Proceedings of the International History Seminar on Irrigation and Drainage

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Organized by:

◈Iranian National Committee on Irrigation and Drainage (IRNCID)
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Preface

Water scarcity, as well as, insufficient precipitation in our country has made the responsible Iranians challenge the technical, institutional, environmental, and social issues to establish sustainable water and irrigation development and management in arid and semi-arid regions of Iran.

Indeed, the history of water supply, irrigation, and drainage in Iran reveals how the relevant structures have played their important roles in forming, flourishing and development of civilizations.

There are over 30,000 ancient Qanats, as well as, thousands of water structures such as weirs, benchings, bed groins, water reservoirs, water-mills, traditional baths, many of which are still under operation.

Water and Irrigation Techniques of Iranian in ancient time and the relevant services to the nation are admirable. Analyzing their experiences,we realize how the civilization of ancient Iran affected on the civilization of the other nations and on the modern sciences & technologies.

Of course, we shouldn't expect the old and new ideas to be the same, as the basis of modern sciences and technology lies on broad and extensive investigations and experiences of all the developed nations during the recent centuries. Comparing the old sciences with the new ones, we respect and are proud of our ancestors, because they solved their difficulties without having the present facilities and equipment.

Considering historical water civilization, Iranian National Committee on Irrigation & Drainage (IRNCID) has proposed that the International History Seminar on Irrigation and Drainage (IHSID) be held in Tehran, in May 2007 as an opportunity to get the honorable participants acquainted with the Iranian initiatives and capabilities on hydrology, irrigation & drainage sciences & technology, as well as, to exchange experiences among the other countries.

Simultaneous with IHSID, the 4th Asian Regional Conference & The 10th International Seminar on Participatory Irrigation Management shall be held in Tehran, during 2-5 May, 2007. IRNCID appreciates all the researchers, experts and professionals for their priceless scientific contributions, enriching the Conference/ Seminar.

Dr. R. Zargar
Deputy Minister for Water Affairs, and
Seminar Organizing Committee, Chairman

Introduction

Development and management of water in arid and semi-arid environment is very delicate. Without due considerations to environmental and social factors, the system developed often result in environmental degradations, particularly salinization and social turmoil. Arid countries and regions, like Iran, have accumulated wisdom and knowledge on how these complicated problems should be tackled. In the seminar, the accumulated knowledge and wisdom, based on the lessons learned from failures and mistakes, will be introduced, and approaches of establishing sustainable water development and management in arid and semi-arid regions will be discussed.

Scarcity of Water resources in the arid and semi-arid regions of the world made the human-beings do their best to innovate, to find out optimum methods, to fulfill their goals of water supply and to satisfy the water demand. They were not equipped with the modern hardware and software; however, their initiatives are still noteworthy after passing so many centuries.
Study and research on “Technical Issues”, “Institutional Issues”, “Environmental Issues”, & “Social Issues” will still be useful and effective. Hence, the chosen seminar main topic is: “Lessons to Learn from the Historical Development and Management of Water in Arid and Semi-arid Regions” to enrich and exchange our experiences and view-points by gaining the knowledge of such lessons from various countries located in the arid and semi-arid regions.

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TRADITIONAL WISDOM IN WATER MANAGEMENT-A CASE STUDY OF DAULATABAD FORT (INDIA)

Pradeep Bhalge[1], Mrs. Charu Bhavsar[2]

ABSTRACT

In the arid zone the spell between the two Rain showers is too large. These dry spells reduce the crop yield drastically. Once the rain disappears, the lands become as dry as like desert, life difficult and water scare to find. In India, the monsoon rainfall occurs only for a short duration. It is not evenly distributed all over the country. It is erratic in nature. Some times it fall with high intensity or some times with very low. Thus the water was a very ephemeral resource for them. To maintain the sustainability in food production and to give protective irrigation they slowly grew the extraordinary traditions of water harvesting in innumerable forms in different parts of India. Depending on the resources available to them, they developed a range of techniques to harvest every possible form of water - form rainwater to ground water, stream water to river water, and floodwater. Various examples spread over the country shows that the water harvesting systems were last for a long period of time, may be 300 to 600 years. The systems were maintenance free, or can run with meager expenses. Indians have given importance not only for the collection of rainwater but equally importance to the purity of the water. Indian civilization is one of the oldest civilizations in the world. It has contributed a large number of aspects such as religion, culture, philosophy, technology, water harvesting, and water management. Several periods of prosperity are quite discernible in the history of India. Numerous documentary and field evidences which attest to the existing water systems which in turn were based on well conceived planning and regulation, are extant in different part of India. The method of water development of respective periods have long been closely linked to the Indian climate, social fabric, and living style. The recently carried out exercise by Maharashtra Water & Irrigation Commission has brought to the fore the possibility of unearthing countless guiding principals through the data that may prove useful in the contest of structures being conceived in the new environment of India. History shows that, though under the dynastic ruler of those days, people lived happily. However owing to the neglect, innumerable structures and an invaluable stock of literary and documentary information pertain thereto are gradually being pushed on the verge of extinction. It is necessary to get all this preserved as a valuable historical heritage. The Medieval rainwater harvesting techniques and management of water resources used at Daulatabad fort

