 8).

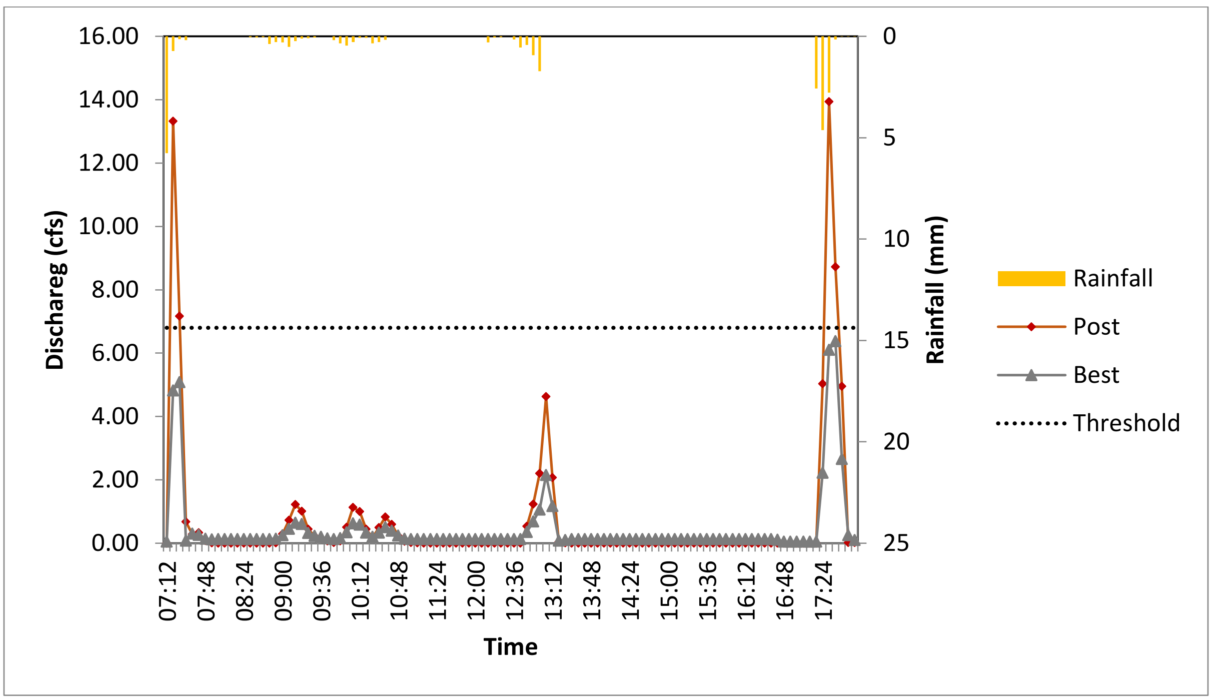

Figure 6. The flow hydrograph of rainwater tanks (cistern) in post development and best solution condition (15.1.1977)

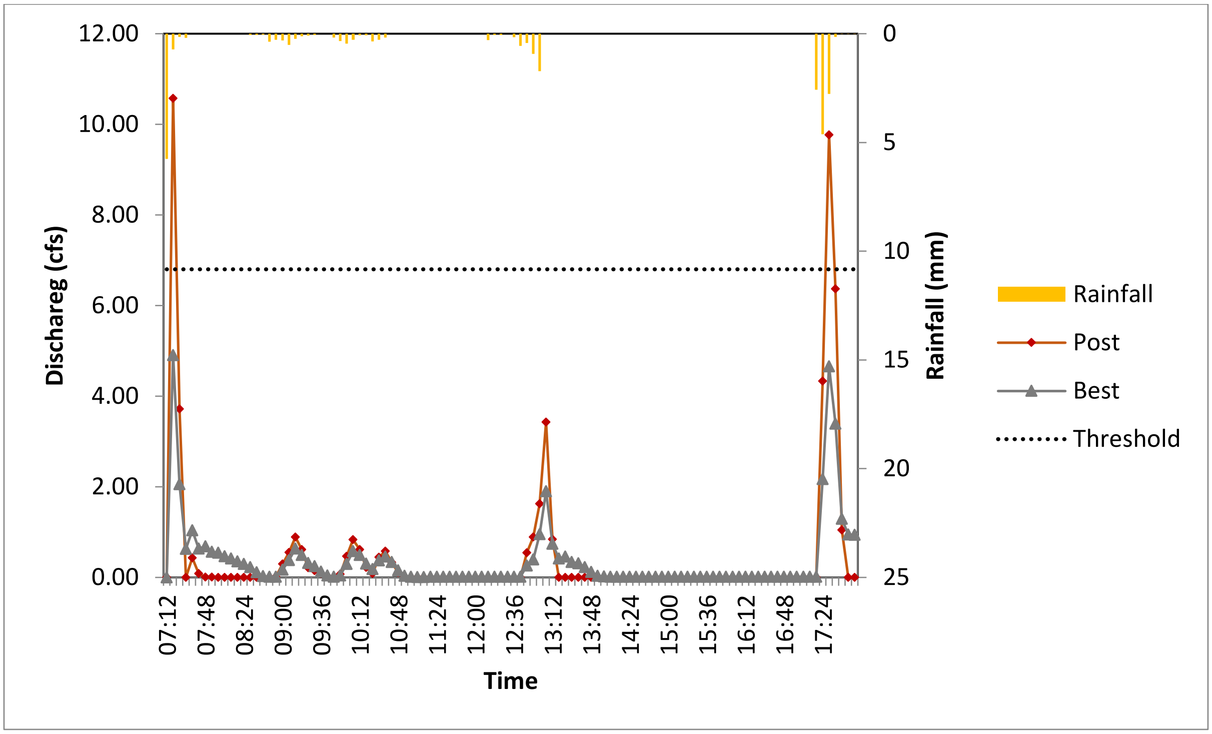

Figure 7. Flow hydrograph of detention tanks in post development and best solution condition (15.1.1977)

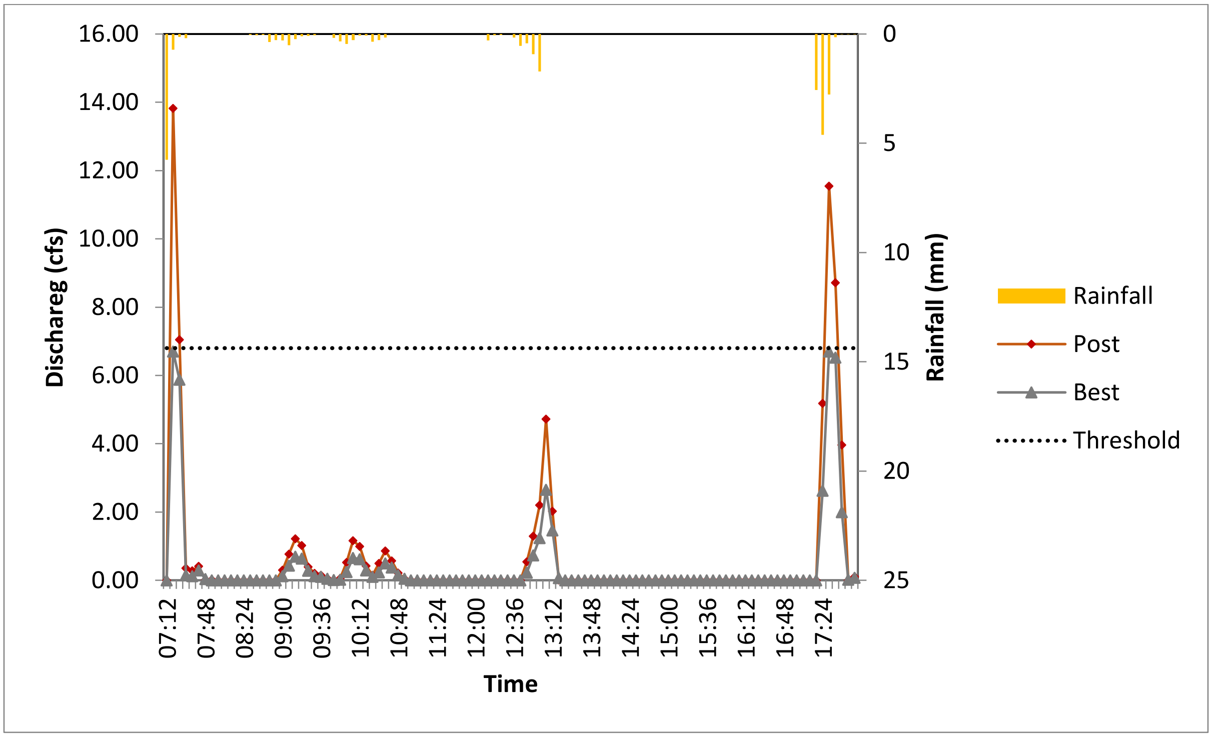

Figure 8. Flow hydrograph of rain garden in post development and best solution condition (15.1.1977)

Conclusion

The US EPA SUSTAIN software tool was used to optimize the placement and design of both a retention and detention scenario in a collection of sub catchments of the Paddocks catchment in Para Hills. SUSTAIN successfully produced results for preserving peak flow rate within the catchment, producing data regarding the least cost solution for the size and placement of retention or detention storages. In the retention scenario, levels of demand (or disposal) greater than 450 L/day of retained water were required to produce an optimum result for the 2 year ARI storm event, and greater than 5000 L/day to preserve the existing peak flow of the 5 year ARI storm event. For detention systems, an orifice 25 mm was successfully used for preserving both the 2 year ARI and 5 year ARI. However, there did not appear to be any clear pattern in the placement of retention or detention tanks, with results varying each time a successful scenario was rerun. Further optimization with multiple outcomes is recommended to produce a pattern of optimal tank arrangement.

It is recommended that further research is undertaken with more urban catchments of smaller and greater size to verify the findings of this research hold true on a broader scale. Also, one reason for the limited effectiveness of the retention and detention systems was the limitations assumed for the contributing impervious area. In this research, the connected impervious area was based on what may reasonably be assumed to be connected to an above ground tank. An underground tank may be a suitable alternative, where higher impervious areas can be connected. Further research is recommended to explore the effectiveness of assumed tank systems in this research with greater connected impervious area.

The current approach to providing acceptable drainage in existing urban catchments where the storm water system is under stress is to design and construct upgraded drainage systems. However, this research demonstrated that a complete catchment retrofit with retention or detention, or even to a limited extent the construction of street scale rain gardens, was effective at maintaining peak flow rates at pre-infill development levels. Based on these outcomes, it is recommended that the economic costs and benefits of retention, detention and rain gardens are assessed with respect to a typical design and upgrade scenario to determine which arrangement provides the most cost effective means of preserving peak flows in catchments subject to infill development.

Further to this, there was little difference between the impact of applying retention or detention for a fixed tank size. This result indicates that the potential peak flow rate and flooding benefits under the conditions simulated in this paper may be discounted when selecting one option in favor of another for a developing catchment. However, these results should be explored on a much larger catchment to investigate the occurrence of any lagging flow issues which were not apparent in the situations examined in this report.

Detention systems with an orifice size between 20 mm to 40 mm were most effective at reducing peak flows. However, this may be expected to vary depending on the size of the catchment. It is recommended that the methodology in this study is repeated for a very large catchment, where the ideal orifice size may differ.

Acknowledgement

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SUSTAINABLE URBAN DRAINAGE (SUD) AND NEW URBAN AGENDA (NUA)

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Abstract

This paper addresses the need to reduce the impact of city development of flooding on residents and in other places, and the worsening of the water quality in streams, rivers and lakes caused by the expansion of cities. The most appropriate current solutions involve Sustainable Urban Drainage Systems (SUDS) but SUDS can only be implemented where good policies, supportive stakeholder groups and partnership working exist in order that these new ideas, which cut across existing methods and practices, will be accepted; moreover it goes on to discuss how the New Urban Agenda (NUA) shall be supporting and addressing these challenges.

Sustainable Urban Drainage Systems require several changes in thinking and practice in city planning and there are many barriers to progress including the perceived costs added to the development itself, and the increased maintenance activities required, in addition to the attractiveness of big infrastructure projects to politicians ;whereas, drainage projects are very often just 'normal work'. The inertia of planning systems also tends to discourage the good new ideas involved. However, the perceived additional costs need to be set against the costs of losing habitats and fish, food and other ecosystem services which follow, and the damage to properties and the danger to people caused by flooding which frequently results from development. The barriers to more sustainable drainage are high but a whole portfolio of potential 'Green' infrastructure solutions are available to be applied to any city in the world. There are no particular problems for high cost, or high value developments since the additional costs of drainage are small and green space is normally an integral element.

However, for most urban developments where money is tight, drainage solutions on a development site are likely to be hard concrete with no financial allocation for maintenance. Consequently, to achieve a more widespread use of sustainable drainage principles, greater integration into Green Infrastructure is necessary, and multiple benefits need to be clear. Otherwise the total operational life costs will not be properly recognized. Major developments and redevelopments give the opportunity for the reallocation of open space to improve its use through multiple functions. Sustainable drainage has the potential to provide habitat improvements which provide places for

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breeding, and to provide connectivity between SUDS and natural areas, in addition to linking directly to zones of natural habitats thus providing more sustainable solutions and greener solutions to drainage problems.

The New Urban Agenda (NUA) aims at enhancing effective urban planning and management, efficiency, and transparency through e-governance, information and communications technologies assisted approaches, and geospatial information management. Further, New Urban Agenda underscores the need to promote adequate investments in accessible and sustainable infrastructure and service provision systems for water, hygiene and sanitation, sewage, solid waste management, urban drainage, reduction of air pollution, and storm water management, in order to improve health and ensure universal and equitable access to safe and affordable drinking water as well as access to adequate and equitable sanitation and hygiene for all; and end open defecation, with special attention to the needs and safety of the fairer sex and those in vulnerable situations. NUA seeks to ensure that this infrastructure is climate resilient and forms part of an integrated urban and territorial development plans, including housing and mobility, among others, and is implemented in a participatory manner, taking into account innovative, resource efficient, accessible, context specific, and culturally-sensitive sustainable solutions.

NUA also recognizes that urban centers worldwide, especially in developing countries, often have characteristics that make them and their inhabitants especially vulnerable to the adverse impacts of climate change and other natural and man-made hazards, including extreme weather events such as flooding, subsidence, storms, including dust and sand storms, heat waves, water scarcity, droughts, water and air pollution, vector borne diseases, and sea level rise that particularly affects coastal areas, delta regions, and small island developing States, among others.

NUA also commits to promote the creation and maintenance of well-connected and well-distributed networks of open, multi-purpose, safe, inclusive, accessible, green, public spaces with high quality to improve the resilience of cities to disasters and climate change, reducing flood and drought risks and heat waves, and improving food security and nutrition,in addition to physical and mental health, household and ambient air quality, noise reduction, and promoting attractive and livable cities and human settlements and urban landscapes, prioritizing the conservation of endemic species.

KEY WORDS: Policies and Planning Systems, Effective urban planning and management, Impacts of climate change and other natural and man-made hazards, quality public spaces to improve the resilience of cities to disasters and climate change.

Introduction

With fast urbanisation there is an urgent need of city development and to reduce the impact of flooding on residents and in other places, and the worsening of the water quality in streams, rivers and lakes caused by the expansion of cities. The best way to reduce surface water drainage charges is to prevent surface water entering the public sewer. Sustainable Urban Drainage Systems (SUDS) provide a natural approach to managing drainage in and around sites. SUDS work by slowing and holding back the run-off from a site, allowing natural processes to break down pollutants. SUDS deal with run-off close to the source, rather than transporting it elsewhere via the public sewer system. Sustainable drainage systems have several benefits which include:

- Slow down surface water run-off from the site to help reduce the chances of flooding
- Reduce the risk of sewer flooding during heavy rain
- Recharge ground water to help prevent drought
- Provide valuable habitats for wildlife for built up areas
- Create green spaces for people in urban areas
- Help reduce surface water drainage charges

Sustainable Urban Drainage Systems (SUDS) are the most appropriate current solutions but SUDS can only be implemented with good policies, supportive stakeholder groups and partnerships so that these new ideas, which cut across existing methods and practices, can be accepted. The New Urban Agenda (NUA) adopted at the HABITAT-III Conference in Quito last October is also supportive to address these challenges.

Sustainable Urban Drainage Systems require several changes in thinking and practice in city planning. There are many barriers to progress including the perceived costs added to development, the increased maintenance activities required, the attractiveness of big infrastructure projects to politicians whereas drainage projects are very often just 'normal work'. The inertia of planning systems also tends to discourage the good new ideas involved. However, the perceived additional costs need to be set against the costs of losing habitats and the fish, food and other ecosystem services which follow, and the damage to properties and danger to people caused by flooding which frequently results from development. The barriers to more sustainable drainage are high but a whole portfolio of potential 'Green' infrastructure solutions are available to be applied in any city in the world. There are no particular problems for high cost, high value developments since the additional costs of drainage are small and green space is normally an integral element.

However, for most urban developments where money is tight, drainage solutions on a development site are likely to be hard concrete with no financial allocation for maintenance. Consequently, to achieve more widespread use of sustainable drainage principles, greater integration into Green Infrastructure is necessary, and multiple benefits need to be clear. Otherwise the whole life costs will not be properly recognised. Major developments and redevelopments give the opportunity for the reallocation of open space to improve its use through multiple functions. Sustainable drainage has the potential to provide habitat improvements which provide places for breeding, give connectivity between SUDS and with natural areas, and, link directly to zones of natural habitats thus providing more sustainable solutions and greener solutions to drainage problems.

Sustainable Urban Drainage Systems (SUDS) in cities and towns are required as part of local development. Use of SUDS contributes towards the city governments' aim of seeking to achieve sustainable development. SUDS are physical structures built to receive surface water run-off and provide a drainage system that:

- Deals with run off as close to source as possible
- Seeks to mimic natural drainage
- Minimises pollution and flood risk resulting from new development; and
- Provides an alternative to conventional drainage systems.

Traditional systems move rainwater as rapidly as possible from where it falls to a point of discharge e.g. watercourse. This causes a number of problems;

- Increased flooding
- Poor water quality as run off can contain a variety of pollutants
- Less infiltration to ground leading to poor groundwater recharge
- Poor biodiversity and amenity of urban watercourse, many of which are hidden underground;

(i) Therefore, using SUDS is most important for sustainable development. All developments must carefully consider appropriate sustainable surface water drainage options. Careful design of drainage systems and/or the provision of treatment facilities prior to discharge will assist in reducing the environmental impact of new development. These range of techniques are known as SUDS. They can be successfully applied to most development and can even be fitted to existing development. As stated above, there are considerable environmental and economic benefits of incorporating SUDS techniques in local development. These include:

(i) Reduced cost by not constructing expensive underground structures
(ii) Reduced cost from simpler maintenance
(iii) Increased amenity and education value
(iv) Improved visual and environmental quality of development and therefore increased economic value
(v) Increased biodiversity
(vi) Reduced pollution
(vii) Recharging of groundwater
(viii) Reduced flood risk

SUDS can be applied to large or small developments due to the variety of techniques available. Use of SUDS on a series of smaller sites can have a significant cumulative effect on minimising harm to water quality and flood risk in an area.

The impact of development on surface water flow and the fact that its disposal is a material planning consideration needs to be acknowledged. All built development tends to extend the area of impermeable ground, from which water runs off rather than percolating into the ground. This can increase both the total and the peak flow from built-up areas, resulting in increased flows downstream and thus increasing the risk of flooding.

There has been growing interest in the use of "soft" sustainable drainage systems to mimic natural drainage. As well as reducing total and peak flows of run-off, these systems can contribute substantially to good design in improving the amenity and wildlife interest of developments, as well as encouraging natural groundwater recharge.

Development should be satisfactorily serviced in terms of water supply, drainage, sewerage, energy supplies. Development which would pose unacceptable risks to the quality and quantity of the water environment both groundwater and surface water, should not be permitted unless suitable mitigation measures are taken to reduce the risk to an acceptable level. Developments which will generate additional foul, combined and/or surface water drainage should only be permitted where arrangements are made for their satisfactory disposal. Positive surface water drainage systems separate from foul drainage systems are required for new development unless it is demonstrated that soak away disposal will be satisfactory under all seasonable conditions.

Cliff stability

The objective of using SUDS is to secure and promote new development. However, there may be areas in close proximity to the cliff top where the use of SUDS may not be appropriate. In such situations, cliff stability must be maintained and it will be more appropriate to use the local piped drainage system to dispose of surface water for new development. The cliff top locations do not preclude the use of measures to recycle water or reduce runoff at source e.g. use of water butts and green roofs (roofs incorporating vegetation).

Policies need to be framed so that proposals for development or redevelopment within certain areas (say 200/500 meters) of cliffs and chines, or in proximity to steep embankments, will incorporate the measures necessary to demonstrate that such development will have no adverse effect upon existing cliffs, chines or steep embankments. Proposals for major developments in these areas may be required to submit a development impact assessment to show the proposal will have no adverse effect on land stability. Developers also need to be advised that they will be required to comply with the requirements of Planning Policy

Nearly one-half of cities are in locations susceptible to flooding. Assessment of the 136 largest world coastal cities, predicts costs resulting from flood events triggered by climate change may exceed USD1 trillion a year.

Building Regulations

Incorporation of SUDS should be reinforced as part of the development process by changes to Building Regulations. Such regulations may stipulate that, in order of priority, rainwater run-off should discharge into one of the following:

a) an adequate soakaway or some other adequate infiltration system; or where that is not reasonably practicable;
b) a watercourse; or where that is not reasonably practicable;
c) a sewer

Methods of Sustainable Urban Drainage Systems

Permeable surfaces and filter drains

Filter drains and permeable surfaces are devices that have a volume of permeable material below ground to store surface water. Run-off flows to this storage area via a permeable surface. Examples of this are: grass, reinforced grass; gravelled areas, solid paving blocks with large vertical holes filled with soil or gravel, solid paving blocks with gaps between the individual units, porous paving blocks with a system of void within the units, continuous surfaces with inbuilt system of cavities. Car park drainage does not have to go to sewer. Infiltration is where surface water is directed via cavities within areas of solid paving. With a porous surface, water is drained directly through the surface.

Permeable surfacing encourages surface water to permeate into the ground. Materials such as porous concrete blocks, crushed stone/gravel or porous asphalt can be used. Depending on the ground conditions, the water may infiltrate directly into the subsoil, or be stored in an underground reservoir (e.g. a crushed stone layer) before slowly soaking into the ground. If necessary, an overflow can keep the pavement free of water in all conditions. Pollutant removal occurs either within the surfacing material itself, or by the filtering action of the reservoir or subsoil.

Infiltration Devices

Infiltration devices drain water directly into the ground. They may be used at source or the run-off can be conveyed in a pipe or swale to the infiltration area. They include soakaways, infiltration trenches and infiltration basins as well as swales, filter drains and ponds. Infiltration devices can be integrated into and form part of landscaped areas. Soakaways and infiltration trenches are completely below ground, so water should not appear on the surface. Infiltration basins and swales for infiltration store water on the ground surface, but are dry except in periods of heavy rainfall.

- **Soakaway** is an underground chamber lined with a porous membrane and used to store surface water, and then allow its gradual infiltration into the surrounding soil. Although soakaways have been traditionally used in more remote locations away from public sewers or where sewers have reached capacity, they may be used as an alternative to connection to the piped system. They are used to dispose of storm water and are typically circular pits with a honeycomb arrangement of bricks to allow water to permeate through them into the ground.
- Gravel drive is an example of permeable surfacing encouraging surface water to permeate into the ground.

- Swales and Basins are dry channels or ditches and basins are dry "ponds". Both can vary in size. They can be created as features within the landscaped areas of the site, or they can be incorporated into ornamental, amenity and screen planted areas where they would be maintained as part of a normal maintenance contract. They provide temporary storage for storm water, reduce peak flows to receiving waters, facilitate the filtration of pollutants and microbial decomposition as well as facilitating water infiltration directly into the ground. Swales and basins are often installed as part of a drainage network connecting to a pond or wetland prior to discharge to a natural watercourse. They may be installed alongside roads to replace conventional kerbs, therefore saving construction and maintenance costs.
- Infiltration trenches and filter drains: Infiltration trenches are stone filled reservoirs to which stormwater runoff is diverted and from which the water gradually infiltrates into the ground. Filter strips, gullies or sump pits can be incorporated at inflow points to remove excess solids. This lengthens the life of the trench.
- Filter Strips: An area of gentle sloping, vegetated land through which surface water run-off is directed. Filter drains are similar to infiltration trenches but have a perforated pipe running through them. They are widely used by highway authorities for draining roads and help to slow down runoff water on route towards the receiving watercourse. They allow storage, filtering and filtration of water before the discharge point. Pollutant removal is by absorption, filtering and microbial decomposition in the surrounding soil.

Basins and Ponds - how they work

Basins are areas for storage of surface run-off that are free from water during dry weather conditions. These structures include: flood plains, detention basins, extended detention basins, Ponds contain water in dry weather and are designed to hold more when it rains. They include:

- Balancing and attenuation ponds
- Flood storage reservoirs
- Lagoons
- Retention ponds
- Wetlands

Basins and ponds store water at the ground surface, either as temporary flooding of dry basins and flood plains, or permanent ponds. These structures can be designed to manage water quantity and quality.

Ponds and Wetlands can be particularly beneficial during time of storm due to their capacity to hold large amounts of water and therefore reduce flood risk. They are most widely used on larger sites. Ponds and wetlands also help with grit removal. Algae and plants in wetlands can significantly assist with filtering and nutrient removal. The ponds and wetlands can be fed by swales, filter drains or piped systems. Use of inlet/outlet sumps assist in reducing sedimentation and reeds planted at these points will cleanse water as it enters and leaves the pond.

Choosing the right SUDS

Of the various methods, large ponds and wetlands are generally more appropriate for larger sites in excess of 5ha. Infiltration trenches, swales and porous pavements are suitable for both large and small sites. Many large sites may incorporate a mix of different mechanisms.

The choice of SUDS depends on a number of factors:

- The pollutants present in runoff (in part dependent on type of development)
- The size of and drainage strategy for the catchment area
- The hydrology of the area and infiltration rate of the soil

Large sites may incorporate a mix of different techniques. SUDS can be incorporated into areas where there is clay subsoil or there is a fairly steep gradient. Soil permeability can have a significant effect on the selection of SUDS techniques. Infiltration techniques for example may not be effective if the infiltration rate is below 10mm/hr for the upper soil layers. Swales and ponds, working by a combination of filtration and infiltration, are more tolerant of poor soils. In highly permeable soils wet ponds need to be lined.

SUDS and Planning

It is important that developers establish the soil conditions and hydrology of the site (storm water run-off, water table height, water quality) and consider appropriate SUDS at an early stage in the site evaluation and design process. This will ensure that the best drainage solution for a particular site is found and incorporated into the layout, development costs and timetable for implementation. SUDS should be incorporated into the detailed project reports (DPRs) of development proposals with detailed design. The adoption and future maintenance of SUDS should also be incorporated at the design stage.

It would be appropriate to link SUDS on new development sites to existing green space and amenity areas. Planning conditions or legal agreements should be used to secure implementation of SUDS where appropriate.

New Urban Agenda (NUA)

At the Habitat-III Conference in Quito in October 2016, New Urban Agenda (NUA) was adopted which aims at enhancing effective urban planning and management, efficiency, and transparency through e-governance, information and communications technologies assisted approaches, and geospatial information management. Further, New Urban Agenda underscores the need to promote adequate investments in accessible and sustainable infrastructure and service provision systems for water, hygiene and sanitation, sewage, solid waste management, urban drainage, reduction of air pollution, and storm water management, in order to improve health and ensure universal and equitable access to safe and affordable drinking water for all; as well as access to adequate and equitable sanitation and hygiene for all; and end open defecation, with special attention to the needs and safety of women and girls and those in vulnerable situations. NUA seeks to ensure that this infrastructure is climate resilient and forms part of integrated urban and territorial development plans, including housing and mobility, among others, and is implemented in a participatory manner, considering innovative, resource efficient, accessible, context specific, and culturally-sensitive sustainable solutions.

NUA also recognizes that urban centers worldwide, especially in developing countries, often have characteristics that make them and their inhabitants especially vulnerable to the adverse impacts of climate change and other natural and man-made hazards, including extreme weather events such as flooding, subsidence, storms, including dust and sand storms, heat waves, water scarcity, droughts, water and air pollution, vector borne diseases, and sea level rise particularly affecting coastal areas, delta regions, and small island developing States, among others.

NUA also commits to promote the creation and maintenance of well-connected and well-distributed networks of open, multi-purpose, safe, inclusive, accessible, green, and quality public spaces to improve the resilience of cities to disasters and climate change, reducing flood and drought risks and heat waves, and improving food security and nutrition, physical and mental health, household and ambient air quality, reducing noise, and promoting attractive and livable cities and human settlements and urban landscapes, prioritizing the conservation of endemic species.

SUDS should be part of local economic development strategies which also coordinate land use, infrastructure and investment planning. Financing and investment planning are also important driving concerns. Coordinated decisions about land use are essential. Urban Local Bodies (ULBs) should identify set of policies that will allow cities and their surrounding regions to reap the benefits of economies of urbanisation and localisation, attract and leverage private investments while minimising risk hazards. New Urban Agenda also underscores the need for urban planning, rules and regulations together with sound financial planning. To be successful, SUDS has to be an integral part of the local and regional urban planning and strong building bye-laws.

Conclusions

Available evidence indicates that in low and middle income countries, urban drainage sector is among few other sectors including sanitation and solid waste management that has made little progress in addressing the need for institutional reform and financial sustainability. New approaches are needed in urban drainage sector in delivering services to the informal settlements.

The whole life costs of the systems of drainage infrastructure can be correlated to the pattern of urbanization, with compact cities providing the most cost-effective solutions to drainage infrastructure investments.

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TRENCHLESS TECHNOLOGY FOR EXECUTION OF DRAINAGE SYSTEM FOR TA PROHM TEMPLE COMPLEX, SIEM REAP, CAMBODIA

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Abstract

Built in 1186 in Siem Reap (Cambodia) and originally known as Rajavihara (Monastery of the King), Ta Prohm was a hindu temple dedicated to the mother of Jayavarman VII. Ta Prohm is a temple of towers, closed courtyards and narrow corridors. Many of the corridors are impassable, clogged with jumbled piles of delicately carved stone blocks dislodged by the roots of long-decayed trees. Bas-reliefs on bulging walls are carpeted with lichen, moss and creeping plants, and shrubs sprout from the roofs of monumental porches. Trees, hundreds of years old, tower overhead, their leaves filtering the sunlight and casting a greenish pall over the whole scene.

The temple has deliberately been left in a state of un-repair; for the tourist to experience "the harmony between man and nature". The decay of the structure partly due to the entwining forestation and partly due to its frequent inundation by rains has resulted in deterioration of many of its walls, floors and the roof.

The whole of the Angkor heritage area had been under study and research for a long time, particularly with regard to the problem of water management and preservation of heritage and its environment. These problem were urgent and unusual mainly because of its essential characteristics of harmony between nature with man had to be retained.

During the rainy season, the water level in the moat closer to the North Eastern side, is higher by about 1 m, than the level in the other moat. Also the rain-water accumulated within the temple complex doesn't get drained and remains standing for 3 to 4 days. The temple complex experiences standing water up to 1m and at times up to floor level within most of the structures which affects tourism during the monsoon season.

To solve the problem of water logging in the enclosures of the temple, the Archaeological Survey of India (ASI) entrusted WAPCOS Ltd., a Government of India Undertaking under the Ministry of Water Resources, River Development and Ganga Rejuvenation to prepare and execute a drainage plan. Due to the fact that the Temple complex is a world heritage site, it was a difficult task to implement the drainage system in an open form. Therefore, a Trenchless method was used to prepare an underground drainage system.

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For the preparation of the Implementation plan, Ground Penetration Radar (GPR) survey was carried out in the Temple complex to determine the actual location, depth and spreading of the tree roots. The laying of pipe lines was decided to be carried out at a lower depth than that of the tree roots to avoid any damage. The findings of the GPR Survey ensured that the Drainage pipe lines could be laid below 2m depths safely without harming the Tree roots.

The execution of the drainage system started in March, 2014 and was completed in March 2015. The drainage system comprises 16 main lines, connecting sinks to chambers and chambers to the Inner Moat, laid by using Trenchless Technology. The Drainage System also envisages 8 mainlines from the Inner Moat to the Outer Moat. The complete network comprises 25 Sinks, 11 Sink cum collection chambers and 1 chamber located in Enclosures II & III.

This drainage system, a unique in its own kind, the first ever implemented at Angkor World Heritage Area and successfully completed within the scheduled time frame. During the execution Year 2014-2015 the work was inspected twice by the Experts of ICC- ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). The experts of ICC-ANGKOR from France, Japan and Kingdom of Cambodia appreciated the technology adopted by WAPCOS and the way it has been implemented on site. The work was also visited by Higher Dignitaries of Royal Government of Cambodia and India and other prominent persons from India and has been well appreciated.

KEY WORDS: Entwining forestation, Water logging, Ground penetration radar (gpr), Cambodia

Introduction

Siem Reap, which literally means the "Defeat of Siam", referring to the victory of the Khmer Empire over the army of the Thai Kingdom in the 17th century was the most prosperous region of contemporary Cambodia. Its close proximity to the Angkor Wat Temple Complex (Figure 1) has turned the city into one of the world's premier tourist destinations. More than two million tourists visit Siem Reap every year to explore over a thousand years of Khmer heritage built near Tonle Sap Lake.

Figure 1: Angkor Wat, Siem Reap, Cambodia

The primary attraction for visitors to Siem Reap is the Angkor Wat Temple Complex, a UN Heritage Site which has hundreds of structures from the 9th to the 14th century which include partially renovated temples, pagodas, imperial residences and recently discovered ruins which are virtually untouched for the last 500 years.

Siem Reap also has the 12th Century Ta Prohm Temple (Figure 2) which has numerous towers, closed courtyards and narrow corridors. Many of the corridors are impassable, clogged with jumbled piles of delicately carved stone blocks dislodged by the roots of long-decayed trees.

Figure 2: Ta Prohm Temple, Siem Reap

Drainage problem in temple complex

The temple has deliberately been left in a state of un-repair for the tourist to experience "the harmony between man and nature". The decay of the structure is partly due to the entwining forestation and partly due to its frequent inundation during rains.

The tree roots have found their way through spaces between blocks of sandstone and laterite thereby causing instability to various parts of the temple structure in general but have also supported them at places. The dislodged stones are strewn all around, thereby blocking not only the passage but also the drainage path of water into the tanks and moats.

The original layout of the temple and the drainage system was not traceable because of collapsed structure, growth of trees and their root system. The whole of the Angkor heritage area had been under study and research for a long time, particularly with regard to the problem of long periods of flooding during rains and preservation of heritage and its environment. These problems were unusual and challenging mainly because the essential characteristics of the temple complex and its harmony with nature that had to be retained. The only viable solution was to construct a sub-surface drainage system without in any way disturbing the foundation of structures and the complex network of roots.

Drainage Scenario in Ta Prohm Temple Complex- Before implementation of Drainage Plan

During the rainy season, the rain-water falling within the temple complex did not get drained and kept standing for 3 to 4 days (Figure 3). The temple complex experienced inundation up to 1m and at times up to floor level of the structures, which adversely affected the tourism during the monsoon season.

Figure 3: Water Stagnation between Third & Second enclosure

Drainage implementation plan

i) Challenges in Preparation of Drainage System

In order to address the problem of water logging in the temple complex, the Archaeological Survey of India (ASI) entrusted WAPCOS Ltd., a Government of India Undertaking under the Ministry of Water Resource, River Development and Ganga Rejuvenation the assignment to prepare and execute a drainage implementation plan. Following were the Challenges in the planning and implementation of the drainage system:

- **No collateral damage to any structure,** however dilapidated and unstable, was acceptable at any stage of the project. Even the collapsed parts of structure, strewn all over the place were not to be disturbed or relocated. Utmost care was to be taken not to damage any part of the root network (Figure 4) proving support to the structure above. This required extensive and precise sub-surface mapping with non-invasive state-of-the-art techniques.

Figure 4: Roots of long-decayed trees

- **Conservation of World Heritage Site:** The temple being a renowned world heritage site, any major or minor construction activity requires proper care and supervision as per safety norms of ICC-ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). This organization also monitors the restoration activities of all the Historical Temples in the Angkor world heritage area.
- **Small Passages and Narrow Gates of Temple:** The narrow passage inside the temple prevented entry and movement of large sized machines/drilling rigs. Due to narrow gates/doors in most of the Enclosure in locations II & III, the machines/equipment/drilling rigs had to be moved in dismantled condition and reassembled. Drilling techniques and

placement of pipes were suitably improvised without compromising on ICC-ANGKOR norms and planned objectives.

ii) Surveys/Studies/Technology involved in Planning of Drainage System

For the preparation of Implementation plan, Ground Penetration Radar (GPR) survey was carried out in the Temple complex to determine the actual location, depth and spreading of the tree roots. The laying of pipe lines was decided at depth lower than those of the tree roots to avoid any damage. GPR surveys were conducted by moving the antennae along the planned drainage lines on the ground (Figure 5). These survey lines were selected in such a way that the entire area was represented. Through the GPR survey, it was recorded that 98% of the tree roots were located within a depth of 1m from the ground surface. No roots deeper than 2m were found. The findings of GPR Survey ensured that the Drainage pipe lines could be laid below 2m depths safely without harming the tree roots. The Geotechnical studies were also done to access the soil profile. Trial Pits (1mx1mx1m) results were used for confirmation of the soil strata. The analysis revealed that the strata essentially constituted silty sand at the surface with a layer of silty sand clay beyond 1.6m to 2m from the ground level. No hard strata were available at a shallow depth and the surface soil did not have any swelling character. The pipe line slope and depth were planned to avoid any damage to foundation and tree roots.

Figure 5: GPR Survey in the Temple Complex

Detailed Topographical survey and hydrological studies were carried out for planning and design of alignment of drainage lines and size and slope of drainage pipes.

iii) Trenchless Technology for Execution of Drainage Implementation Plan:

Drainage lines were so selected that there would be minimum interference with the critical areas of the Temple walls and Gopuras. Trenchless Technology using the Horizontal Auger Boring (HAB) method was adopted for implementation of sub-surface drainage system.

Trenchless technology is a type of subsurface construction work that requires few trenches or no continuous trenches (Figure 6). Trenchless construction includes construction methods such as Tunneling, Micro-tunneling Method (MTM), Horizontal Directional Drilling (HDD), Pipe Ramming (PR), Pipe Jacking (PJ), Horizontal Auger Boring (HAB) and other methods for the installation of pipelines and cables below the ground with minimal excavation.

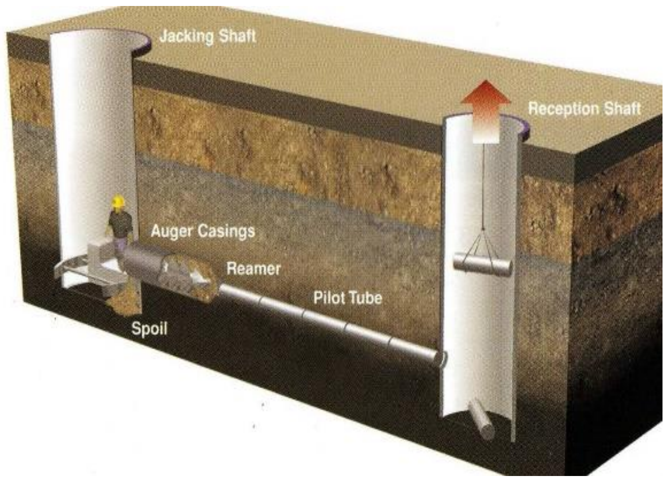

Figure 6: Trenchless Technology for Execution of Drainage

Following are some of the Trenchless techniques for different soil types.

Method	Soil Type	Remarks
Pipe Jacking	All soil types	Exception of non-displaceable hard soil and rock
Micro tunnelling (MTM)	All soil types	Very fast and reliable system
Impact Moling	Soft clays and silts	Minimum disruption
Auger Boring	Soils with sufficient stand-up time	Suitable for shallower depths
Thrust Boring	All soil types	No limitation, As to what can be achieved

Since the entire sub-surface drainage network was within 3 to 5 m below ground level, Horizontal Auger Boring Machines were used.

Execution of drainage system

The execution of drainage system started in March, 2014 and was completed in March, 2015.
The drainage system (Figure 7) comprised of 16 main lines, connecting links from chambers and from chambers to Inner Moat, laid by Trenchless Technology. The Drainage System also included 8 mainlines from Inner Moat to Outer Moat. The complete network comprised of 25 Sinks, 11 Sink cum collection chambers and 1 chamber.

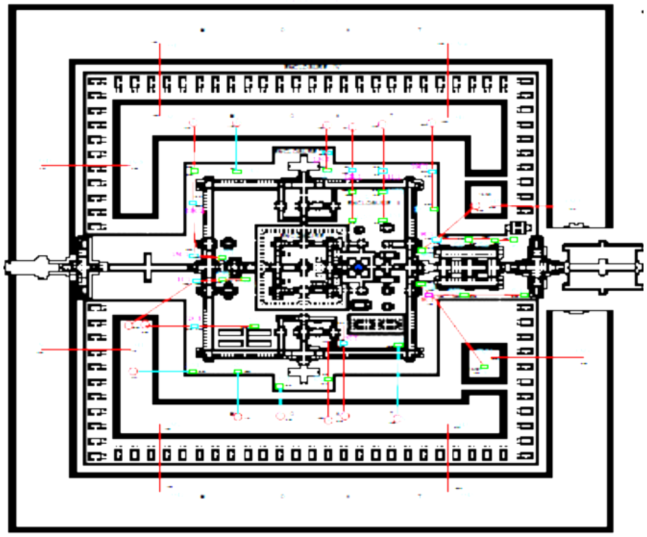

Figure 7: Drainage Plan

The Drainage Plan consisted of following main components:

- **Construction of Sinks:** Sinks were provided at the selected low-lying areas inside the temple enclosures. These were designed to collect the surface water and feed it to the network of pipes. Geo-textile filters were fixed on the top of sink, to trap silt from the surface runoff. Mechanism for periodical removal of silt has been suggested. The depths of sinks have been planned in a way to avoid damage to the tree's roots and foundation of structures. Pit for sinks were excavated for 2mx2m size. The sinks were modified into a size of 600mm x 600mm from 300mm x 300mm size to facilitate the machine to drill in the ground.

Figure 8: Fixation and Monitoring of Pipeline Levels

- **Construction of Chambers:** Collection chambers provided in Enclosures were connected to the sinks by 300 mm MS Pipes. These chambers are designed to collect the water from sink through the pipelines and also from the ground surfaces and finally drain it out into the inner moats. Pit for chambers were excavated for 2mx2m size. The chambers were modified into sink cum collection chamber by provision of silt trap. This helped to drain out the water of surrounding area of Chamber.

- **Pipe line Installation by Trenchless Technology:** A total of 1050.60m of MS pipe network was laid below the ground to drain off the Storm Water. Inner moat and outer moat were connected with 300 mm dia. MS pipes. One HAB machine was brought from India for work execution inside the temple and HDD machine was used for the Moat connections. Pipes were used in 800 mm segments and pushed into the drilled hole by HAB machine. These M.S. pipes were coated with epoxy on their outer surface and plastic paint on inner surfaces to prevent corrosion. The alignment of lines beneath the Ground Surface was fixed by Total Station, and continuous monitoring was done to ensure maintenance of levels (Figure 8).

- **Construction sequence for Trenchless Process (Figure 9)**
  The laying of drainage lines was completed in following steps:
  1. Excavation of pit
  2. Placement of HAB Machine into the pit up to required level
  3. Pilot bore drilling at a required level
  4. Removal of soil with Helical Shaped Augers (enlargement of Hole)
  5. Pipe Insertion into the drilled hole by machine
  6. Construction of Sink and Chambers
  7. Installation of Silt Traps and Covers

(Figure 9: Construction Workflow)

- **Instrumentation for Monitoring and Control of Drilling**
  Following instruments were used and installed to monitor & control the drilling and behavior of surrounding structures during the work execution:
  - **Directional Probe and Magnetic Field Locator with monitor**: This device was used to control the movement of the pilot inside the ground (Figure 10). The device can sense changes

in soil profile and even a small stone and suitably change the direction and slope of the pilot tool. With the help of the locator, the errors in desired slope and depth were minimized and kept within permissible limits.

- **Ground Settlement Points**: Ground settlement point were used for monitoring of vertical settlement on the surface and soil mass.
- **Building Settlement Points:** Building settlement points were used to monitor the vertical settlement of structure due to nearby excavation & activities.
- **Crack Marker:** Crack markers were used to monitor the crack in vertical wall or structure due to excavation and pipe laying operations. To avoid nailing on the temple walls, sticker type crack marker was used.
- **Testing**: During execution of drainage system, random water testing of pipe lines was carried out to ensure tightness of pipe joints. Concrete cubes were also cast for each sink and chamber and got tested in recognized labs in Siem Reap.

Figure 10: Detection of Drilling tool path by Directional Probe & Magnetic Field Locator

Project completion and recognition by clients

This drainage system, a unique in its own kind was the first to be ever implemented successfully in Angkor World Heritage Area. The project was completed within the scheduled time frame. During the execution Year 2014-2015 the work was inspected twice by the Experts of ICC-ANGKOR (International Coordinating Committee for the Safeguarding and Development of the Historic Site of Angkor). The experts of ICC-ANGKOR from France, Japan and Kingdom of Cambodia appreciated the technology adopted by WAPCOS and the way it has been implemented. The work was also visited by Higher Dignitaries of Royal Government of Cambodia and India and various Experts from India and was well appreciated (Figure 11).

Figure 11: Temple Site Visit by High level Dignitaries of the Government of India, ICC-Angkor and other prominent personalities from India

References

Drainage Implementation Plan (2008), Ta Prohm Temple Complex, Siem Reap Cambodia by WAPCOS Limited

Project Completion Report (2015), Ta Prohm Temple Complex, Siem Reap Cambodia by WAPCOS Limited

Ta Prohm Temple- A Conservation Strategy by Archaeological Survey of India

APPLICATION OF HYDRUS-2D FOR PREDICTING THE INFLUENCE OF SUBSURFACE DRAINAGE ON SOIL WATER DYNAMICS IN A RAINFED-CANOLA CROPPING SYSTEM

Fatemeh Karandish[1,*], Abdullah Darzi-Naftchali[2], Jiří Šimůnek[3]

Abstract

Although subsurface drainage systems in paddy fields provide a suitable condition for winter cropping by combatting the waterlogging and ponding problems, they may alter the natural soil water dynamics. The cost and time involved in frequent field observations pertaining to quantification of such alterations lead to the use of simulation models, which are more plausible approaches. Therefore, in this research, the HYDRUS-2D model was applied to investigate the probable effects of different subsurface drainage systems on the soil water dynamics under rainfed-canola cropping system in paddy fields. Field experiments were conducted during two rainfed-canola growing seasons at the subsurface- drained paddy fields of the Sari Agricultural Sciences and Natural Resources University, Mazandaran province, northern Iran. A drainage pilot consisting subsurface drainage with different drain depths and spacings was designed. Canola was cultivated as the second crop after rice harvest. Measurements of water table depth and drain discharge were made during the growing seasons. The performance of HYDRUS2D model during calibration and validation phases was evaluated using the model efficiency (EF), root mean square error (RMSE), normalized root mean square error (NRMSE), and mean bios error (MBE) measures. Based on the criteria indices (MBE=0.01-0.17 cm, RMSE=0.05-1.02 and EF=0.84-0.96 for drainage fluxes, and MBE=0.01-0.63, RMSE=0.34-5.54 and EF=0.89-0.99 for water table depths), the model was capable enough for predicting drainage fluxes as well as the other soil water balance components. The simulation results demonstrated that water table management can be an effective strategy to sustain shallow aquifers in the subsurface- drained paddy fields during winter cropping.