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[India], is an inspiring example for the water harvesting experts. It gives the guidelines for How to manage the available water resources effectively? The water harvesting techniques at Daulatabad can be said as one of the best examples in the world. The details of the scheme are discussed in this paper.

INTRODUCTION

In monsoon countries like India, rainfall is seasonal and its variation from place to place is appreciable large. Daulatabad is situated in central-southern part of India. In this region the monsoon rainfall is quite scanty and highly erratic. There were no permanent water supply sources, like river or big tank in the vicinity of Daulatabad fort. Hence rainwater was the main source for the contemporary people. All this area is covered with Amygdaloidal basalt; in which rainwater do not get percolate inside the ground. Therefore only ground water source was not sufficient to fulfill the needs of the people. But History revels that though the water was scanty, the agriculture based economy flourished in this area and the period was known as golden era. This means that the people were well managing the available water resources and making good yield from their farms.

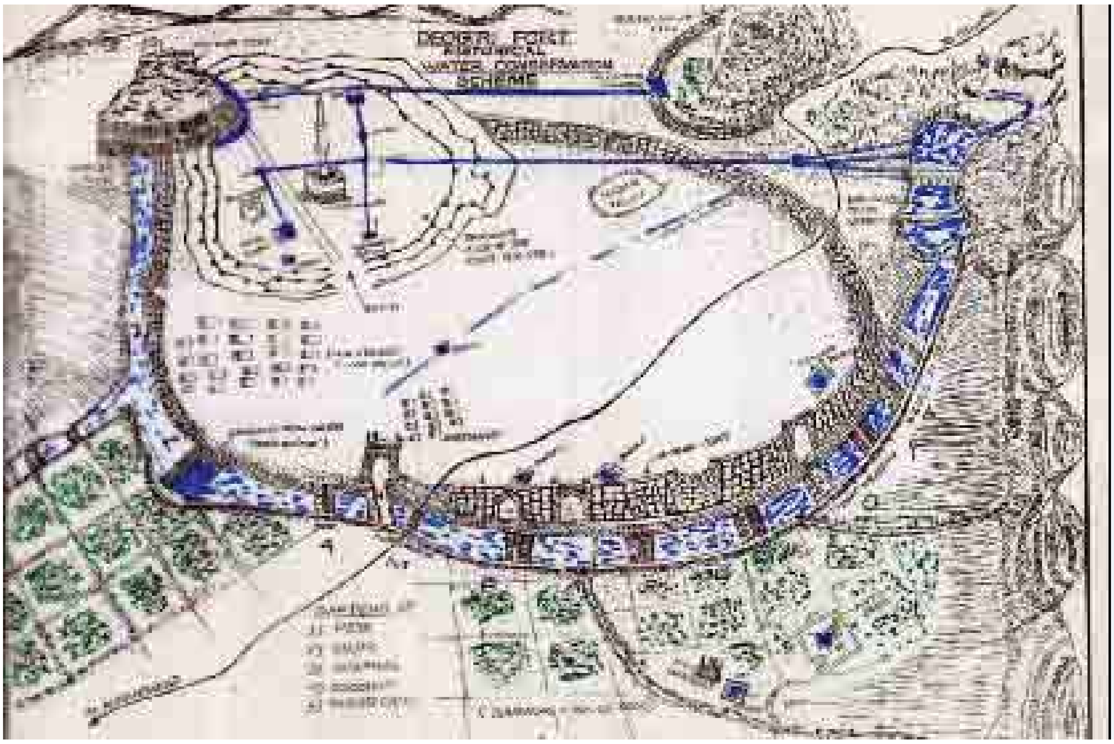
It is believed that Bhillama the fifth king of Yadava had constructed the Daulatabad fort in the year 1187A.D[1]. For the purpose of defense he selected an isolated cone shaped hill, suddenly rising from the plains to the height of 700 feet and surrounded by spurs of the Balaghat ranges. The hill is separated from the rest of the area by naturally scarped cliff. Due this feature minimum artificial defense would necessary. Bhillama made it more impregnable by scarping it further. An official chronicler Mr. Lahori wrote that, the scarping was so smooth that neither an ant nor a snake could scale it[2]. From the defense point of view the above arrangement was very good. But water supply to the high level fort was a big problem. Pertaining to the water supply schemes at Daulatabad, the contemporary historians and travelers even known for their details are silent. Therefore in this paper we have thrown a light on the issue, how? The dynasties had solved the water problems.