KEY WORDS: HYDRUS-2D, Drainage flux, Dynamic simulation, Paddy field, Water table.

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Introduction

Subsurface drainage in poorly drained paddy fields of the Northern Iran provides suitable conditions for growing winter crops, mainly by improving soil conditions by lowering the water table below the rooting zone, creating a deeper aerobic zone, enabling faster soil drying, and improving the root zone soil conditions (Jafari-Talukolaee et al., 2016). Improved crop productivity may readily justify the installation costs of subsurface drainage systems and provide suitable conditions for the adaptation of such technology by local farmers. Although subsurface drainage provides suitable conditions for winter cropping by combating the waterlogging problem, it also alters the soil water dynamics. Therefore, further research is required to analyze such effects under different drainage systems.

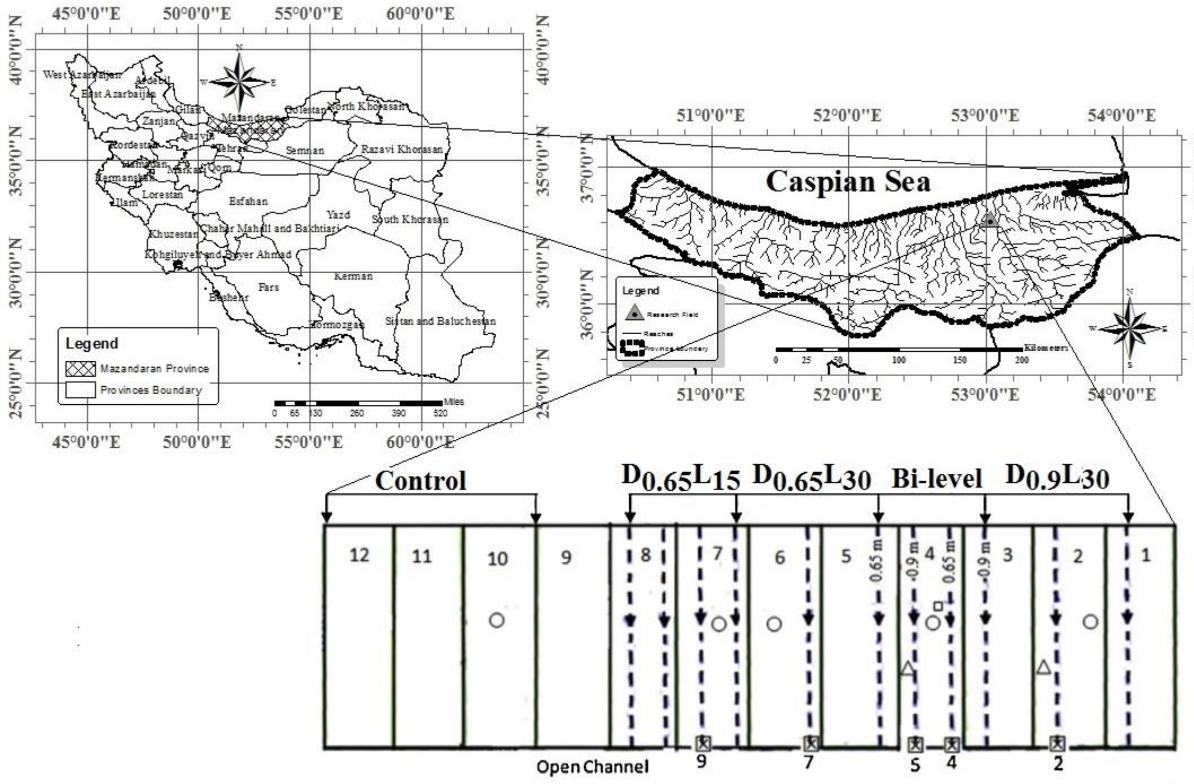
Field investigations for assessing long-term consequences of different subsurface drainage systems are usually restricted by high costs. However, some general knowledge is required in the planning and optimizing stages of drainage projects prior to their implementation at the large scale. Simulation models, which are effective tools for capturing soil-water-crop interactions, have been developed during the past decades (Wagenet and Hutson, 1987; Wessolek, 1989; Vanclooster et al., 1996; van Dam et al., 1997; Fernández et al., 2002; Cameira et al., 2003; Panigrahi and Panda, 2003; Neitsch et al., 2005; Nishat et al., 2007). Among different models, HYDRUS-2D (Šimůnek et al., 2008, 2016) is one of the most widely-used dynamic, physically-based models to simulate soil water dynamics (e.g., Cote et al., 2003; Skaggs et al., 2004; Ajdari et al., 2007; Rahil et al., 2007; Crevoisier., 2008; Lazarovitch et al., 2009; Siyal and Skaggs, 2009; Mubarak et al., 2009; Ramos et al., 2012; Tafteh and Sepaskhah, 2012, Karandish and Šimůnek, 2016ab). One of the advantages of this model is that its input parameters are closely related to soil physical properties, which could be measured either in-situ or in the lab (Karandish and Šimůnek, 2016b). Moreover, since the input parameters of HYDRUS-2D are directly related to soil, crop, and climate properties, the model often provides superior predictions than simpler soil water balance models.

Several earlier studies applied HYDRUS-2D for predicting soil-water-crop interactions in the paddy fields (Janssen and Lennartz, 2009; Garg et al., 2009; Tan et al., 2014; Li et al., 2014 and 2015). The results of these studies generally emphasized the high capability of this model to simulate water and nutrient fluxes at the field scale. However, no research has been yet conducted on the applicability of the HYDRUS-2D model to analyze the effects of drainage systems on soil water dynamics during winter cropping in poorly drained paddy fields. Therefore, this research was designed to evaluate the capability of the HYDRUS-2D model to predict daily fluctuations of drainage fluxes and water table depths during second cropping on subsurface-drained paddy fields.

Materials and methods

Field trial

A field study was conducted during two rainfed canola growing seasons (2011-12 and 2015-16) at the 4.5 ha consolidated paddy field at the Sari Agricultural Sciences and Natural Resources University in the Mazandaran province of northern Iran (Figure 1). The area is located in the coastal zone of the eastern part of the Caspian Sea. The climate of the region is alternatively influenced by cold Arctic air, humid temperate air from the Atlantic Ocean, dry and cold air associated with Siberian high pressure zones, and Mediterranean warm air. The soil on the site is silty clay and clay to a depth of 300 cm. The saturated hydraulic conductivities of different layers of the soil profile are very low.



(1 to 12 plot no, ○ :location of observation wells and open end Lysimeters for measuring evaporation+deep percolation (E-DP), Δ :location of closed end Lysimeters for measuring evaporation (E), □ :location of open end Lysimeter for measuring evapotranspiration (ET), – ➔ –: subsurface drain lines and ⊠ :points of drain flow measurements).

Figure 1. Location of the study area in the Mazandaran province (top right) of Iran (top left) and the layout of the drainage systems (bottom).

Eleven PVC corrugated drain pipes (100 m long, with an outside diameter of 100 mm) were installed at the study site in June-July of 2011 at depths of 0.65 and 0.9 m and spacings of 15 and

30 m. Four different subsurface drainage systems were analyzed by installing drains at different depths (D_x, where subscript x indicates a drain depth in meters) and spacings (L_y, where subscript y indicates a drain spacing in meters): $D_{0.9}L_{30}$, $D_{0.65}L_{30}$, and $D_{0.65}L_{15}$. The last drainage system, denoted as *Bilevel,* has a drain spacing of 15 m and alternate drain depths of 0.65 and 0.9 m. Further details about the experimental design can be found in Darzi-Naftchali et al. (2013). Figure 1 shows the location of the research field in the country and the layout of the drainage systems in the research field.

Before crop cultivation, soil samples were taken from each treatment plot every 30 cm to a depth of 200 cm. Soil physical and chemical properties were determined on these soil samples. Soil water contents at 14 different pressure heads (from 0 to 16 bars) were measured in the laboratory using a pressure plate apparatus. The van Genuchten-Mualem model (van Genuchten 1980) was then fitted to the observed retention curves using the RETC model. Crops were then sown at November 28, 2011 and October 3, 2015. All agricultural operations followed the conventional practices of the local growers in the study area. Daily measurements of water table depths were manually made in the observation wells that were dug midway between drains. Moreover, drainage discharge was measured daily in all treatments. Drains were only plugged during the last one month of the growing seasons before the harvest. Crops were harvested on May 8, 2012 and May 3, 2016.

Simulation approach

HYDRUS (2D/3D) (Šimůnek et al., 2008) is a powerful software for simulating transient, two- or three-dimensional movement of water and nutrients in soils for a wide range of boundary conditions, irregular boundaries, and soil heterogeneities. Water flow in soils is described using the Richards equation as follows:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) - \frac{\partial k}{\partial z} - WU(h, x, z) \tag{3}$$

where θ is the volumetric soil water content (SWC) [L^3L^{-3}], K is the unsaturated hydraulic conductivity [LT^{-1}], h is the soil water pressure head [L], x is the lateral coordinate [L], z is the vertical coordinate (positive downwards), t is time [T], and $WU(h, r, z)$ denotes root water uptake [T^{-1}].

The van Genuchten-Mualem constitutive relationships (van Genuchten 1980) were applied for modeling soil hydraulic properties. A rectangle 200 cm deep (since the impermeable layer was at the 200 cm soil depth) and either 30 m wide for the $D_{0.9}L_{30}$ and $D_{0.65}L_{30}$ drainage systems or 15 m wide for the $D_{0.65}L_{15}$ and *Bilevel* drainage systems was defined as a two-dimensional transport domain in the model. The transport domain was discretized using unstructured, triangular, finite element mesh (FEM). A non-uniform FEM was generated by HYDRUS-2D with finite element sizes gradually increasing with distance from the drains. Six soil horizons with different soil hydraulic properties were defined for the 0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm, 120-150 cm, and 150-200 cm soil depths (Table 1). An additional soil layer was considered to represent the backfilled drain trench (gravel), with a higher hydraulic conductivity above and around drains. Measured. The measured pressure head distribution was applied to define the initial conditions for flow simulations. Atmospheric boundary condition was applied at the top of the transport domain. A seepage face boundary condition was used to represent the drains during the drainage periods. All other remaining boundaries were assigned a no-flow boundary condition. Measured temporal variations of water depths (*WD*) and drainage water fluxes (*DF*) during 2011-12 growing season were used for calibrating HYDRUS-2D. The model was then validated using similar data from the 2015-16 growing season.

Results and discussion

Daily measured drainage fluxes (*DF*) as well as water table depths (*WD*) in the 2011-12 growing season were employed to calibrate the HYDRUS-2D model for all treatments. During the calibration process, the saturated hydraulic conductivity (K_s), the residual soil water content (θ_r), and the saturated soil water content (θ_s) were optimized using the inverse analysis of HYDRUS-2D and measured data, while the shape parameters α, l, and n in the van Genuchten-Mualem model (van Genuchten 1980) were kept equal to the values obtained by the RETC model. Finally, the accuracy of HYDRUS-2D was assessed based on the criteria indices including mean bias error (*MBE*), root mean square error (*RMSE*) and model efficiency (*EF*).

Temporal variations of the observed and simulated drainage fluxes (*DF*) for different drainage systems as well as the related scatter plots are displayed in Figure 2 for the calibration period. The correlation coefficients of 0.93-0.96 reveal a good agreement between observed and simulated daily *DF*s for all treatments when the optimized soil hydraulic parameters were used during the calibration period. A higher R^2 (0.96) was obtained for $D_{0.65}L_{15}$ where *DF*s were higher, while $D_{0.9}L_{30}$ with observed *DF*s in the range of 0-2.25 mmd^{-1} had the lowest R^2 (0.93). Figure 2 shows that HYDRUS-2D performed very well in simulating average *DF*s during the growing season of 2011-12. The average observed *DF* for the *Bilevel*, $D_{0.65}L_{15}$, $D_{0.65}L_{30}$, and $D_{0.9}L_{30}$ drainage systems in 2011-12 growing seasons were 1.6, 2.66, 0.69 and 1.37 mm d^{-1}, respectively, while the corresponding simulated values were, 1.61, 2.69, 0.7 and 1.38 mm d^{-1}, respectively. Although HYDRUS-2D is capable of capturing the temporal trends of *DF*s, the model slightly overestimated the peak *DF*s, especially after heavy rainfall events in the $D_{0.65}L_{15}$ treatment.

The performance of the HYDRUS-2D model in simulating *DF*s and *WD*s in terms of *RMSE*, *MBE* and *EF* is summarized in Table 1. For the calibration period, the *RMSE* values characterizing differences between observed and simulated *DF*s were 0.09 mm d^{-1} for the $D_{0.9}L_{30}$ treatment, 0.11 mm d^{-1} for the *Bilevel* treatment, 0.05 mm d^{-1} for $D_{0.65}L_{30}$ treatment, and 0.18 mm d^{-1} for the $D_{0.65}L_{15}$ treatment. Despite of a slight overestimation (*MBE*=0.01-0.02 mm d^{-1}), the *EF* values, ranging from 0.92 to 0.96, indicated that the simulated *DF*s agreed well with the observed values for all treatments during the calibration period. In addition, having *RMSE*=0.37-2.23 cm, *MBE*=-

0.01-0.25 cm, and *EF*=0.96-0.99, the HYDRUS-2D-simulated *WD*s agreed well with the observed values (Table 1). *WD*s were generally overestimated during the 2011-12 growing season for all treatments except for $D_{0.9}L_{30}$, in which *WD*s were overestimated by less than 1%. In general, higher accuracy in estimating *DF*s and *WD*s was obtained for the $D_{0.65}L_{15}$ treatment while the highest error was observed for the $D_{0.65}L_{30}$ treatment during the calibration period (Table 1).

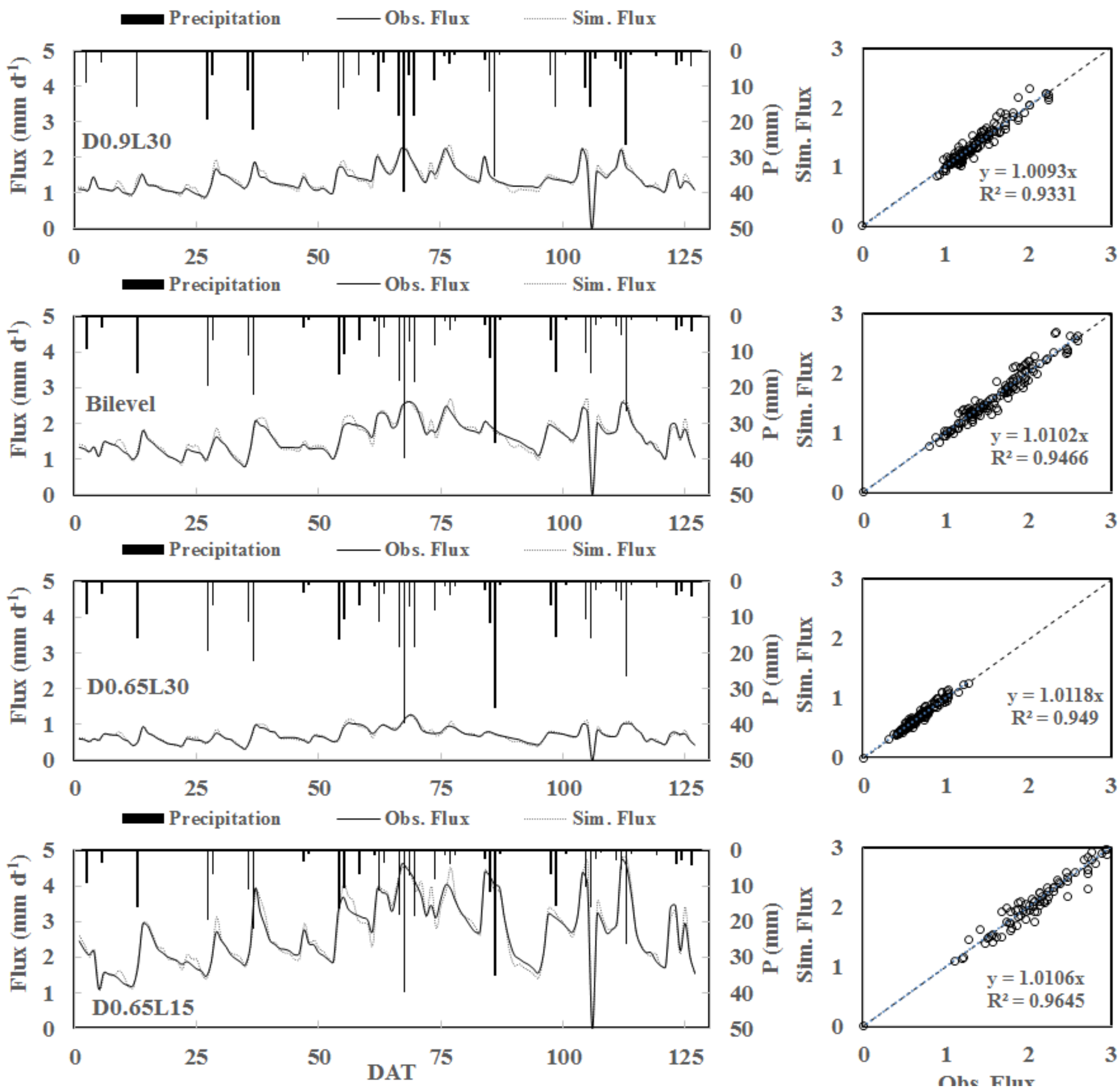


Figure 2. Temporal variations of drain discharges and precipitation (P) during the 2011-2012 growing season (the calibration period) for the four drainage systems.

Table 1. The criteria indices comparing the observed and simulated drain discharges (*DF*) and water table depths (*WD*) during the calibration and validation periods.

Year	Parameter	Criteria Index	Drainage systems			
			$D_{0.9}L_{30}$	*Bilevel*	$D_{0.65}L_{30}$	$D_{0.65}L_{15}$
2011-2012	*DF*	*MBE* (mm d^{-1})	-0.01	-0.01	-0.01	-0.02
		RMSE (mm d^{-1})	0.09	0.11	0.05	0.18
	EF	0.92	0.94	0.94	0.96	
	WD	*MBE* (cm)	-0.01	0.10	0.13	0.25
		RMSE (cm)	0.37	1.30	1.75	2.23
		EF	0.99	0.99	0.98	0.96
2015-2016	*DF*	*MBE* (mm d^{-1})	-0.07	-0.13	-0.06	-0.17
		RMSE (mm d^{-1})	0.46	0.85	0.40	1.02
		EF	0.84	0.84	0.86	0.85
	WD	*MBE* (cm)	-0.16	-0.45	-0.53	-0.63
		RMSE (cm)	1.67	3.96	3.89	4.54
		EF	0.91	0.92	0.96	0.89

The calibrated model was then applied to simulate *DFs* and *WD*s for different treatments during the 2015-16 growing season (the validation period). The agreement between observed and simulated *DF*s and *WD*s was quantitatively assessed using the *RMSE* and *MBE* statistics (Table 1). The model performance criteria for the validation period indicated the strong predictive capability of the model. *EF*, *RMSE*, and *MBE* for *DF*s ranged from 0.84-0.86, 0.4-1.02 mm d^{-1}, and –(0.06-0.17) mm d^{-1}, respectively, across different drainage systems, while for *WD*, the considered indices ranged from 0.89-0.96, 1.67-4.54 cm, and –(0.16-0.63) cm, respectively. Table 1 indicates that overestimation was about 6.4-7.9% for *DF*s and 2.8-3.8% for *WD*s.

The comparison between simulated and measured values of *DFs* with the 1:1 line in Figure 3 also indicated that HYDRUS-2D can be successfully used to predict daily fluctuations of *DF*s for different drainage systems in the 2015-16 growing season. The averages observed *DF* for the *Bilevel*, $D_{0.65}L_{15}$, $D_{0.65}L_{30}$, and $D_{0.9}L_{30}$ drainage systems during the validation period were 1.78, 2.18, 0.87 and 1.1 mm d^{-1}, respectively, while the corresponding simulated values were 1.91, 2.35, 0.94 and 1.1 mm d^{-1}, respectively. In addition, the correlation coefficients varied in the range of 0.91-0.93 across different drainage systems, indicating the strong predictive capability of the model.

Overall, both the visual inspection of the scatter plots and the calculated values of the criteria indices, which compare the observed and HYDRUS-2D-estimated *DF*s and *WD*s during both growing seasons (the calibration period of 2011-2012 and the validation period of 2015-2016), clearly indicate the high potential of the HYDRUS-2D modeling. There was a close match between the observed and simulated data, with acceptable errors in all treatments. This capability makes the model applicable to the assessment of different water table management strategies during the canola growing season. The high accuracy of HYDRUS-2D is mainly due to the use of a deterministic approach for simulating soil water dynamics based on the Richards equation (Doltra and Munoz, 2010). Earlier research has also demonstrated the high potential of HYDRUS-2D for simulating soil water dynamics in different drained fields (Janssen and Lennartz, 2009; Garg et al., 2009; Tan et al., 2014; Li et al., 2014 and 2015).

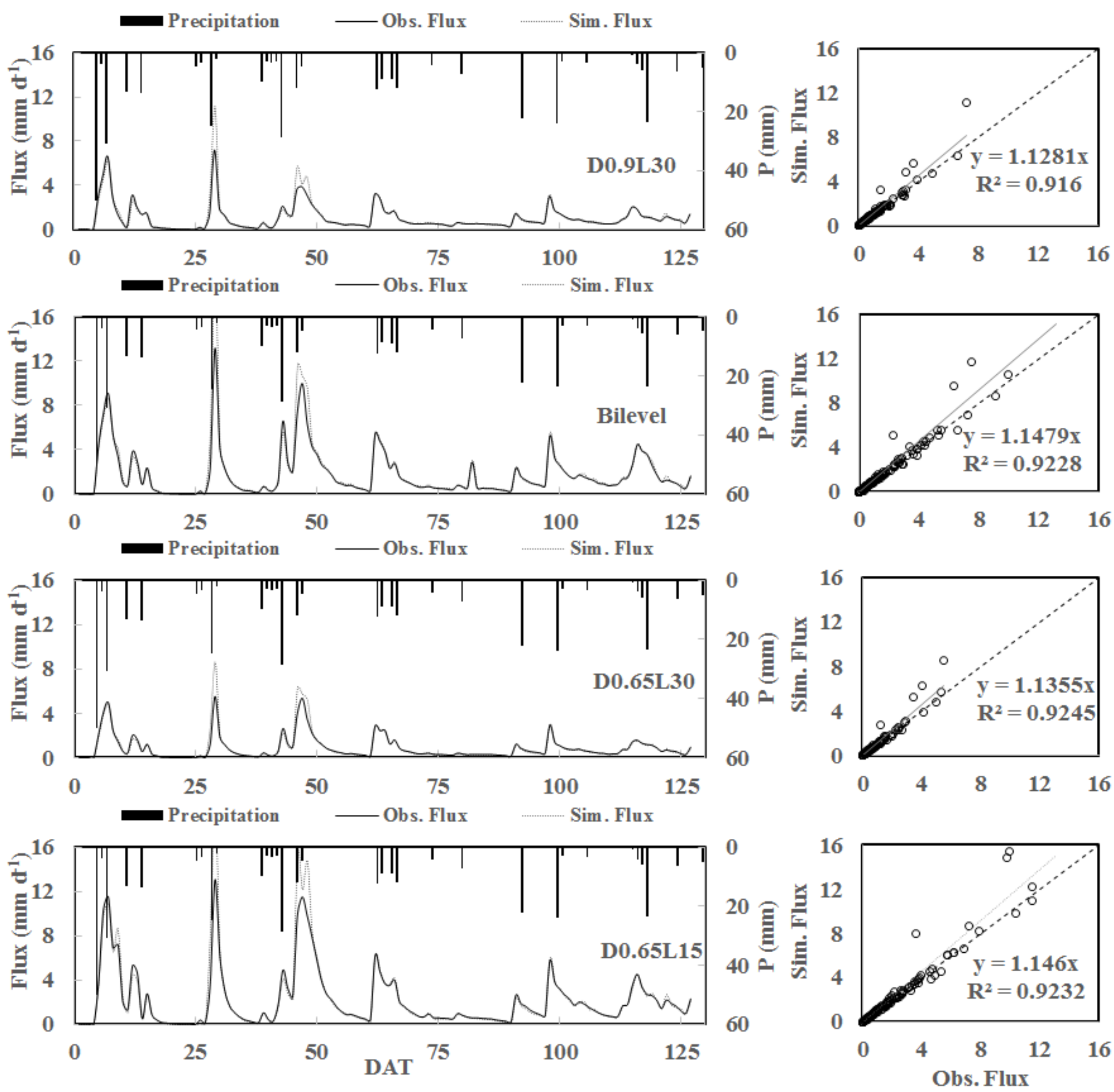


Figure 3. Temporal variations of drain discharges and precipitation (P) during the 2015-2016 growing season (the validation period) for the four drainage systems.

Conclusion

Improving the land and water productivity by modifying soil conditions is the main reason of the installation of subsurface drainage in the Northern paddy fields of Iran. Such technology also assists with winter cropping after rice cultivation, which can bring additional economic benefits to the local farmers. Nevertheless, subsurface drainage may lead to the negative consequences regarding soil water dynamics, especially under free drainage conditions. Therefore, this experimental and numerical study was carried out to evaluate the accuracy of the HYDRUS-2D model for simulating soil water dynamics under different drainage systems during the rainfed canola cropping in the paddy fields. The correspondence between both values and temporal trends of the observed and HYDRUS2D-simulated water fluxes and water table depths during the calibration and validation stages was good, indicating that the model is well suited for the experimental field conditions. Based on the results, it could be concluded that the HYDRUS-2D model, instead of labor- and time-consuming and expensive field investigations, could be reliably used for determining the optimal drainage system for the Northern paddy fields of Iran.

Acknowledgement

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EVALUATION AND COMPARISON OF LOCALLY MANUFACTURED PP450 SYNTHETIC ENVELOPES FOR COMPLEX CLAY SOILS OF NORTH AND SOUTH KHUZESTAN (IRAN)

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Abstract

The performance of subsurface drainage pipes installed utilizing granular envelopes for 100000 ha of sugarcane/irrigation-related projects in Khuzestan has been satisfactory. However due to rising transportation and installation costs for granular envelopes requiring a wider trench, a great tendency for the use of synthetic envelopes has developed in recent years. More than 300000 ha of new irrigation projects are planned to install only locally manufactured synthetic envelopes. The complexity of soil horizons in the vast Khuzestan plain, weakness of synthetic envelope manufacturing standard enforcement laws, lack of experience, insufficient field and laboratory research are the main reasons of concern about the successful long term performance of these envelopes. In this laboratory research three different PP450 synthetic envelopes (types 1, 2 and 3) were tested on two representative soil samples obtained from North and South Khuzestan in an upward directed flow permeameter. Outflow rates from drains with increasing total head at various time intervals, gradient ratio tests as well as hydraulic conductivity of soil-envelope tests were conducted. Analysis of the results revealed that while envelope type 1 was suitable for the soil from the north (Dehkhoda project) and envelope type 3 was suitable for the soil from the south (Ramshir project).

KEY WORDS: Gradient ratio, Hydraulic conductivity, Permeameter, Variations of discharge.

Introduction

Climatic and soil conditions in addition to the availability of water resources, makes the Khuzestan province a suitable place for agricultural development especially in the form of large irrigation

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projects, however; the providing of suitable drainage systems for successful production is necessary. Drainage is required to control the buildup of the water table due to irrigation water losses , deep percolation and salinity buildup in the root zone. Over the past four decades more than 100000 hectares of sugarcane projects in the Khuzestan province have had underground drainage pipes with sand gravel envelopes installed all showing a satisfactory performance.

Currently with due regards to the rising cost of sand gravel envelopes and transportation difficulties, there is a growing interest and urgency to use synthetic factory wrapped envelopes in new projects under development in the Khuzistan province which is estimated to be more than 300000 hectares. Synthetic envelopes have been used successfully in the United States, Pakistan, Egypt and the Netherlands since t synthetic envelopes have proven to be very effective in most cases, and have less cost compounded by easier installation. However their successful long term use has yet to be verifiedand requires extensive research taking into account Khuzestan soils; moreover, Geotextile filters can retain and prevent fine grains of soil from passing into and clogging the drain pipes (Hassanoghli and Rahimi, 1996).

Palmeira and Gardoni (2002) studied the biological clogging of geotextile and mineral envelopes under different pressures applied for filtering agricultural drain water over a five year period and showed that synthetic geotextile envelopes perform better and are more economical than other synthetic envelopes.

Agar (2011) used a permeameter to evaluate 3 geo-synthetic woven and unwoven envelopes and a gravel sand envelope used as drainage pipe covers in two different soils that is for clayand silt loam soils to preventsilt from entering into drainage pipes. The results show that all in all the geotextile envelope performance was superior in preventing silt from entering the drainage pipe as compared to a gravel sand filter.

Pedram et al., (2011) studied the clogging potential of synthetic PP450 envelopes under saline and non-saline conditions. This study was performed in laboratory conditions using two physical models permeameters. PP450 was used as the envelope as per the design criteria, and appropriate soil was selected to simulate the area. It was observed that water quality can affect the clogging of envelopes, which is an issue that must be considered when working in the Khuzestan province due to its saline soil and water conditions.

Mehdinezhadiani et al., (2008) used an upward flow permeameter to evaluate a certain type of PP450 and then compared its operation to gravel sand filters based on USBR standards, and concluded that both envelopes were acceptable for use in silt- clay soils found in the North of the Khuzestan province.

Nowshadi et al. (2015) evaluated the performance of 2 PP450 locally manufactured envelopes and a sand gravel envelope made according to USBR standards for silt loam soil, installing them in a soil tank model and concluded that discharge outflow from the gravel sand filter was considerably more as compared to that of synthetic envelopes. It was concluded that in areas where there is a need to lower the groundwater table rapidly synthetic envelopes are not suitable.

PP450 envelopes manufactured in the Khuzestan province are currently endorsed and used extensively for all the drainage projects under construction in the province. Gharamohammadlu (2013) examined 3 types of PP450 synthetic envelopes manufactured locally and identified the variations in their characteristics as shown in table 1 which affect their performance in different soils..

Table 1. Characteristics of the three locally manufactured envelopes reported by Gharemohammadlu (2013)

Synthetic envelope	O_{90} (μm)	Envelope thickness under a load of 2 (mm) kPa	Sample weight (gr. m^{-2})
Type 1	400	4. 05	510
Type 2	430	3. 47	462
Type 3	465	4. 075	478. 8

With due regards to the differences in characteristics, it was deemed necessary to study the suitability of all the 3 locally manufactured PP450 envelopes for the soils in the North and South of the Khuzestan province using an upward flow permeameter in the laboratory.

An important often neglected factor in the design and selection of drainage envelopes for the Khuzestan province's predominantly clay soils, is their complexity due to the presence of intermixed silt- sand lenses at shallow depths. This factor was considered in developing a specific method of soil sampling for this study.

Materials and methods

This research was performed in the laboratory using a standard upward flow permeameter. The pemeameters used in this research were designed, based on ASTM D5101 standards. They were made of transparent plexiglass material of 5 mm thickness and 90 mm inside diameter. Each was 250 mm in length and had 10 manometers installed on the sides to show the hydraulic head at the soil-envelope contact interface.

The Hydraulic head was applied via a constant head tank with an adjustable water surface to create the desired head and hydraulic gradient for each experiment. Figure 1 shows the permeameter used in this study.

Figure1. Photograph of the permeameter used in this research

The standard Soil sample height in the permeameter was 100 mm. Initially a hydraulic head of 30 cm was applied at the on start of the experiment. With due regards to soil sample height this would create an average hydraulic gradient of 0. 5. By applying hydraulic gradients of 0. 5, 1, 2 and 3 a steady constant discharge at each gradient ratio was recorded for the gradient ratio; and the hydraulic conductivity of the soil-envelope was obtained from it. Results for a gradient of 0. 5 were not logical and thus were discarded. The standard test for envelope performance is the Gradient Ratio test. According to Vlotman() recommendations this experiment should be carried out with an upward flow permeameter. GR is a factor of the soil and envelope that shows a potential clogging of envelopes. This parameter should be calculated at each hydraulic gradient using equation (1). Any increasing trend of GR with the gradient is an indication of envelope clogging. By increasing the hydraulic head over time, the discharge, hydraulic conductivity, GR and hydraulic conductivity of soil-envelope is measured. Discharge was measured using equation (2) and hydraulic conductivity corrected at standard temperature was calculated using equation (3).

Soil samples were collected from drain depth in trenches dug for pipe laying in the projects under construction. Due to the occurrence of sand silt lens deposits at shallow depths in the plain, collecting samples from these weak layers, occurring at drain depths that are more likely to cause envelope clogging was attempted .

$$GR = \frac{i_{es}}{i_s} \quad (1)$$

$$Q = \frac{V}{t} \quad (2)$$

$$K_{est} = \frac{Q}{i_{es} \times A} \quad (3)$$

Results and discussion

Steady Outflow Discharge

The constantoutflow discharge for each envelope with an increasing hydraulic gradient (at gradients 1, 2 and 3) is shown in Figure 2 for soils in the Dehkhoda area ..

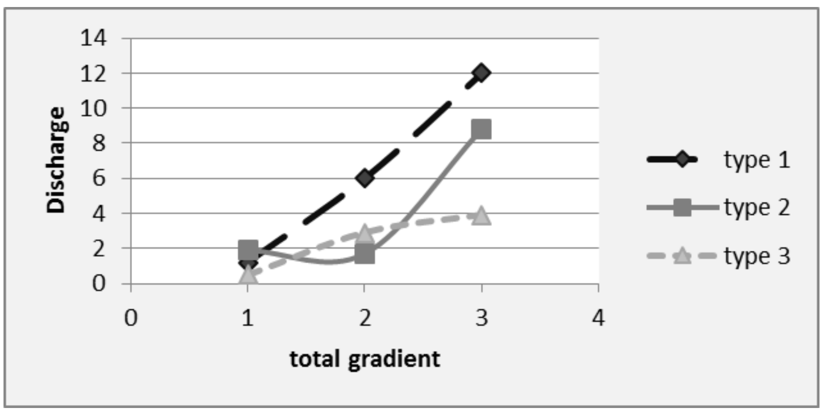

Figure 2. Discharge versus total gradient (Dehkhoda soil)

It takes about 24 hours for the discharge to reach a steady constant rate at a new gradient. Gradient was increased and set at 1,2 and 3 and the steady constant discharge rate corresponding to these gradients was recorded after 48, 72 and 96 hours, , respectively. As shown in Figure 2 the gradient of the discharge rate is more for envelope 1 showing a higher discharge rates in all the gradients. Thus envelope type 1 is considered more desirable as compared to the other 2 types. Steady constant discharge for envelopes 1, 2 and 3 was recorded as 3.9, 8.8 and 12 mm/min respectively.

In Figure 3 the variation of the steady discharge with its gradient is shown for soils in the Ramshirarea . In this test the system was adjusted to reach a gradient of 1 after approximately 48 hours from the beginning 72 hours after the onstart the gradient was adjusted at 2 and 96 hours later it was adjusted to a gradient of 3. Figure 3 shows the steady constant discharge at each gradient after reaching the steady state values of discharge. As observed, the discharge values corresponding to envelope 1 are the highest and for envelope 2 is the lowest. After 3 days at gradient 2, the trend of increasing discharge is faster for type 1 envelope as compared to types 2 and 3 which continue rising at equal rates. Therefore for soils in the Ramshir region type 1 is the most suitable because it can deliver the highest discharge. Envelopes 3 and 2 are the next suitable choices, respectively.

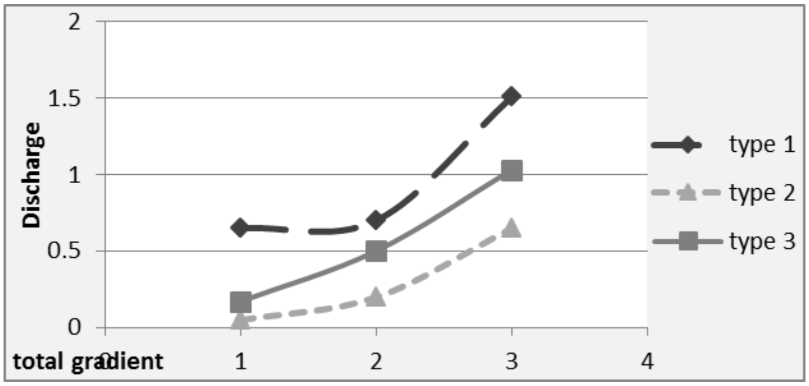

Figure 3. Discharge changes versus total gradient (Ramshir soil) total gradient

Gradient Ratio

Gradient ratio is measured for the determination of the threshold of soil particle movement and clogging potential. When GR is greater than one it means that envelope clogging has occurred due to soil particle movement. Furthermore the trend of increasing GR in relation to the total gradient is an indication of envelope clogging.

Figure 4 shows the results of the GR tests for soils in the Dehkhoda region. The graph shows that for all the gradients, GR is less than one. Envelope type 3 clogging starts at gradient 3 and GR of one. Since clogging has not occurred for envelope type 1 at gradient 3 despite soil failure, is is considered a better envelope at higher gradients.

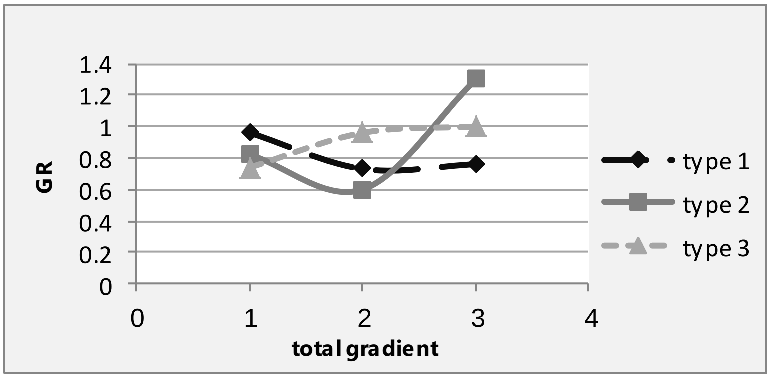

Figure 4. Gradient ratio versus total gradient (Dehkhoda soil)

Figure 5 shows the GR at different gradients for soils in the Ramshir area. As seen in the graph the lowest values of GR belong to envelope 3. The value of GR at all points , even at gradient 3, where soil failure occurs, is less than 0.5. Therefore clogging did not occur in envelope 3 and therefore is considered asthe best envelope type for soils in the Ramshir area. For envelope 2, GR at gradient 1 is slightly larger than one and increases after soil failure at gradient 3 whereas for envelope 1 at gradient 3 where soil failure occurs the GR does not show a rising trend indicative of envelope clogging.

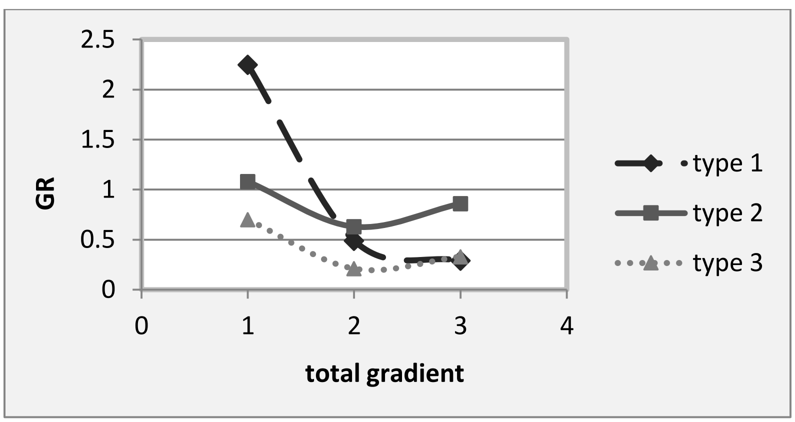

Figure 5. Gradient ratio versus total gradient (Ramshir soil)

Hydraulic conductivity of the soil-envelope and total gradient

Figure 6 shows the change in hydraulic conductivity of the soil-envelope with a total gradient for soils in the Dehkhoda region. As the gradient increases for all three envelope types, the hydraulic conductivity of the soil-envelope increases providing a higher value for envelope type 1. The

Hydraulic conductivity of the soil-envelope for type 2 envelope at gradient 2 shows a slight decrease and increases slightly at gradient 3. The increase in hydraulic conductivity after the decreasing trend is an indication of soil failure. Therefore in terms of hydraulic conductivity, envelope 1 is suitable for soils in the Dehkhoda region followed by envelope type 2.

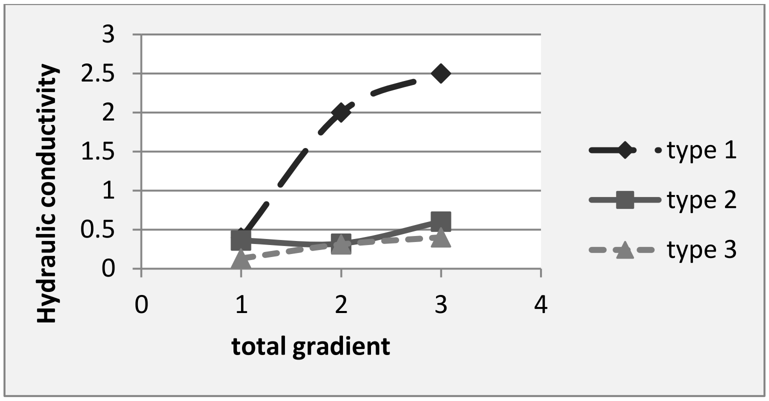

Figure 6. Hydraulic conductivity of soil-envelope at different gradients (Dehkhoda soil)

The corrected hydraulic conductivity of soil-envelopes in soils in the Ramshir area are shown in Figure 7. For all 3 envelopes that have an increasing total gradient, the hydraulic conductivity of the soil-envelope increases. The increasing trend of the hydraulic conductivity of the soil-envelope for envelope type 3 is greater as compared to types 1 and 2.

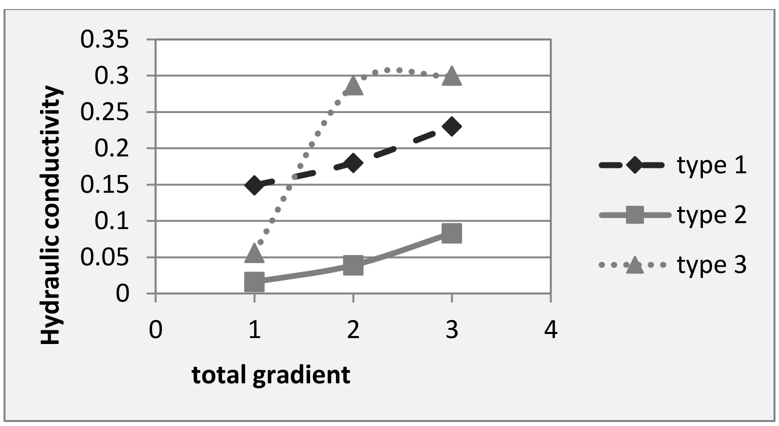

Figure 7. Hydraulic conductivity of soil-envelope at different gradients (Ramshir soil)

Conclusion

The analysis of the experimental results for soils in the Ramshir area show that the largest discharge rates correspond to type 1 envelopes followed next by type 3 envelopes. The highest hydraulic conductivity of soil-envelope is related to type 3 and type 1 envelopesrespectively. from the results from the GR test results show that the type 3 envelope was more suitable followed by type 1 envelope. Therefore taking into account all 3 of the obtained test results, envelope 3 is the most suitable choice for soils in the Ramshir area followed by envelope 1. Test results for soils in the Dehkhoda area show that type 1 envelope is more suitable followed by type 2. Furthermore the performance of type 3 envelope for soils in the Ramshir area was weak and is not recommended

In conclusion , the researchers found that the three locally manufactured envelopes under PP450 specification showed considerable differences in performance which have to be taken into account during their application for soils in the Khuzestan province.

Recommendations

1- The impact of chemical factors on the envelopes should also be examined since this parameter was not incorporated in the study.

2- For a more thorough and comprehensive analysis of the performance of envelopes, it is recommended that a field test be conducted with due regards to the various limitations that laboratory experiments have (time limitations, disturbances in soil structure etc…)

Acknowledgement

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INVESTIGATION THE METHODS TO ASSESS OF IMPERMEABLE LAYER DEPTH IN THE TIDAL LANDS OF MINUSHAHR

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Abstract

The depth of the impermeable layer or the barrier in soil is one of the most important parameters in the designing of subsurface drainage systems; however the assessment of the layer is not always easy. In practice, a soil layer is considered as being impermeable or slowly permeable if its hydraulic conductivity is very small (one fifth to one tenth) as compared to the hydraulic conductivity of the upper layers. The impermeable layer is found where the soil is poorly aggregated or exhibits a massive structure. If it is permanently saturated as part of the soil profile in the lowlands and coastlands where saturation conditions prevent organism activities, soil aggregating resulting into a layer with slow permeability in the soil. The identification of the impermeable layer depth is complicated especially in regions having a variable groundwater table such as tidal regions; thus, different methods are recommended to be used for the accurate determination of the impermeable layer depth. The aim of the present study is the investigation and comparison of the results obtained from the main and practical methods of identification of the impermeable layer depth in the tidal lands of Minushahr in the Khuzestan province, Iran. Three sites were chosen randomly in Minushahr to test and compare the three methods of estimating the depth to the impermeable layers, i.e. soil properties in different strata, one fifth to one tenth of the weighted mean hydraulic conductivity of the upper layer and infiltration rate differences of successive layers. The results showed that the soil had a massive structure, without any roots or plant activity and organic matter in the layer of 120 to 150 cm; also, there is a change in color and mottles were observed e which in itself can be attributed to redox conditions due to the tide and fluctuation of the groundwater table; in addition there an increase in soil consistency and digging resistance in the layer of 140 to 160 cm was seen as compared to the upper layers. The results from the experiments of the saturated hydraulic conductivity indicated that the hydraulic conductivity in depths of about 150 cm is approximately one seventh of the upper layers., a ring infiltrometer test in different depths of soil also revealed a significant decrease at a depth of 150 cm as related to surface soil. The results of the present study were almost the same for soil layering, saturated

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hydraulic conductivity and soil infiltration rate tests in successive layers so that the impermeable layer was determined in a depth of 150 to 200 cm.

KEY WORDS: Impermeable Layer, Saturated Hydraulic Conductivity, Infiltration Rate.

Introduction

Plants require air as well as moisture and nutrients in the root zone. Excess water from rainfall, irrigation, and the water table restricts the available air and inhibits plant growth. In arid and semi-arid irrigated regions, poor natural drainage causes water logging in the field and soil salinity develops due to the rise of the water table. In arid and semi-arid areas, low rainfall with an uncertainty in its occurrence results into moisture deficiency during most of the crop season subsequently irrigation is necessary for improving crop production, but in these areas, if irrigation canals are available, farmers have a general tendency to over irrigate. If lands are flat with no or little natural drainage, the ground water table will rise and this will often leadto salinity development and water logging (Pali, 1986; Pali, 2015). Salt-prone land and water resources are major impediments to the optimal utilization of crop production systems in many arid and semi-arid regions of the world, including Iran (Alizadeh et al. 2004; Moghaddam and Koocheki 2004). In order to improve saline and water logged soils which occur due to the rise in the groundwater table, the installation of subsurface drainage system is considered as one of the best remedies. Determining the depth of the impermeable layer or barrier in soils is one of the most important parameters in the designing of subsurface drainage systems. Most of the drainage formulae for determining the depth and spacing of the drains require information about the distance to the impermeable layer (Luthin, 1973). However, the assessment of the distance to the impermeable layer is not always easy. An impermeable layer is a soil layer through which no flow occurs or, in a practical sense, the flow is so small that it can be overlooked. In other words, an impermeable layer or barrier is a stratum or layer that prevents or restricts the saturated movement of water in the soil. Since soil layers in irrigated areas are found in a generally horizontal orientation parallel to the ground surface, an impermeable layer is usually considered as a barrier to the vertical movement of water which may also restrict the horizontal movement of water because of geologic nonconformity (USBR, 1978; Ahmadi, 1999).

Despite all this, the term "impermeable" is relative and all soils are permeable to some extent, but there are some methods to determine and identify the depth of the impermeable layer in the soil. In practice, a soil layer is considered impermeable or slowly permeable if its hydraulic conductivity is very small (one fifth to one tenth) as compared to the hydraulic conductivity of the upper layers (USBR, 1978; Ahmadi, 1999). Other applicable methods for the identification of a barrier are the evaluation of the infiltration rate differences in successive layers of soil, in addition to the investigation of soil properties variation (texture, structure, moisture, soil consistency, digging resistance, soil color, and mottling and gley condition) in the soil profile.

An impermeable layer is found where the soil is poorly aggregated or exhibits a massive structure. In permanently saturated layers of the soil profile in the lowlands and coastlands, biologic activities and soil aggregation are preventive and thus form a layer that has a slow permeability in the soil. The identification of the impermeable layer depth is complicated, especially in regions having a fluctuating groundwater table such as tidal regions; thus, it is recommended that different methods be applied to more accurately determine the depth of the impermeable layer. Therefore, the aim of the present study is the investigation and comparison of the results obtained from the major and practical methods applied for the identification of the impermeable layer depth in the tidal lands of Minushahr in Khuzestan, Iran.

Materials and methods

Experimental site layout

Three sites (S_1: cultured by palm: S_2: barren lands with canebrake and S_3: cultivated with vegetables) were chosen in the tidal lands of Minushahr, in the Khuzestan Province, Iran (Figure1) to test and compare the three methods of estimating the depth to the impermeable layers, i.e. the conducting of a soil survey by logging the soil properties in different strata, the determination of saturated hydraulic conductivity coefficients in different layers (one fifth to one tenth of the weighted mean of the hydraulic conductivity of the upper layer) and the determination of the infiltration rate differences in successive layers.

Soil survey

A soil survey in the selected sites was performed using an auger boring method. The auger boring method is a means of obtaining soil samples from different depths by drilling, without having to dig a pit. This way, a continuous series of soil samples is taken which makes it possible to assemble a core showing the soil horizons. Soil samples were obtained from a borehole created by an auger and were analyzed qualitatively by an experienced technician, in terms of soil color, observation of mottling and gley condition, soil texture (using the feel method) and structure, state of the root in the soil, the soil consistency and soil resistance against digging.

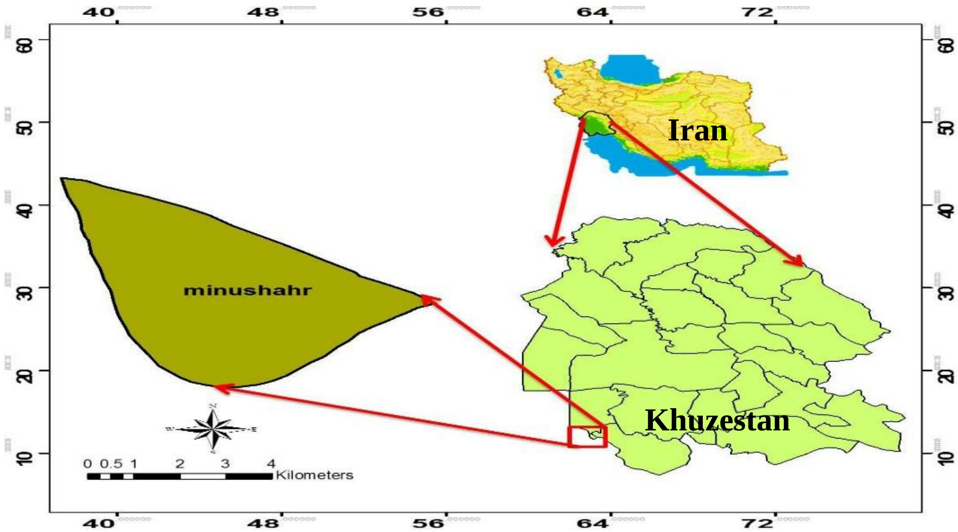

Figure 1. The study area map

The Determination of the Hydraulic conductivity of Saturated Soil

The Determination of the hydraulic conductivity of saturated soil in different layers of soil was done in layers of 0-50, 50-100, 100-150 and 150-200 cm using three replicates created by the auger hole and the inverse hole methods. The methods consist of pumping the water out or in an auger-hole extending below and up the water table and then measuring the rate of the rise and fall of the water in the hole, respectively (Figure 2). All of the tests were carried out when the ground water table was stable

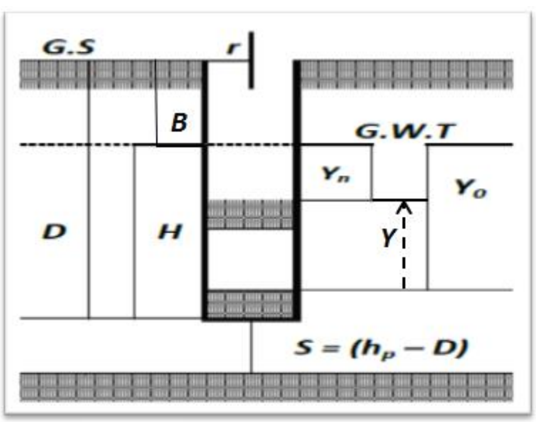

Figure 2. Borehole characteristics

(D is depth of borehole (m), B is depth to stable ground water level from the surface* (m), H is the stable ground water level (m), Y_0 is the ground water level difference from the stable ground water after its removal at the beginning of the rise rate measurement (m), Y_n is the ground water level difference from the stable ground water at the end of the rise rate measurement (m), Y is the ground water level during the rise rate measurement and r is the borehole radius (m).

*Depths of stable ground water level from the soil surface in the selected sites were regarded as an average of ground water depth from surface during one month

Determination of soil infiltration rate

Determination of soil infiltration rate in different layers was done in layers of 0 (surface), 50 cm, 80 cm and 120 cm depths based on the stair method (Figure 3) in three replicates. All of the infiltration tests were conducted to the upper section of the water table depth (about 120 cm) for the qualitative evaluation of the soil permeability value trend.

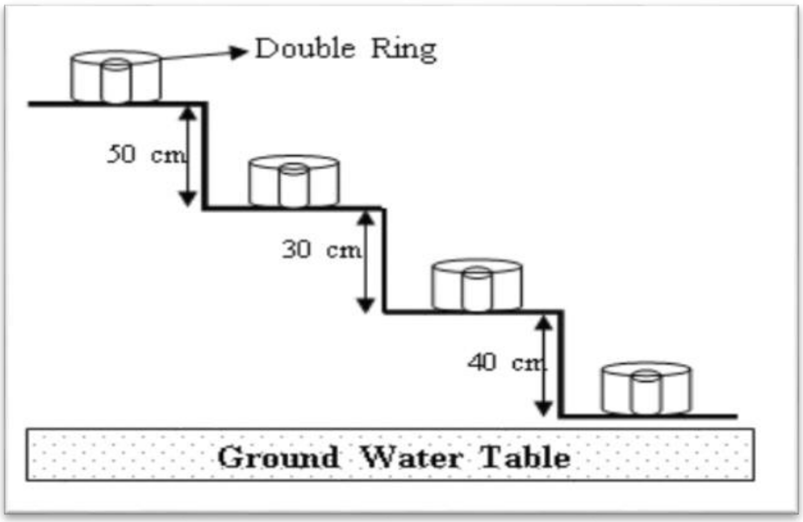

Figure 3. Method of determining the infiltration rate in different layer as a stair state

The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water or other liquid, and then maintaining the water at a constant level. The volume of water added to the inner ring, to maintain the water level constant was the measure of the volume of water that infiltrates the soil. The volume infiltrated during timed intervals was converted to an incremental infiltration velocity, expressed in millimeter per hour and plotted versus elapsed time. The maximum-steady state or average incremental infiltration velocity, depending on the purpose/application of the test was regarded equivalent to the infiltration rate. Finally, the obtained results from the three studied methods were compared qualitatively at three sites with each other.

Results and discussion

Soil logging data obtained from soil hole surveys are shown in Table 1. The results of the saturated hydraulic conductivity and infiltration rate of water tests in different layers of soil at three sites are indicated in Table 2 and 3, respectively.

Table 1. Soil logging results of three sites (a): Site 1; (b) Site 2; (c): Site 3 and (d): The list of symbols and abbreviations in the table

(a)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	*SiC*	*1*	*LG*	-	-	+	*SG.*	+++
30-60	*SiC*	*2*	*GB*	-	-	+	*Co.*	+
60-100	*SiC*	*3*	*DB*	-	-	+	*Gr.*	+
100-150	*SiC*	*4*	*GB*	-	++	+++	*Ma.*	-
150-200	*SiC*	*4*	*OG*	++	+	++	*Ma.*	-
200-250	*SiCL*	*4*	*G*	++	+	++	*Ma.*	-
250-300	*L*	*4*	*G*	++	-	+	*Ma.*	-
300-400	*SiCL*	*4*	*LG*	++	-	+	*Ma.*	-

(b)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	*SiC*	*1*	*LG*	-	-	+	*Co.*	++
30-60	*SiC*	*2*	*GB*	-	-	+	*Cr.*	++
60-100	*SiC*	*3*	*GB*	-	-	+	*Cr.*	+
100-150	*SiC*	*4*	*DB*	+	+	++	*Pl.*	-
150-200	*SiC*	*4*	*OG*	++	++	++	*Ma.*	-
200-250	*L*	*4*	*G*	++	++	++	*Ma.*	-
250-300	*L*	*4*	*G*	++	-	+	*Ma.*	-
300-400	*SiCL*	*4*	*LG*	++	-	+	*Ma.*	-

(c)

Depth (cm)	*Texture*	*Moisture*	*Color*	*Gley*	*Mottling*	*Resistance*	*Structure*	*Root*
0-30	*SiC*	*1*	*LG*	-	-	+	*SG.*	++
30-60	*SiC*	*1*	*LG*	-	-	+	*SG.*	+
60-100	*SiC*	*2*	*GB*	-	+	+	*Ma.*	+
100-150	*SiC*	*3*	*GB*	-	++	++	*Ma.*	-
150-200	*SiCL*	*4*	*GB*	++	++	++	*Ma.*	-
200-250	*SiCL*	*4*	*OG*	++	+	++	*Ma.*	-
250-300	*L*	*4*	*OG*	-	-	+	*Ma.*	-
300-400	*L*	*4*	*OG*	-	-	+	*Ma.*	-

(d)

Texture	*Moisture*	*Color*	*Mottling & Gley*	*Resistance*	*Structure*	*Root*
SiC: Silty Clay *SiCL: Silty Clay Loam* *C: Clay* *L: Loam*	*1: Dry* *2: Moist* *3: Wet* *4: Saturate*	*B: Brown* *RB: Raddish Brown* *DB: Dark Brown* *LB: Light Brown* *OB: Olive Brown* *GB: Grayish Brown* *G: Gray* *LG: Light Gray* *DG: Dark Gray* *OG: Olive Gray*	*(-): Less than 2% of exposed surface* *(+): 2-20% of exposed surface* *(++): More than 20% of exposed surface*	*(-): Non* *(+): Soft* *(++): Average* *(+++): Hard* *(++++): Extremely Hard*	*Pl: Platy* *Pr: Prismatic* *Co: Columnar* *Gr: Granular* *Ma: Massive* *SG: ingle Grain* *Cr.: Crumb*	*(-):Non* *(+):Few* *(++):Average* *(+++):Many*

The results of soil logging indicate that the region soil has a relatively heavy texture (silty clay) in surface and soil texture has a growing trend towards heavy texture (clay and silty clay loam) and it can be observed as a layer consisting of green, olive green and light green loam and silty clay loam soil generally at depths of 150-400 cm. Generally, the layer properties of soils in Minushahr can be divided into 3 classes including:

A) The Upper layer (0-150cm): The Presence of roots, organism activities and organic matter in these layers lead to the creating and developing the soil aggregates and increasing the soil hydrodynamic coefficients such as saturated hydraulic conductivity (K_s) and infiltration rate (I_b) coefficients.
B) The Middle layer (100-250 cm): These layers are exposed to fluctuations of ground water table that it leads to the appearance of mottling and red-brown spots due to sequential periods of oxidation-reduction. The soil of these layers is usually saturated; subsequently, the plant roots could not develop largely in these layers and soil has an undeveloped soil with a massive structure, dark green color and a hard resistance against digging. Therefore, the soil does not have a desirable hydrodynamic condition in this region.
C) The lower layer (250-400 cm): The layer has an undeveloped soil because a perennial saturation condition that prevents soil aeration and leads to the appearance of the gley condition. Water flow characteristics in the present layer are very limited.

Slow percolating permeable and impermeable layers are found where the soil is poorly aggregated or exhibits a massive type of structure. The soil of such layers typically belongs to one of the following textural classes: sandy clay loam, silty clay loam, clay loam, sandy clay, silty clay, and clay (Farr & Henderson, 1986). Therefore it can be claimed on the basis of available evidences that the barrier is near depths of 150-200 cm.

The results from the experiments of the saturated hydraulic conductivity indicated that the hydraulic conductivity in the layers 130 to 150 cm is about one seventh of the upper layers. By definition, as used by the US Bureau of Reclamation (USBR, 1978), a barrier zone is a layer that has a saturated hydraulic conductivity less than or equal to one fifth of the weighted average hydraulic conductivity of the strata above it. Therefore, on the basis of the coefficients of saturated hydraulic conductivity in the selected sites, there is a barrier layer in depths of 130-150 cm.

Table 2- Coefficients of saturated hydraulic conductivity (K_s) in different layers of three sites

Depth	K_s (m/day)		
	Site 1	Site 2	Site 3
0-50 cm	4.24	2.12	2.93
50-100 cm	3.62	1.68	1.34
100-150 cm	1.21	0.87	0.64
150-200 cm	0.58	0.32	0.41

On the other hand, the results of ring infiltrometer test in the different depths of soil revealed a large decrease in the intake rate of soil at a layer of 120 cm as compared to the surface and upper layers of the selected sites .This is shown as the decreasing trend of soil permeability with an increase in the depth.

Table 3- Infiltration rate (I_b) of water in different layers of three sites

Depth	I_b (mm/hr)		
	Site 1	Site 2	Site 3
Surface soil	9.63	5.25	11.3
50 cm	6.86	4.33	5.61
80 cm	5.08	2.86	5.02
120 cm	4.04	2.58	2.83

Conclusion

Three methods including soil properties changes, saturated hydraulic conductivity coefficients and soil infiltration rates in successive layers were tested for estimating the soil impermeable layer depth in tidal lands where the ground water table fluctuates. The results of the present study are almost the same for soil layering, saturated hydraulic conductivity and soil infiltration rate tests in successive layers so that the impermeable layer was determined in depths of 130 to 160 cm. However the determination of the hydraulic conductivity of the soil layers is difficult, thus it is proposed that various methods be used to identify theimpermeable layers using a higher confidence degree more precisely

Acknowledgement

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DETERMINING AN APPROPRIATE SYNTHETIC ENVELOPE FOR A SALINE SOIL AND EVALUATING DRAINAGE WATER QUALITY BY MEANS OF ONE DIRECTION PERMEABILITY TEST AND CYCLIC FLOW (CASE STUDY: SHADEGAN, KHUZESTAN)

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Abstract

The selection of an appropriate envelope (filter) and management of drainage water from subsurface drainage systems play a significant role in the design and implementation of these systems. By applying synthetic envelopes instead of mineral envelopes (sand and silt), subsurface drainage systems benefit from environmental, economic and technical issues. In this research, an effort has been made to select the most proper synthetic envelope among the three prevalent PLM synthetic envelopes (Iranian PP450 and PP700 and foreign PP450) using a permeability test in accordance with ASTM D-5101 standard and the saline soil of the Shadegan drainage project (Khuzestan). In addition, salinity variations of drainage water were analyzed on the most suitable envelope through four cyclic flows (applying a flow for five days and pausing it for three days) and two hydraulic gradients (1 and 2.5). In conclusion, the average hydraulic conductivity of Iranian PP450 and PP700 and foreign PP450 respectively were measured as 0.11, 0.13, and 0.21 m/day and the average gradient ratio were equal to 0.78, 0.84, and 1.86 m/day. According to the permeability test, Iranian PP700 was considered as the best synthetic envelope due to lesser changes of hydraulic conductivity and gradient ratio. In the study of drainage water salinity variations which have been obtained from soil- Iranian PP700 envelope combination, the main changes of drainage water salinity, due to the soil volume limitations in the permeameter apparatus, occurred in the first 24 hours. Furthermore, drainage water salinity decreased during other days of the test. By providing more dissolution opportunity as a result of the cyclic flow, the electric conductivity of drainage water increased immediately after applying the flow.

KEY WORDS: Subsurface drainage, Synthetic envelope, Physical clogging, Permeameter, Drainage water, Shadegan.

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Introduction

From the beginning of the 19th century subsurface drains have been installed to improve crop growing conditions in agricultural soils. Silts and fine particles are considered to be the problem in subsurface land drainage system with due regard to the risk of mineral clogging (Vlotman, 1998 and Skaggs et al., 2012). In order to achieve a better drain performance in reclamation projects, envelope materials are required. In the 1990's, gravel, prewrapped organic and synthetic fabrics (geotextiles) have become the most common drain envelope materials used to protect drain pipes from the entry of sediments. Geotextiles are preferred to granular envelopes, mainly for economic and environmental reasons and due to the fact that appropriate granular materials are often not available continuously or locally (Knops et al., 1979; Dierickx, 1980; Irwin and Hore, 1979; Eggelsmann, 1980; Stuyt et al; 2000). The need for a drain envelope depends primarily on the soil properties and the soil characteristics in the region where subsurface drainage is planned (Dieleman and Trafford, 1986). In general, for all projects in Iran the cost of material and transportation of synthetic materials is lower than the cost of gravel which nowadays is the most common material used as drainage envelop in Iran. The PLM envelopes are of a permeable structure composed of loose randomly oriented yarns, fibers, filament, grains granular or beads, around a corrugated drainpipe made by specialized companies. Most PLMs are manufactured from recycled material like polypropylene waste fibers from the carpet industry. Whatsmore, the increasing growth of petrochemical industries in Iran, provide the possibility of manufacturing these products in Iran. In order to select the most suitable drain-pipe envelope material, regardless of time consuming field tests, laboratory tests are the most optimal means due to the short duration and relatively low cost. Several experimental techniques can be applied to determine physical and hydraulic properties of synthetic envelopes (Hassanoghli, 2009). One of these laboratory experimental methods is the permeability test which is based on determining the soil -synthetic envelope system permeability and clogging behavior (ASTM, 1993).

Large-scale development of irrigation has taken place in many arid and semi-arid areas since the late nineteenth century. In many irrigated areas around the world, rising water tables have subsequently led to waterlogging and associated salinity problems. This has occured where drainage development has not been able to keep pace with irrigation development or where the maintenance of drainage facilities has largely been neglected (FAO, 2004). Salinization affects about 20–30 million ha of the world's 260 million ha of irrigated land. Water and soil salinity are two important limitations for agricultural production in arid and semi-arid regions (FAO, 2003). Soil degradation resulting from salinity is a worldwide environmental issue since it contributes to severe adverse impacts on agricultural productivity, especially in arid, semiarid and coastal areas (Qadir et al. 2007; Rengasamy, 2006). Saline soils can be considered to be highly degraded and least productive due to their simultaneous effect of salinity on soil physical, chemical and biological properties (Rengasamy and Olsson, 1991). Dispersed saline soils are compacted and have reduced water infiltration and hydraulic conductivity, which play a major role in water, air, and solute movement through the soil profile (Shainberg and Lety, 1984; Suarez et al., 2006). Gan et al. (2010), using the horizontal soil column infiltration method, proved that water diffusivity significantly increased when soil salinity increased. However, soil texture plays a major role in determining whether soil salt contents would significantly affect hydraulic properties (Dongli et al., 2014).

Drainage water management (DWM) is gaining popularity and being increasingly implemented in the Midwestern U.S. and has received considerable attention in the scientific literature (e.g., Adeuya et al., 2012; Breve et al., 1997; Fausey 2005; Gaynor et al., 2002; Jaynes 2012). Current estimates of land under DWM are not available; however, the implementation of DWM is increasing as a result of water quality concerns (Skaggs et al., 2012). Environmental and agronomical benefits are associated with controlled subsurface drainage such as yield boosts and reduced drainage pollution to the environment (Drury et al., 2006; Mejia et al., 2000; Ghane et al., 2012; Skaggs et al., 2012; Sunohara et al., 2014; Nash et al., 2015). Leaching of salts from root zone in saline soils is one of the most important DWM techniques to prevent excessive accumulation of salts that would limit the yield potential of crops (Letey et al., 2011). Concerning the evaluation of leaching soluble salts from soils profiles, Dileman and Trafford (1986), Hoffman (1980), Konuku et al. (2005) and Corwin et al. (2007) reported that the leaching of soluble salts is basically done by mass flow. Furthermore, Raj and Nath (1980) concluded that one unit volume of water is adequate for leaching a great deal (%90) of soluble salts from soil profile. Also in Iran Pazira and Homaee (2010) in Khuzestan plain, Rajabzadeh (2009) in central part of Khuzestan province, Mostafazadeh-Fard (2008) in Roudasht of Isfahan province, Rahimi (2005) in Kaveer Namak of Bajestan have had experiments on saline soils. Results for investigation of trend of saline soil improvement using leaching methods showed that using leaching process, soluble salts were washed away from soils profile of the agronomy programs and the salinity of the soil surface layer were reduced to a level suitable for cultivation of salt tolerant and semi tolerant plants). Comparing between two leaching methods in saline and sodium soils of Roudasht in Isfahan (Iran) and in his experimental condition, Mohammadi (1992) concluded that cyclic leaching is more effective in leaching salt (Mohammadi, 1991). Results of field experiments in Ramshir, Khuzestan to reduce the salinity and sodium level of soil, indicated that adding average 100cm water to soil, electrical conductivity was reduced from an average 27.03 to 16.93dS/m (Shabani et al., 2014). In addition, research shows that salinity level of the drainage water is high in the beginning of growing season. This is due to an imbalance between soil and irrigation water. So applying leaching before planting decreases clogging drainage envelope risk and reduce yield (Rajabzadeh et al 2009).

Further studies operate steady flow for leaching process to decrease soil salinity and comparison of cyclic and steady flow operation has been neglected in leaching studies. In this study, the soil and drainage water were collected from one of the drainage projects in south of Iran (Shadegan) which show significant salinity, to simulate real condition in permeability tests. In one hand, performance of three synthetic envelopes through common permeability test in accordance with ASTM D-5101 standard and saline soil of Shadegan drainage project (Khuzestan) was examined.

On the other hand, cyclic leaching operation according to irrigation regime was applied in order to analyze salinity variations of drainage water on the most suitable envelope.

Materials and methods

In the present study (from October to December 2012), permeability test was done for determining the soil-synthetic envelope system permeability and clogging behavior for cohesion less soils under unidirectional flow conditions (ASTM, 1993). The test requires setting up a cylindrical, clear plastic permeameter (figure 1) with a PLM and soil, and passing water through this system at varying heads. Measurements of heads and flow rates were taken at different time intervals. The changes in gradient ratio values with time versus the different system hydraulic gradients, and the changes in the rate of flow through the system were noted carefully. Soil-envelope permeameter equipped with support stand, soil-envelope support, Two Constant Water Head Devices, one mounted on jack stand (adjustable) and one stationary (figure 1).

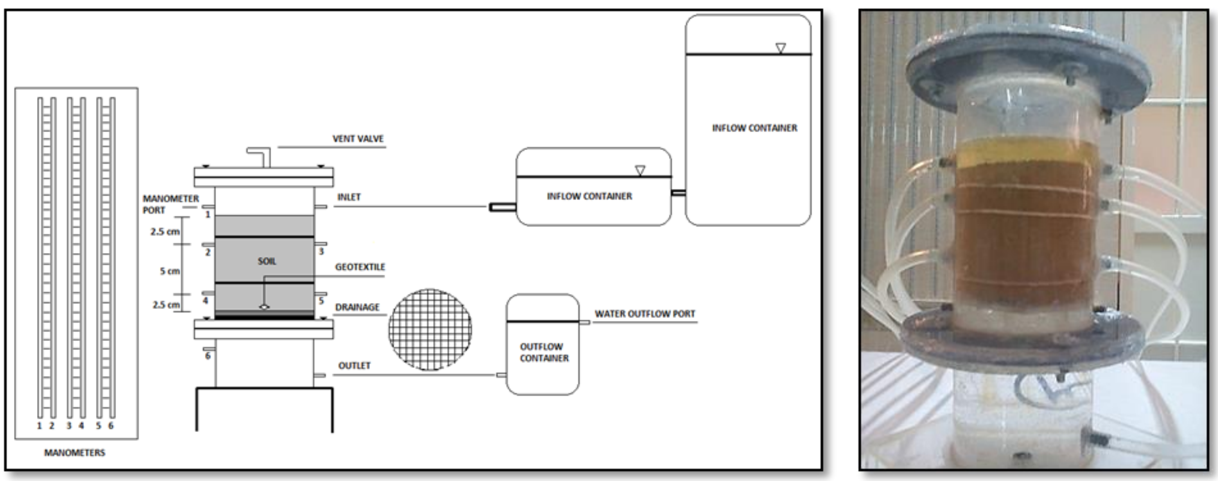


Figure 1. permeameter "set up" diagram (ASTM, 1993)

The values of hydraulic gradients used in these tests were established by moving up and down the inlet reservoir. Permeameter test was implemented in two main parts that are described below:

1. First of all, to select the most appropriate geotextile, the value of hydraulic gradients were equal to (1, 2.5, 5, 7.5 and 10) respectively. Tests were repeated three times for each envelopes, each time for a constant hydraulic head. Therefore, nine tests performed to choose the most suitable geotextile for Shadegan soil.
2. In the second part of examination, permeameter test was done during 32 days with the suitable envelope chosen in previous section in three repetitions. The simulation of cyclic leaching was adapted to irrigation regime for five days applying the flow and three days for pausing it. Electric conductivity of drainage water extracted from permeameter apparatus was measured during the test.

Envelope material

Three synthetic PLMs (pre wrapped loose material) which are permeable structure consisting of loose, randomly oriented yarns, and usually wrapped around the corrugated plastic drainpipes by specialized companies were used in present study. One circular specimen from each swatch was cut in the laboratory sample with the specimen having a diameter of 110 mm (4.33 in). Table 1 shows the properties of these three geosynthetics materials. In this research, Foreign PP450, Iranian PP450 and Iranian PP700 are called respectively as PP450 A, PP450 B, and PP700.

Table 1. Properties of geosynthetics materials

Mass variations (%)	Thickness (mm)	Mass per unit area (g/cm2)	Hydraulic conductivity (m/d)	O90 (μ)	Synthetic envelope
38.6	7.0	0.067	52.21	450	PP450 A
51.2	6.2	0.056	149.21	450	PP450 B
54.0	8.9	0.065	169.36	700	PP700

Test water and soil preparation

Test water should be maintained at room temperature about 16 to 27°C (60 to 80°F). Permeameter test should be done by non-saline water to obtain best suited envelope (Anon, 2006). Therefore, in this study all of the permeability tests were carried out by with normal water of EC: 0.7dS/m. Test water chemical properties are shown in table 2.

Table 2. Chemical properties of test water

SAR $(meq/lit)^{0.5}$	Nitrate (parts per million)	Anions $(meq/lit)^{0.5}$			Cations $(meq/lit)^{0.5}$				pH	EC (ds/m)
		SO_4^{2-}	Cl^-	HCO^{3-}	Ca^{2+}	Mg^{2+}	Na^+	K^+		
0.83	28	2.4	2.9	1.5	4.4	1.3	1.4	Negligible	7.52	0.7

Table 3. Physical and chemical properties of Shadegan soil

Soil texture	Sand (%)	Silt (%)	Clay (%)	Anions $(meq/lit)^{0.5}$			Cations $(meq/lit)^{0.5}$				SAR $(meq/lit)^{0.5}$	OC (%)	pH	ECe (ds/m)
				SO_4^{2-}	Cl^-	HCO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+				
Silty clay	12	47	41	43	700	17	91	211	462	Negligible	37.6	0.71	7.25	76.2

According to soil properties shown in table 3, the EC of soil collected from south of Iran, was 76.2 dS/m. Shadegan soil is categorized as saline- sodic soil because of having EC more than 4 dS/m and SAR more than 13 $(meq/lit)^{0.5}$. For processing the soil the air dried (for 3 days) material passed through 10 mm (3.8 in.) and retained on the No.10 sieve was subjected to a second round of grinding to ensure that the sample has been broken down into individual grains. A representative sample weighing about 1300 g (or 3000 g for the 150-mm diameter drain pipe) was subdivided into four parts using a soil splitter, with one part to be used for the tests. Air-dried processed soil was placed above the support cloth to a depth of 103 mm (4.12 in.). The final depth of soil after settlement will be approximately 100 mm (4 in). The soil was placed carefully into the permeameter with appropriate tool in layers not exceeding 25 mm (1 in.) at a time until the total soil height of 103 mm (4.12 in.) was reached. Table 2 and 3 show the properties of water and soil used in experiments (ASTM, 1993).

Procedure

After fitting the constant head devise, the manometer tubes, the outlet tubes, overflow tubes to their corresponding permeameters, the geotextile-soil-water system was saturated. For the first step, the inflow level was adjusted to achieve a hydraulic gradient (i) of 1. Then flow was let in and the initial starting time was recorded and the following data at 0, 0.5,1, 2, 4, 6, and 24 h from the initial starting time were recorded : the time in hours (cumulative), the flow rate from the system; time in seconds (t) for a measured quantity of flow (Q) in cm3 (for a minimum duration of 30 s and a minimum quantity of flow of 10 cm3), the temperature (T) of the water in the system in 0C, the water level readings from the individual manometers. After the final reading when the system has stabilized, the inflow was raised to obtain next hydraulic gradient and measurements were repeated, and so on till i = 10. The test was run continuously (Anon, 2006). For the second step, the inflow level was adjusted to achieve two hydraulic gradient of 1 and 2.5 and all of measurements were carried out as previous step. In addition, drainage water salinity was obtained from measuring electric conductivity of water that was egressed from geotextile -soil system. It is necessary to mention that each test of two steps repeated three times. According to soil texture and infiltration rate of irrigation water that was suggested in previous researches in Shadegan drainage project, it was considered to flow water for five days (simulation of irrigation) and pause it for three days (Esmaeili et al., 2011). After every manometer reading, drainage water sample was taken from the lowest inlet port which was located exactly under the soil column. Thus, water sample gathered from this port passed whole soil volume and is an appropriate drainage water sample (figure 2).

Figure 2. Sampling the drainage water extracted from the apparatus

Calculation

Hydraulic gradient (i): The hydraulic gradient was Calculated as follow (ASTM; 1993)

$$i = D\ h/L \tag{1}$$

Where, D h = difference in manometer readings for soil zone analyzed, manometer 1 minus manometer 6, cm, and L = length or thickness of soil between manometers being analyzed, cm

System permeability (k): the system permeability was obtained at the temperature of the test and corrected to 20°C using Eq (3).

$$K_T = \frac{v}{i \times t \times A \times 100} \tag{2}$$

$$K_{20} = \frac{K_T \times \mu_T}{\mu_{20}} \tag{3}$$

Where:

K_T=system permeability at test temperature, m/s,

K20 = system permeability at 20°C, m/s,

Q = quantity of flow measured, cm3,

i = hydraulic gradient of the system,

A = cross-sectional area of the specimen, cm2,

t = time for measured quantity of flow, s,

μT = water viscosity at temperature of the test, and

μ20 = water viscosity at 20°C.

Gradient ratio: For each hydraulic gradient the gradient ratio, GR, was reported for the system using Eq. (4) and data for the final time interval used, Shows the meaning of the values in the equation schematically.

$$\Delta h_s = \frac{(M_2 - M_4) + (M_3 + M_5)}{2} \quad (4)$$

$$\Delta h_{SF} = \frac{(M_4 - M_6) + (M_5 - M_6)}{2} \quad (5)$$

Mn = the manometer reading, cm, for the manometer numbered n.

L_s= 5.10 cm (2 in.), and

L_{sf} = 2.55 cm (1 in. + the specimen thickness)

Experimental site layout

Shadegan plain is a flat drainage network of 2500 ha field which is located in south of Iran in Khuzestan province. The highest and lowest level of this land are seven and two meters above sea level. Its average slope is too low and equal to 0.0005. The drainage network is positioned in semi-arid region with wheat as the dominant cultivation. According to consulting engineers studies, drainage pipes installed in depth of 1.7, distance of 50 meters with lateral length of 220 to 230 meters (figure 3). Also, drainage pipes diameter is equal to 125 mm which are made of PVC materials (Hassanoghli et al., 2013).

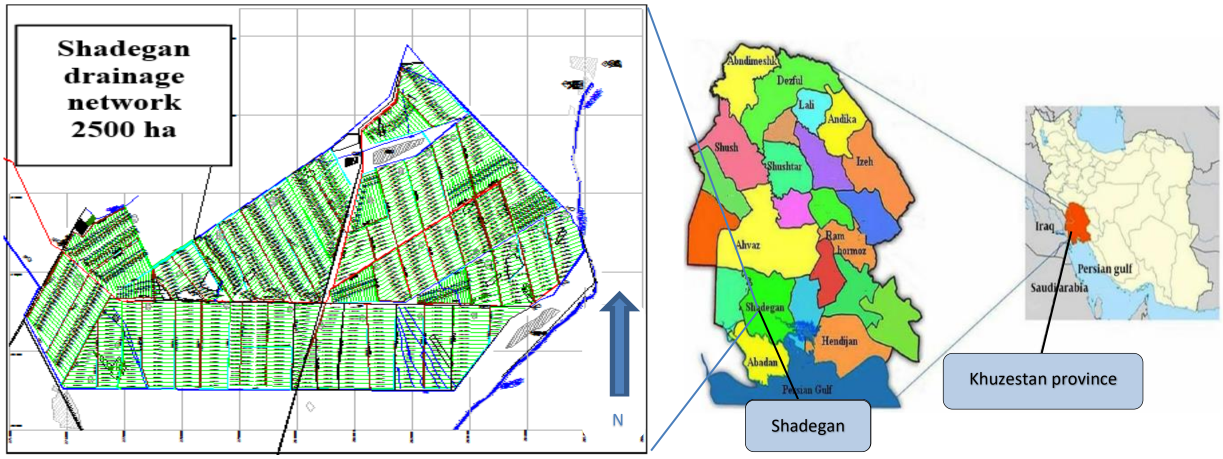
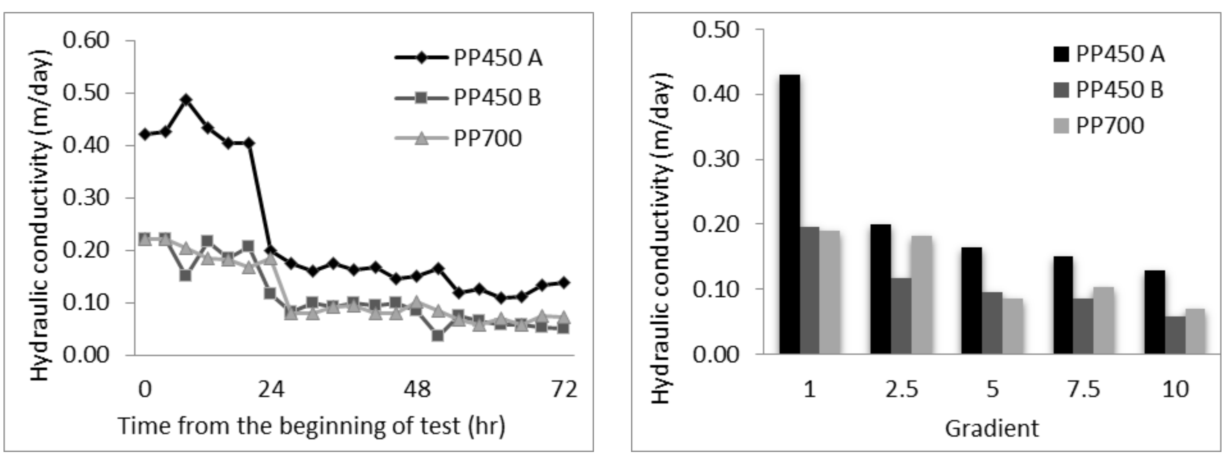


Figure 3. Geographical location of Shadegan drainage network in Khuzestan province

Results and discussion

Selecting the most appropriate geotextile

Considering hydraulic conductivity variations in figure 4, it is obvious that this parameter is high at the beginning of test and gradually decreases by passing time and increasing hydraulic gradient. The average of hydraulic conductivity for PP450 A, PP450 B, and PP700 in gradient 1 respectively is equal to 0.43, 0.2, and 0.19 meter per day, in gradient 5 is 0.16, 0.09, and 0.09 meter per day, and in gradient 10 is 0.13, 0.06, and 0.07 meter per day.

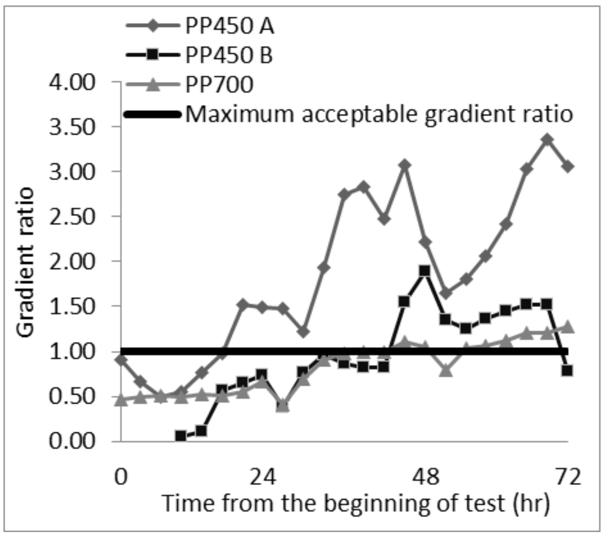


A B

Figure 4. variations of hydraulic conductivity versus time (A) and versus gradient (B)

Increasing gradient and passing time leads to a decrease in hydraulic conductivity. This phenomenon is as a result of displacement of fine particles of soil into pores and even geotextiles. In addition, pressure caused by high gradients leads to geotextile clogging and subsequently hydraulic conductivity decrease.

Results of comparing three envelopes operation show that the hydraulic conductivity of PP450 A in all gradients is higher than both. Furthermore, the average of the hydraulic conductivity from high to low for PP450 A (0.214 m/d), PP700 (0.126 m/d), and PP450 B (0.112 m/d) have been obtained respectively. The Results of the hydraulic conductivity of the geotextile- Shadegan soils are similar to another research in the Khoramshahr region (Pedram et al., 2011). Moreover, according to the above mentioned results in figure 4, the hydraulic conductivity of PP700 has greater uniformity than PP450 A and PP450 B. ; thus its function during the beginning period of agricultural lands operation has less risk.



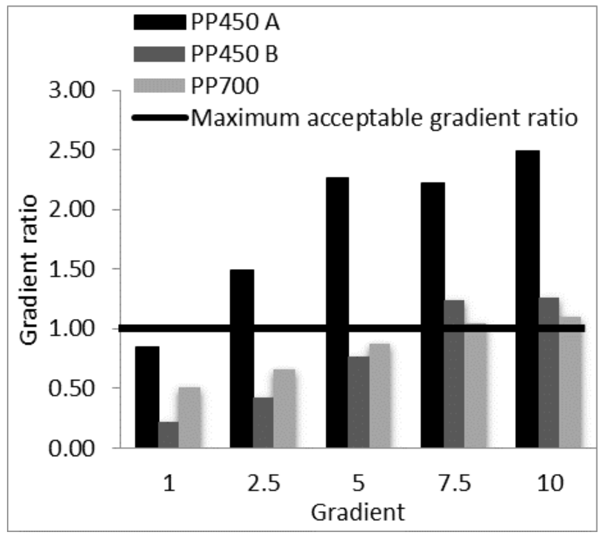


Figure 5. variations of gradient ratio versus time (A) and versus gradient (B)

Results shown in figure 5 demonstrate the fact for all geotextiles the hydraulic gradient increases lead to the increment in the gradient ratio. Based on the soil characteristics particles transfer into geotextile and pores as a result of water head increase, and thus envelope clogging potential increases.

The average of the gradient ratio for PP450 A, PP450 B, and PP700 in gradient 1 is equal to 0.84, 0.22, and 0.51, in gradient 5 is 2.25, 0.77, and 0.87, and in gradient 10 is 2.48, 1.26, and 1.1 respectively. Therefore, the minimum gradient ratio and maximum gradient ratio are obtained respectively from PP700 and PP450 A. The gradient ratio amounts of PP450 A are not in the acceptable range and this is a sign of geotextile clogging. The comparison of the function of the two other geotextiles, PP450 B and PP700 are nearly equal for gradients 1 and 5. While, PP700 has a lesser amount of gradient ratio in hydraulic gradient 10 than PP450 B. So, gradient ratio of PP700 has further uniformity than PP450 B.

Evaluation of drainage water salinity by means of the cyclic flow

In most repetitions from both gradients of 1 and 2.5, the electric conductivity variations versus time are the same as shown in figure 6. Drainage water salinity is represented in the graph is low at the beginning of test and is 2.2 ds/m. Following that, the passing of more volume of water from the and the soil column, electric conductivity of water extracted from apparatus increased considerably. Afterwards, the EC of the obtained samples'were reduced as a result of continuing the test. Eventually, because of the limited volume of soil in the permeameter and continuous inlet flow, the main salinity changes to drainage water occurred during the initial 24 hours of the test. Therefore, water quality had no significant variations from the second day of the test.

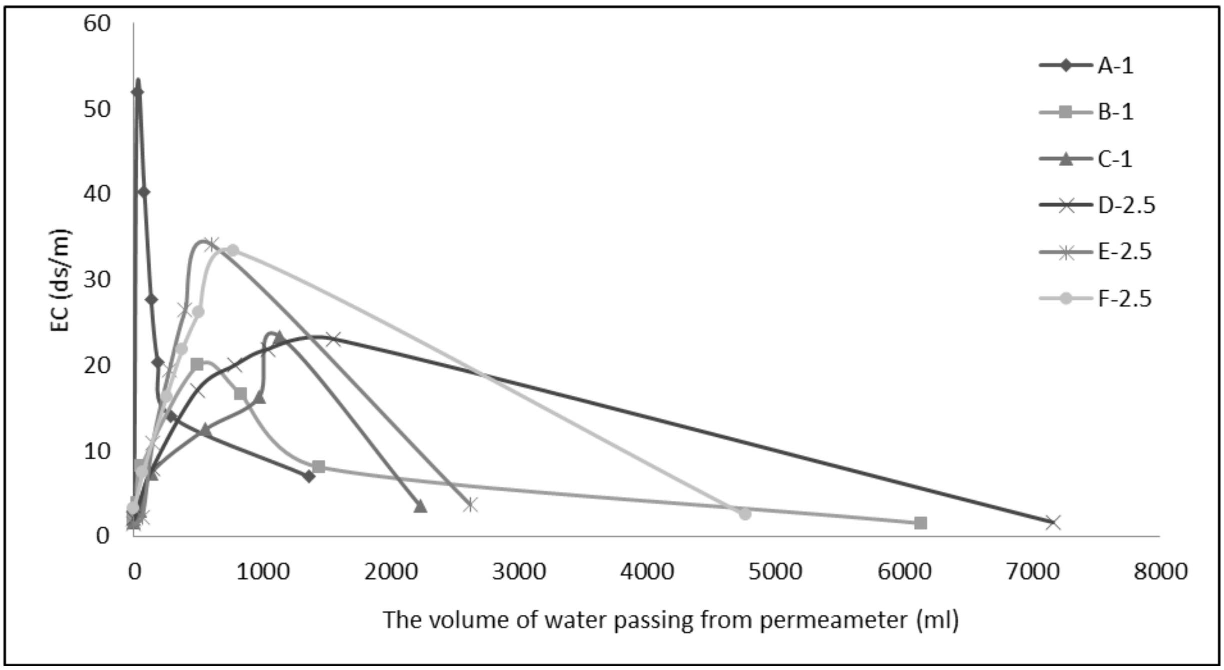


Figure 6. Electric conductivity changes versus the volume of water passing from permeameter (every gradients of 1 and 2.5 with three repetitions) during primary 24 hours

According to the results portrayed in figure 7, it is agreed that applying a cyclic flow might change the leaching process and water drainage quality. The Maximum changes of drainage water salinity occured in the initial 24 hours of test. This amount then reduced until the pausing of the flow and the the desisting of irrigation for three days, where it was observed that soil salts solubility increased. Therefore, after re-applying the flow, drainage water salinity increased after being applied for five days. Finally, test results illustrate that the salinity of drainage water decreased during the test as a result of the leaching process in general and increased slightly in the alternating flow. Thus, by applying cyclic flow , the leaching process will be done more quickly. Eventually, the upward growth of Drainage water EC is directly connected to the water drainage volume outflow from apparatus and the time required for the dissolution of soil minerals. In this test, due to the limited soil volume in the permeameter, leaching operations occurred over a short time.

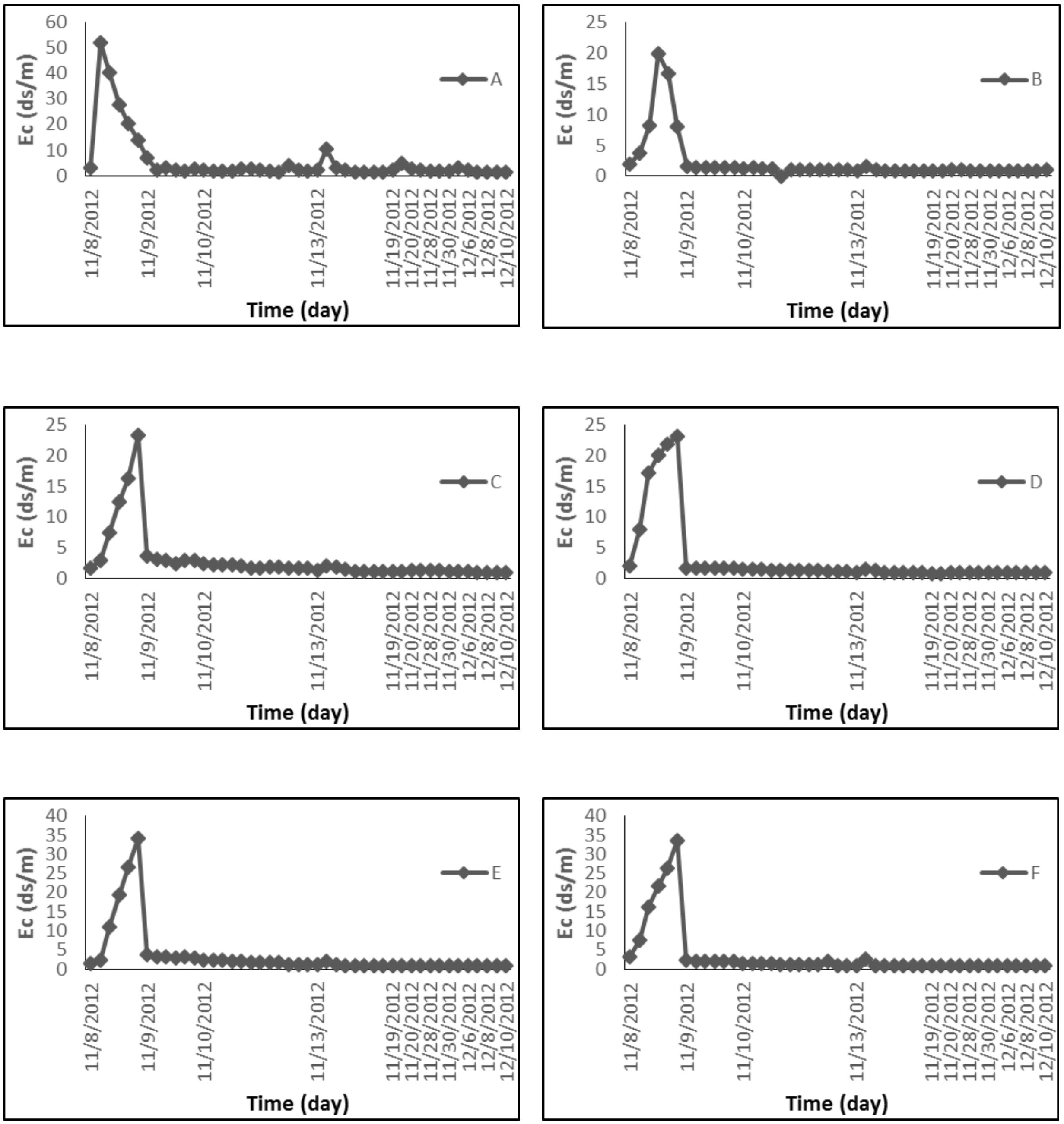


Figure7. Variations of water drainage electric conductivity versus time (A, B, and C for gradient 1 and D, E, and F for gradient 2.5)

Conclusion

The main conclusions of this research are described below:

- ✓ According to ASTM D5101, two geotextiles of PP450 B and PP700 are appropriate for Shadegan soil and even PP700 is more suitable as a result of having higher hydraulic conductivity and lower variation range in both hydraulic conductivity and gradient ratio.
- ✓ By applying the cyclic flow (similar to the irrigation process), leaching will be done more quickly than constant flow due to the increase in the time required for the dissolution of soil minerals

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APPLICATION AND EFFICIENCY OF DIFFERENT DRAINAGE TYPES ON IRRIGATED LAND IN UKRAINE

D. Savchuk[1], O. Babitska[2,*], O. Kharlamov[3]

Abstract

The processes of farming lands and settlement flooding are very wide spread in the south of Ukraine. These processes are accompanied with an increase in the ground water levels and thus create a lot of harmful effects.

Different types of drainage systems are widely used to protect rural areas from flooding. More than 400 thousands of hectares of horizontal type drainage systems have been constructed in irrigated areas and more than 200 thousands of hectares of vertical type drainage systems have been constructed. In addition, drainage systems of different types were built.in more than 550 settlements,

During field investigations authors have estimated a high efficiency and operational reliability of gravity type horizontal drainage systems and unstable working modes of vertical type drainage systems due to its discreet working regime.

As an example, the project for a drainage system for the village of Nova Mayachka was developed taking into account experience in the design, construction and operation of drainage systems to solve the issues of flooding. In recent years this village suffered the most from flooding. The existing engineering system in the village consists of 20 wells of vertical drainage, which were made for the intake and removal of ground water, but they do not insure the removal of surface water.

This system has recently provided a number of measures aimed at removing surface and ground water by means of the constructing of new open horizontal drainage systems, artificial ponds and closed discharges of drainage water to water lowering wells in the existing vertical drainage system. The project was developed taking into account the maximum use of the existing system of vertical drainage and the existing system of surface water removal in vicinity of the settlement.

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Such drainage system construction will insure an essential increase of village security level from the harmful effects of flooding; reduce the drainage discharge and expenses for electricity to pump water out.

KEY WORDS: Flooding, groundwater levels, Drainage systems, Efficiency, Correlation.

Introduction

Underflooding of agricultural lands and rural settlements is substantially widespread in Ukraine. It is accompanied by the raise of groundwater levels and stipulates different negative processes. Drainless territories on which large volumes of surface water are accumulated in wet periods especially suffer from underflooding that transforms here into stable and long lasting phenomena.

Drainage systems in the country are located in different regions and have an area of about 4 mln.ha, from which 3,3 mln.ha are located in humid zone, 0,6 mln.ha – in the zone of irrigation and 0,2 mln.ha – in the zone influenced by Dnieper reservoirs (fig. 1). The largest number of drainage systems is located in western, northern and southern regions [Savchuk D.P., Babitska O.A., Maliuha V.V., 2015].

Long term of operation (30-50 years) and insufficient financing of maintenance activities in the period of economic crisis starting from 1991 lead to worsening of drainage systems technical conditions and lowering of their efficiency. In the same time, large part of drainage units has normal operation conditions and still have an ability for long time functioning.

Modern conditions of existing drainage systems functioning necessitate assessment of their state, determination of reconstruction volumes, modernization and application of more efficient protective measures.

To solve the problems, comprehensive research has been conducted in the massifs of horizontal and vertical drainage in Kherson region (Inguletsky and Northern-Crimean irrigated massifs) in which efficiency of different types of long term operation of drainage systems has been assessed and means and measures that improve their efficiency has been determined [Demchenko O., 2007].

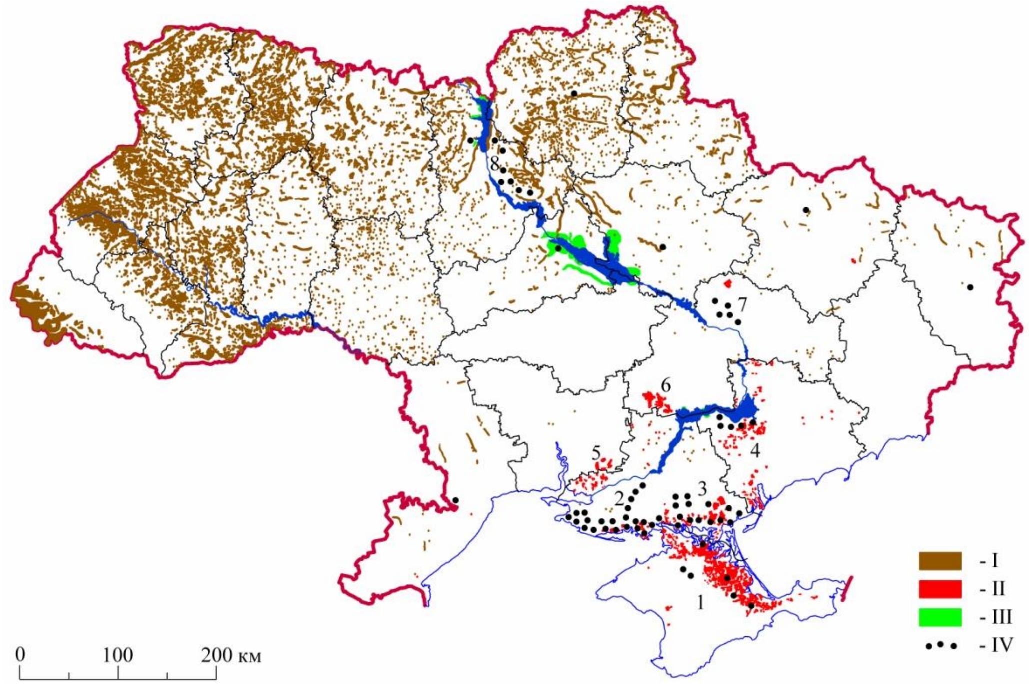


Figure1. Drainage systems location scheme:

I – overmoistured lands; II – irrigated lands; III – Dnieper reservoirs; IV – vertical drainage; irrigation massifs: 1 – Crimean, 2 – Krasnoznamiansky, 3 – Kakhovky, 4 – Pivnichno-Rohachytsky, 5 – Inguletsky, 6 – Kryvoriz'ky, 7 – Frunzensky, 8 – Bortnytsky

Mathematical relationship between groundwater levels and atmospheric precipitation has been determined as a result of the researches.

It was established that, in the regional scale, maximal groundwater level increase is observed in the spring almost every year. It indicates substantial influence of atmospheric precipitations in winter and spring on groundwater levels.

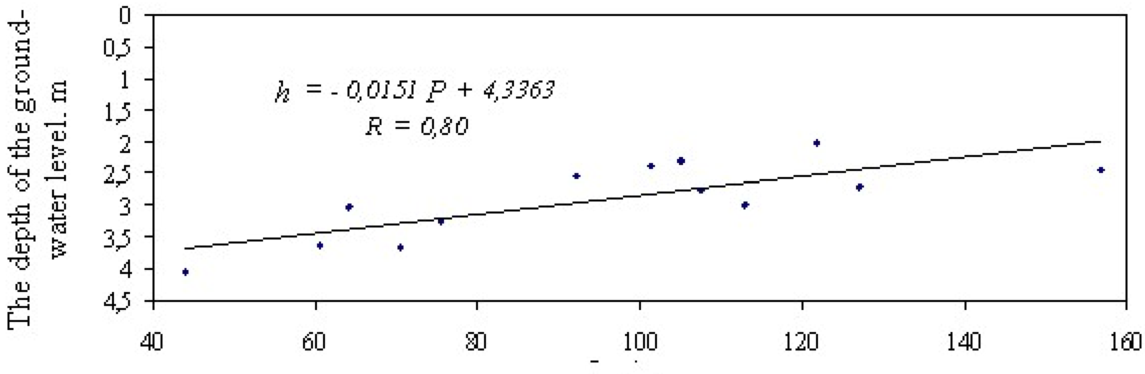
Statistical methods were used to establish correlations between water regime and factors it is determined with. Such methods can be used for steady state ground water regimes typical for irrigated massifs with relatively stable irrigational and economic conditions [Bishoff E. A. and others, 1977; Kats D.M., 1967].

Correlation was determined between independent variable – regime factor P (precipitations, mm) in the considered case, and dependent variable h (groundwater level, m).

Observation data about ground water levels in observation wells in the period between 1995 and 2008 was used in the calculations.

As the largest values of groundwater levels are observed in the spring, monthly averaged values for March was used to determine correlation. Precipitations sum was calculated for three winter months – December, January and February.

As the result of processing long term observation, correlation between precipitations and groundwater levels (fig.2) was established. Established relationship type is linear negative correlation which implies that increase of precipitations leads to increase of groundwater level (on 0,5–2,0 m).



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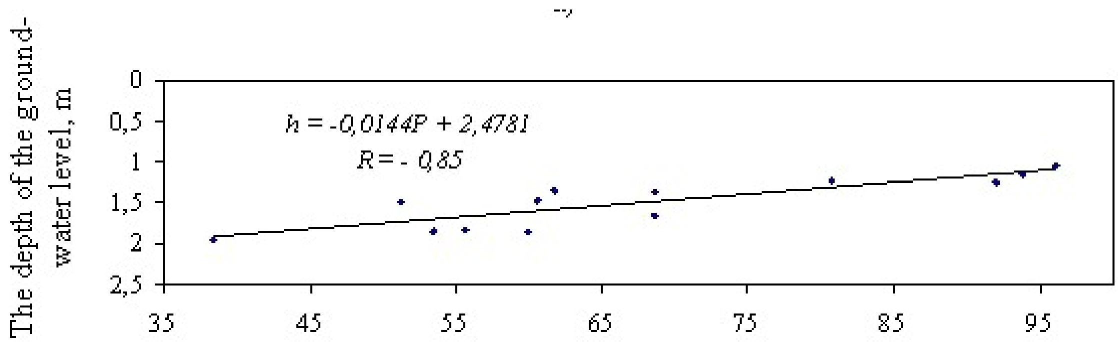

b)

Figure2. Regression relationships between groundwater levels in the spring and winter and spring precipitations: a – on the areas with horizontal drainage; b– on the areas with vertical drainage

Coefficient of correlation varies from 0,62 to 0,80. Comparison of correlation coefficient values with theoretically predicted ones shows significant relationship between groundwater levels in the spring and winter precipitations.

It was determined that on vertical drainage systems, groundwater levels in the spring vary from 0,5 to 2,0 m (that is higher than critical depths and drainage rates). This can be explained as a consequence of discreet vertical drainage working regime that do not give an ability to use entire available potential and do not insure persistent drainage of territories [Romashchenko M.I. and others, 2007; Demchenko O., 2007].

In general, it can be stated that winter atmospheric precipitations are a powerful factor of underflooding processes development in the spring even if drainage is present.

On the base of generalized materials of performed researches, the complex of measures has been developed to protect the settlements of the south of Ukraine and nearby territories that suffers from flooding [Savchuk D.P. and others, 2012; Babitska O.A., 2009, Kuzmin V.V. and others, 2011]. Protection complex includes creating local systems of surface water removal, modernization of present vertical drainage system, horizontal drainage construction, and consecutive transition to modern water saving irrigation methods (drip irrigation, micro-sprinkling). This complex of measures is proposed for the following settlements in Kherson region: Nova Mayachka, Skadovsk, Henichesk (fig. 3, 4, 5).

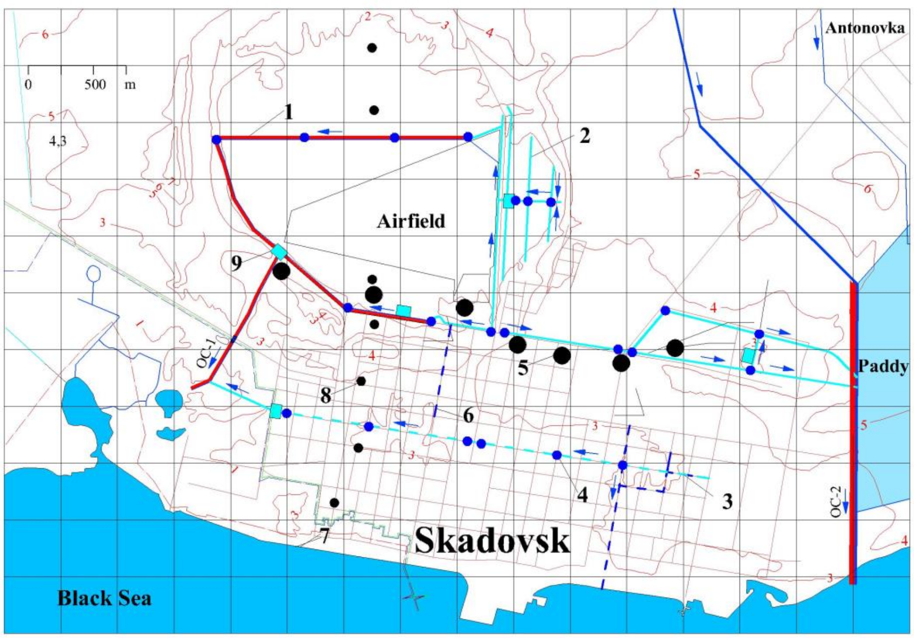

Figure3. Drainage system in Skadovsk town:

1 – open spillway canals, 2 – network of drainage collectors, 3 – closed horizontal drains, 4 – water absorbing wells, 5 – vertical drainage wells, 6 – storm water collectors , 7 – catch-water (sea), 8 – wells for monitoring ground water level, 9 – artificial water bodies.

Protective system of Skadovsk town provides creating open spillway canals that insure surface and drainage water removal. Network of drainage collectors insures interception of ground and surface water. Collector with a drain combines functions of surface and drainage water removal to narrow areas of alienated lands. Closed horizontal drains insure interception of ground water flow. Combined drainage of self-flowing type reinforces draining effect of collector network. Arrangement of drainage intake wells allows converting surface water flow into underground. In the case of high flow intensity, excess water is pumped in the drainage network, the network of collectors and storm water drains. Water intake wells can be arranged in households located in the zones affected by flooding. Vertical drainage network operation in persistent mode is performed to lower ground water level and pressure. Development of towns' storm water collection system insures arrangement of surface water flow while reconstruction of drinking water supply system and development of sewer network lowers water losses. Monitoring of flooding processes is done using monitoring wells while artificial water bodies insure additional accumulation and partial detoxification of surface water.

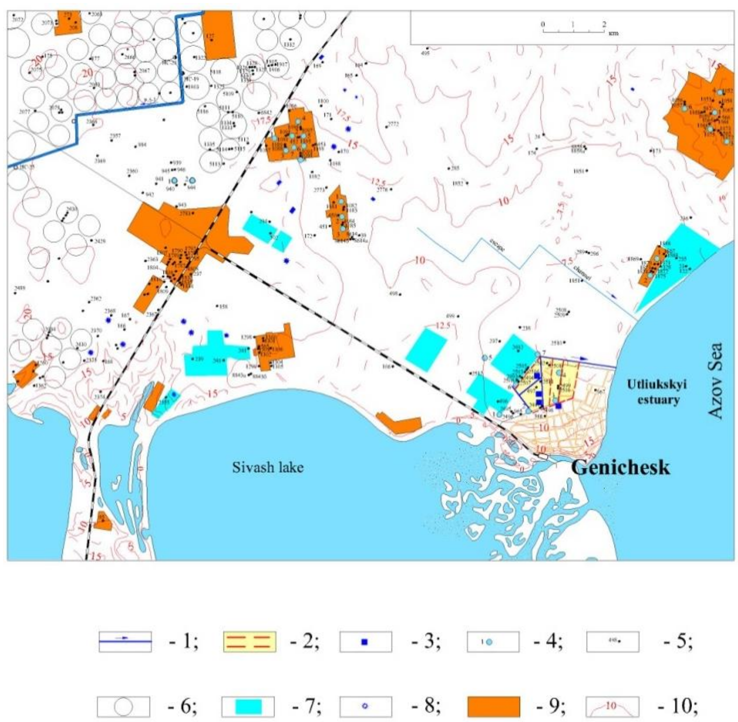

Figure4. Situational scheme of flood protection system located in Henichesk town and nearby territory:

1 – system of self-flow water removal collectors with drains (projected), 2 – system of closed horizontal drainage, 3 – nature conservational water body; 4 – vertical drainage wells, 5 – monitoring wells, 6 – irrigation systems («Fregat» sprinklers), 7 – local (small scaled) irrigation; 8 – artificial water bodies, 9 – settlements, 10 – relief contours.

Complex of measures for Henichesk town and nearby territories provides building of Jaroshyns'ky main and side self-flow collectors, construction of closed horizontal drainage system, restoration and development of vertical drainage and storm water collection systems, replacement of old water supply systems, creating means for hydroecological monitoring of territory state. In the lowest places along the collector, arrangement of artificial evaporation pounds that in the same time function as nature conservation complexes for steppe landscapes is planned.

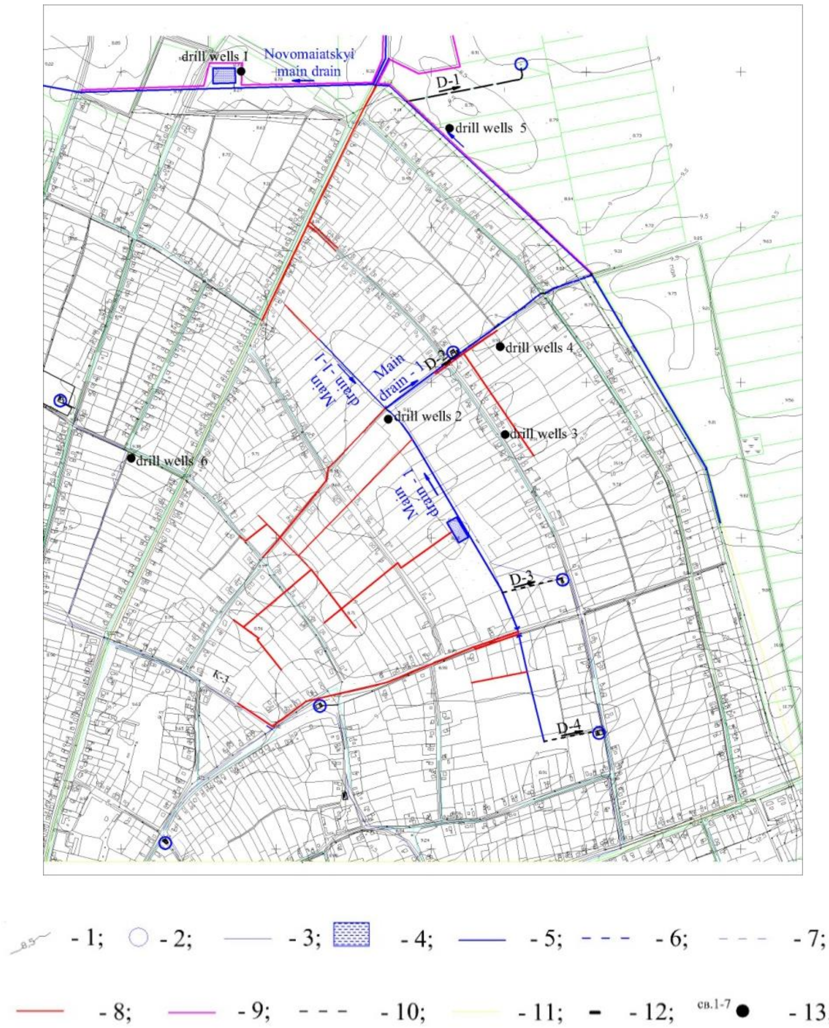

Figure5. Horizontal drainage system in Nova Mayachka 1 – relief contours and levels; 2 – vertical drainage wells; 3 – pressure pipelines; 4 – artificial water bodies; 5 – main open collector (Novomayatsky main collector, MC – 1, MC - 1-1); 6 – main closed collector (MC - 1), 7 – closed drainage collector (D-1 – D-4); 8 – water removal trenches and ditches; 9 – embankment; 10 – drain to inset into water lowering well; 11 – boundary of area of protection from harmful water effects; 12 – pipe crossing; 13 –drilled wells.

Horizontal drainage system on the territory of Nova Mayachka is arranged in the northern part of the settlement which hypsometrically is the lowest and suffers the most from flooding. Horizontal drainage systems include catch-water, Novomayatsky main collector - MC, main collector - MC-1, collector - MC-1-1, water removal trenches. A peculiarity of the drainage system consists in the fact that water lowering wells of existing vertical drainage systems work as catch-waters. Novomayatsky main collector is an open canal built in the central part of Novomayatsky drainless depression (valley). Embankment with the height equal to 1,5 m have to be constructed on the right side of the canal. Embankment catches surface flow from the other part of Novomayatsky depression and does not admit flooding of settlement territory. Water volume that floods the settlement drops by a half in this case.

Construction of such protection complexes insures substantial increase of the level of settlements and nearby territories protection from flooding along with lowering of drainage flow and expenses spent on electricity needed for forced water removal.

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GROUNDWATER MAPPING WITH GEOSTATISTICAL METHODS: THE CASE OF MANISA SALIHLI

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Abstract

Groundwater mapping using classical methods may take months and even years based on the size of the area to be mapped. However, recently developed methods decreased the time consumed for such mapping practices to minutes. Geostatistical methods are the most commonly used methods for groundwater mapping over large areas in a short time. In the present study, groundwater levels were measured using groundwater wells opened in 9101 in a 2 ha net irrigation area under the jurisdiction of Salihli Right Bank Irrigation Association located within the boundaries of the Manisa province of Turkey (between 38° 30' – 38° 37' East Longitudes and 28° 00' – 28° 16' North latitudes of Gediz basin of Aegean region). Measurements were made in September, which is the most critical month for groundwater levels. Groundwater levels were assessed through geographical information systems (GIS) and geostatistical methods. Then, spatial distribution maps were created for groundwater levels and geostatistical methods were compared. Current findings revealed that groundwater levels in the North Western section of the irrigation district was closer to plant root regions and created a threat for sensitive plants in 2003. By the year 2015, groundwater levels were 150 cm or deeper. Such levels indicated efficient operations of drainage systems and high irrigation efficiency levels. Leaching and salinity monitoring were recommended for the study area.

KEY WORDS: Ground water, Geostatistics, Manisa Salihli.

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Introduction

Water scarcity is among the most significant problems experienced by world countries. All human activities more or less depend on quantity and quality of water. Increasing demands for fresh water resources brought together comprehensive assessment of potential water resources and efficient used of current resources. Groundwaters can provide a significant alternative resource for fight against present droughts and optimum use of limited water resources. In irrigated fields, beside groundwater tables, salinity should also be monitored, assessed and salinity levels should be kept below threshold values for sustainable agriculture. Monitoring groundwater quality and quantity with classical methods is a quite time-consuming and costly process. Together with developing technologies, various new methods have recently been developed for groundwaters monitoring and assessment. However, it is quite significant to get accurate data in short time. Groundwater mapping with conventional methods may take days, even months, just based on the size of the land to be mapped. However, newly developed methods may reduce the time to map such lands to minutes. The methods to be sued in groundwaters maps, especially the geostatistical methods, are directly related to accuracy of the maps to be used. Geostatistical approaches present spatial distribution of relevant parameters and they are quite convenient to map spatial distribution of groundwaters levels and quality parameters. Geostatistical methods can present the relationships among the investigated parameters and the relationships in their spatial distributions with less cost and time. Such methods are employed in various disciplines. They may estimate the parameter value of unsampled locations and may create estimation maps accurately and reliably.

Soil physical, chemical and biological characteristics can vary spatially even within couple meters. Identification of such spatial changes and distributions is a quite significant issue in agricultural productions. Changes or variations in soil characteristics may result in differentiations in resultant yields even with the same cultural practices (Mulla and McBratney, 2000; Jiang et.al., 2006).

Classical statistical methods may not be sufficient in assessment of spatial variations in data obtained from different sections of the field since sampling locations are not taken into consideration in variance and standard deviation calculations of classical methods. To overcome this problem, Matheron developed the concept of “local variations” in 1960s. The model was first applied in mining to identify the reserve sites and the method was later on called as “Geostatistics” (Köksal, 1988; Gündoğdu, 2004). Geostatistical methods were initially employed in geological sciences, then widespread in other science disciplines. Carlson and Osiensky (1998) used geostatistical methods to determine spatial nitrate distribution in groundwaters of Northern Idaho (Gündoğdu, 2004).

In geostatistics, the similarity between the data of two points decreases as the distance between them increases and the ultimately disappear after a certain distance (Erşahin, 1999). The knowledge on such a distance with similarities between data points may provide significant advantages in agricultural and scientific practices (Akbaş, 2004).

Kriging is a geostatistical approach and provide the least variation and unbiased results as compared to other interpolation methods. It allows also the calculation of standard deviations for estimations (Deutsch and Journel 1992, Abtew et.al., 1993, Başkan 2004). As compared to again other interpolation methods, the most significant characteristics of kriging is to calculate variation for each estimation points or area. With kriging variance, the error in estimation is also assessed (Tercan and Saraç, 1998). If the kriging variance is lower than the actual variance, then the data estimated for unsampled location can be assumed to be reliable (Başkan, 2004).

In present study, water table levels of Salihli Right Bank irrigation scheme were assessed through geographical information systems and geostatistical methods. Spatial distribution maps were created with relevant methods, geostatistical methods, interpolation methods and Semivariogram/covariance methods were compared and the best geostatistical method was decided for groundwaters or water table mapping.

Materials and Methods

Study Area

The irrigation district of Manisa Salihli Right Bank Irrigation Association located in Gediz Basin of Aegean Region between 38° 30' - 38° 37' East Longitudes and 28° 00' – 28° 16' North latitudes were selected as the study area (Figure 1).

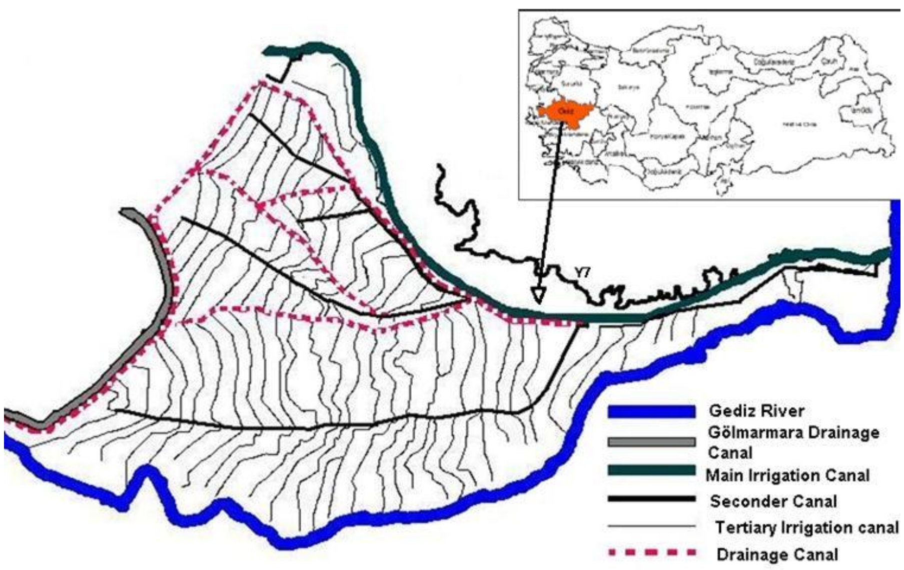

Figure 1. Map of study area

The irrigation scheme was opened for operation in 1963. Earth tertiary canals were concrete paved in 1968. Drainage canals were completed in 1984. Demirköprü Dam over Gediz River is the primary water resource of the scheme. Total canal network is 718 km, net irrigation area is 9101.2 ha. Irrigation canal length per unit area is 32.3 m/ha, drainage canal length is 12 m/ha (Tekiner, 2008). There are 18 different soil series within the study area. With regard to soil characteristics, 9.2% of soils were 2nd class, 22.9% were 3rd class, 57.9% were 4th class and 10% were 5th class (Usul and Bayramin, 2004).

Climatic Characteristics of the Basin

Study area has a humid or semi-humid climate with hot and dry summers and warm winters. Long-term meteorological data (1960-2015) for the study area are provided in Table 1. Annual average temperature is 16.6°C, average maximum temperature is 23.1°C, average minimum temperature is 10.2 °C. Average relative humidity is 62.5% and wind speed is 1.5 m/s. Annual precipitation is 457.9 mm. December has the greatest precipitation with 75.6 mm and August has the least precipitation with 4.8 mm. Annual average open water surface evaporation is 1262.2 mm (Anonymous, 2016).

Table 1. Meteorological data for study area (1960-2015)

Months	Average Temperature (°C)	Average Maximum Temperature (°C)	Average Minimum Temperature (°C)	Average Relative Humidity (%)	Average Total Precipitation (mm)	Average Wind Speed (m/s)	Average Open Water Surface Evaporation (mm)
January	6.4	11.2	2.4	74.6	66.1	1.4	1.1
February	7.5	12.7	3.1	70.6	61.3	1.5	
March	10.5	16.5	5.0	66.8	54.3	1.6	2.5
April	15.3	21.7	8.9	61.5	40.7	1.6	96.8
May	20.6	27.6	13.1	56.0	28.4	1.7	162.7
June	25.2	32.4	16.8	50.0	18.0	1.8	215.7
July	27.5	35.0	19.0	49.9	5.6	1.9	254.1
August	26.9	34.7	18.5	52.1	4.8	1.8	235.2
September	22.6	30.5	14.6	56.2	15.0	1.5	159.9
October	16.9	24.3	10.6	65.3	30.7	1.2	94.8
November	11.5	17.9	6.4	71.5	54.5	1.1	32.3
December	7.9	12.8	3.9	75.6	78.5	1.3	7.1

Irrigation and drainage water quality

Analyses results for water samples taken from main irrigation and drainage canal are provided in Table 2. Based on US Salinity Lab classification system, main irrigation canal water was classified as C_2S_1 and drainage canal water was classified as C_3S_1. According to Ayers and Westcot (1994), irrigation water does not have any problems, but drainage water may exert salinity and toxicity problems, there were not any problems with regard to infiltration and pH.

Table 2. Irrigation and drainage water quality analyses

Analyses	Main Irrigation Cana	Main Drainage Canal
pH	7.33	7.84
EC (dS/m)	0.56	1.34
Sodium Absorption Ratio (SAR)	0.75	3.85
Sodium (me/l)	1.16	7.25
Chlorine (me/l)	0.80	1.90
Calcium (me/l)	2.22	3.43
Magnesium (me/l)	2.57	3.67

Groundwater measurements

For reliable measurements, 40 groundwater observation wells should opened in 1000 hectare and 100 wells should be opened in 10 000 hectares (Güngör and Erözel 1994). By the year 2003, there were 81 wells opened the study area, but reliable measurements were able to be performed only 35 of them. The number further decreased to 19 in 2015. Locations of groundwater monitoring wells are presented in Figure 2.

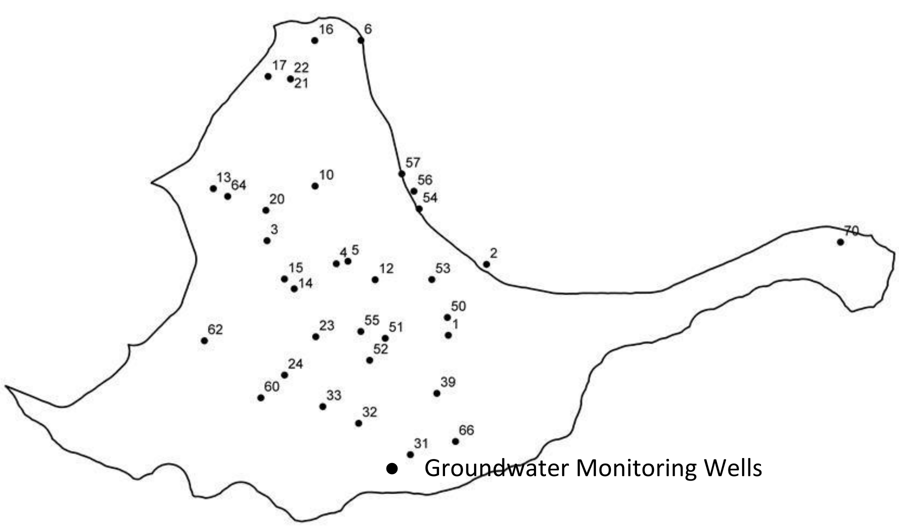

Figure 2. Groundwater monitoring wells in study area

Results and discussion

Geostatistical methods

Geostatistical interpolation methods were employed in this study to map groundwater levels. Kriging method yielded better outcomes than Inverse Distance Weighting (IDW), Global Polynomial Interpolation (GPI), Local Polynomial Interpolation (LPI) and Cokriging methods. AMong the kriging methods (Ordinary, Simple, Universal, Indicator, Probability and Disjunctive), Ordinary kriging yielded the best results. Ordinary kriging and Cokriging are two geostatistical techniques used to create continuous maps of spatially auto correlated attributes. Both procedures use the same primary variable, but CoKriging, like multivariate statistics, incorporates additional independent variables (King et. al., 2016). Kriging interpolation method uses the data of sampled locations and estimates the optimum values of unsampled locations (İnal et.al., 2002). Kriging interpolation allows unbiased optimum identification of spatial distribution of the relevant traits of unsampled locations by using semivariogram structural characteristics (Trangmar et.al., 1985, Başkan, 2004). The greatest attribute of kriging method separating it from the other interpolation methods is to calculate variance values for each point or area, such a variance is the measure of accuracy fort he estimated value (Başkan, 2004; Yaprak and Arslan, 2008).

Descriptive statistics for pre and post-irrigation season are provided in Table 3. Exponential function with the least nugget value was used to create the groundwater maps in kriging and semivariogram/covariance methods (Table 4). Semivariogram values increases with increasing distances between sampling locations. The maximum value of semivariogram yields “sill” value and observation points vary around this value. The distance in which semivariogram reaches to sill value is called as “range”. It indicates that distance in which observation values are independent from each other. From this distance and further, there aren’t any spatial relationships between any two sampling locations. In range values lower than the distance between the closest points, variation of differences between the values are not able to be identified. Such a case results in a positive semivariogram value different from zero. Sampling and analyses errors also result in similar effects. These positive values, which theoretically should be zero, is known as “nugget” effect (Bailey end Gatrell, 1995; Hengl, 2009; Fotheringham et.al., 2010; Kalkhan, 2011; Chun and Griffith, 2013; Oliver and Webster, 2014; Aydin et.al., 2015). Therefore, exponential model was selected as the best semivariogram model and used in groundwater mapping.

Table 3. Descriptive statistics

Parameters	Pre-Irrigation		Post-Irrigation	
	2003	2015	2003	2015
Count	35	19	35	19
Min	102	107	50	143
Max	351	310	309	321
Mean	247.2	198.68	193.74	203.32
Std. Dev.	55.851	62.826	56.626	57.475
Skewness	0.3208	0.425	0.17692	0.89721
Kurtosis	2.8073	2.3574	2.7521	2.6937
1-st Quartile	213	147.75	156.75	153.5
Median	247	197	187	191
3-rd Quartile	293.25	234.25	243.25	229

Table 4. Semivariogram values

Model Type	**Lag size**	**Nugget**	**Range**	**Partial sill**
Circular	1363.5	1470.3	10755.1	3182.5
Spherical	1363.5	1467.8	12686.9	3252.1
Tetraspherical	1363.5	1474.4	14871.4	3365.3
Pentaspherical	1363.5	1461.7	16046.5	3354.4
Exponential	1363.5	1228.1	16046.5	3477.6
Gaussian	1363.5	1865.9	12366.1	3554.0
Rational Quadratic	1363.5	1663.2	16046.5	2682.3
Hole Effect	1363.5	1857.8	15057.2	2427.7
K-Bessel	1363.5	1876.3	15089.2	4269.4
J-Bessel	1363.5	1829.9	15367.7	2208.3

Groundwater levels

Groundwater levels were measured from observation wells pre and post-irrigation seasons between the years 2003-2015. The maps created by using these values are presented in Figures 3, 4, 5 and 6. While groundwater levels were around 200 cm at northern and northwestern sections of the study area in pre-irrigation season of 2003, the level was more than 300 cm at South and southeastern sections of the study area. In 2015, groundwater levels slightly increased in pre-irrigation season and reached to 150 cm. Such a rise was mainly because of sufficient precipitations in relevant period.

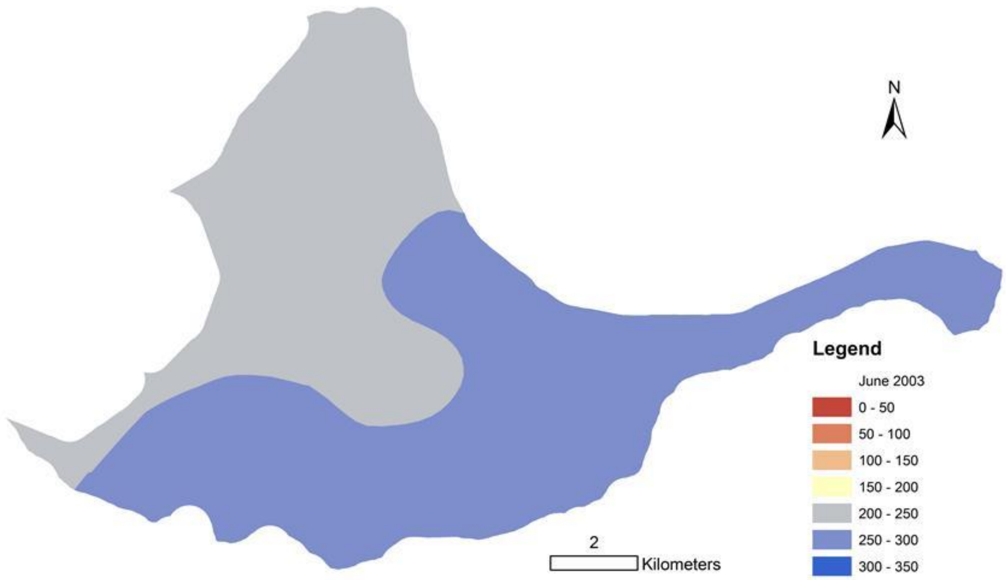

Figure 3. Groundwater levels in pre-irrigation season of 2003 (cm)

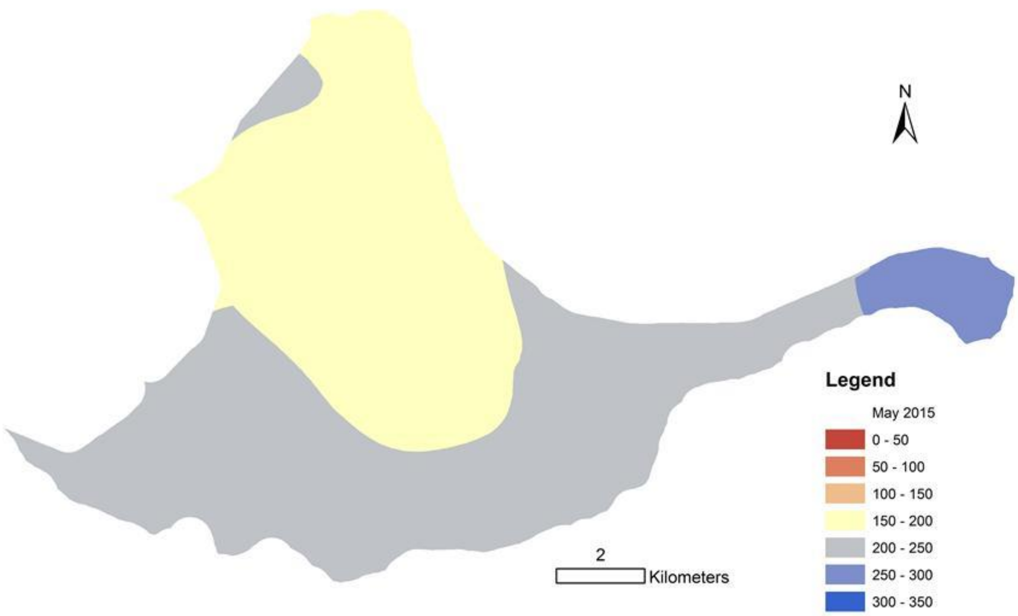

Figure 4. Groundwater levels in pre-irrigation season of 2015

During the post-irrigation periods, groundwater levels raised. Despite the sub-surface drainage systems of the study area, 50-100 cm rises were observed in groundwater levels in post-irrigation seasons and groundwater levels reached to plant root regions at Northwestern section of the study area. Groundwater levels reached to 100 cm at northern and Northwestern sections of irrigation district. Such a case created a threat on plants sensitive to high water tables. In 2003, 911 mm irrigation water was applied throughout the irrigation season (it was estimated that about 58.7% of it charged groundwater) (Tekiner, 2008). In post-irrigation period of 2015, such rises were observed as 50-100 cm decreases. The closest groundwater level was around 150 cm and deeper within the study area.

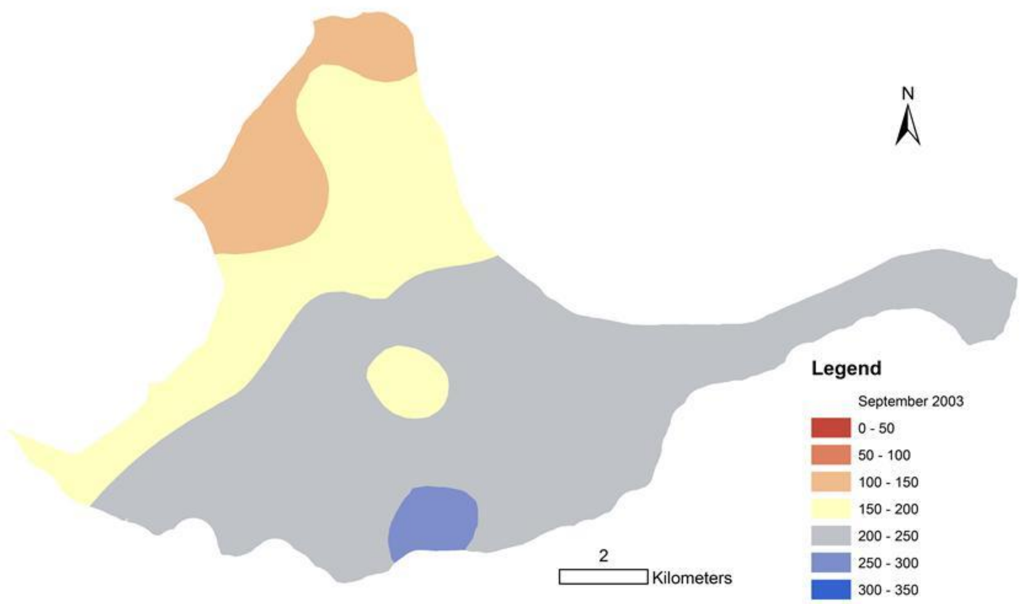

Figure 5. Variation in groundwater levels in post-irrigation season of 2003

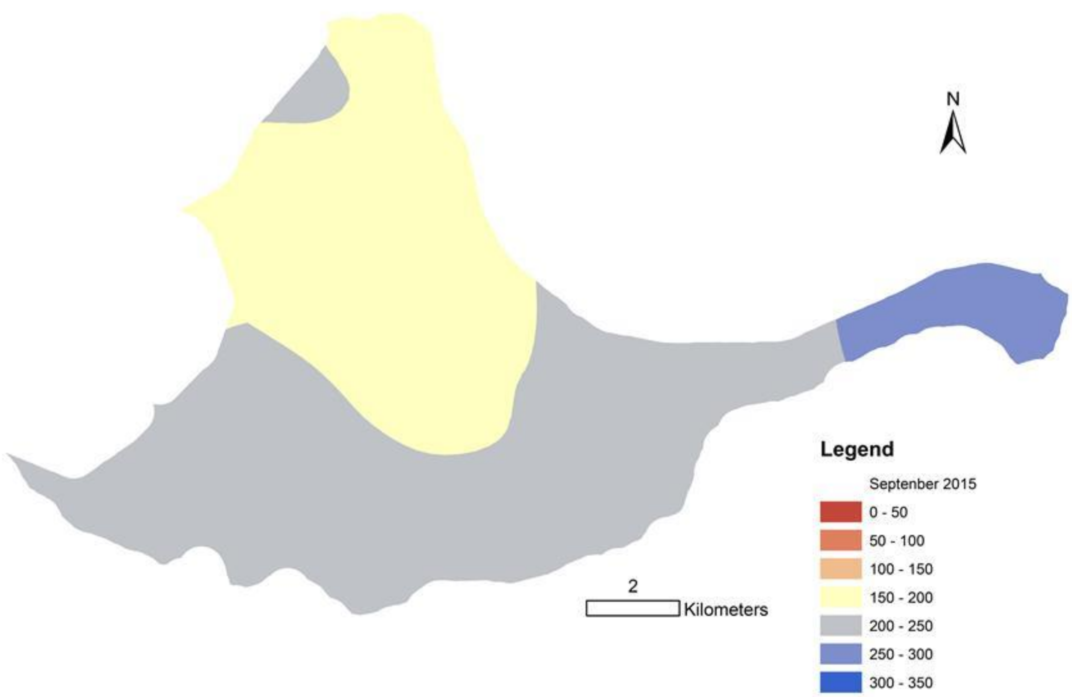

Figure 6. Variation in groundwater levels in post-irrigation season of 2015

In 2003 between the beginning and end of irrigation season, groundwaters exhibited a rising trend. In 2015, a reverse case was observed, in other words, groundwater levels decreased at the end of irrigation season. The reason of such a case was the use of high-efficiency irrigation systems, recent droughts and efficient operation of drainage systems during 13-year observation period.

Conclusion and recommendations

Kriging was identified as the best interpolation method to map groundwater levels through geostatistical methods. Among the kriging methods, ordinary kriging yielded the best outcomes. As semivariogram/covariance method, exponential model with the least nugget value was found to be the most reliable model for the production of groundwater level maps.
Increasing irrigation efficiencies, excessive input use (water, fertilizer, pesticides and etc.) may result in soil salinity in long-run especially in regions with insufficient precipitations for leaching. Such increasing salinity levels then create various burdens in agricultural activities. Therefore, further studies are recommended for the efficiency of leaching practices.

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