It was a capital of Maharashtra state for a long period and imperial capital for a short duration. From contemporary record it is evident that the Daulatabad of Yadava's period was a twin city comprised of the suburbs of Kataka and Devagiri. It was the wealthiest trading center of south-central part and the seat of intense political activities, and the army head quarter. It was under the Islamic rule for more than 600 years. Hence it has assimilated the Islamic way of life in its true sense.

Daulatabad is known for its medieval hill–cum land fort. It is most significant of all forts in India. It is associated with number of dynasties. Their names are listed below.

1. The Yadava [1187-1294 A.D.]
2. The Khalaji [1295-1320 A.D.]
3. The Tughlaq [1320-1343 A.D.]
4. The Bahamanis [1350-1484 A.D.]
5. The Nizam [1490-1635 A.D.]
6. The Mughal [1635-1724 A.D.]
7. The Asafzahi [1724-1948 A.D.]
8. The Maratha [1750-1780A.D.]

Being capital of the region, the population in this region was high. Thus demand of water was also high. The dynasties had solved these water problems. They adopted various rainwater harvesting methods and efficient water management techniques. Rainwater harvesting methods adopted at the world famous Daulatabad fort in the olden days are inspiring examples to the present water crises problems[3].



WATER SUPPLY DURING YADAVA’S PERIOD

Yadavas were the founder of the fort and the city. It was their capital. The township of Daulatabad included the citadel with few palace complexes at the central hill and suburbs of the towns of Daulatabad and Kataka. Daulatabad was reserved for civil population and kataka for the army.

Baring rain was the only source of water source. They constructed two cisterns cut in rock for storing the rainwater. Storage capacities of these cisterns are very small. With adequate monsoon, the stored water would suffice for approximately two hundred persons per year. There were about 100 wells including step wells in the vicinity of the suburbs. Further the extensive exploration also revealed that there are four big tanks at different altitudes. These tanks were constructed in the Yadava’s reign. After Muslim occupation they were renamed as Parion-Ka-Talab, Hauz-A-Qutlaq and Ab-Pash-Darra. The rock – cut cisterns, open dig wells and tanks were the sources of water supply during the Yadava’s period. The estimated population was about 50000.

WATER SUPPLY DURING KHALAJI’S PERIOD

Khalaji’s reign was very short. They did not add in to the existing water supply schemes.

WATER SUPPLY DURING TUGHLAQS’S PERIOD

Tughlaq followed Khalaji. He resolved to shift his capital from Delhi to Daulatabad. New fortification walls were constructed and the fort was made strong to withstand the attacks of enemies. According to Yaha sirhindi, the city was erected within a span of six years [1321-27 A.D.] and peoples were forced to migrate from Delhi to Daulatabad. Because of the forcible migration its population was reached to zenith. This abnormal increase in population warranted a guaranteed water supply. For that purpose he diverted the water from Mausala tank to the forte.

WATER SUPPLY DURING BAHAMANI’S PERIOD

For about one and half century, Daulatabad was under the possession of the Bahamani dynasty. During these occupations some fortification walls namely the double wall of Mahakota and Kalakota were added, The Chandminar complex was erected. Some palaces, mosques, gardens, and residential quarters were also erected.

There were wells within and out side the forts. For the purpose of water supply, some of the wells were sunken deep. The earlier water supply system was renovated.

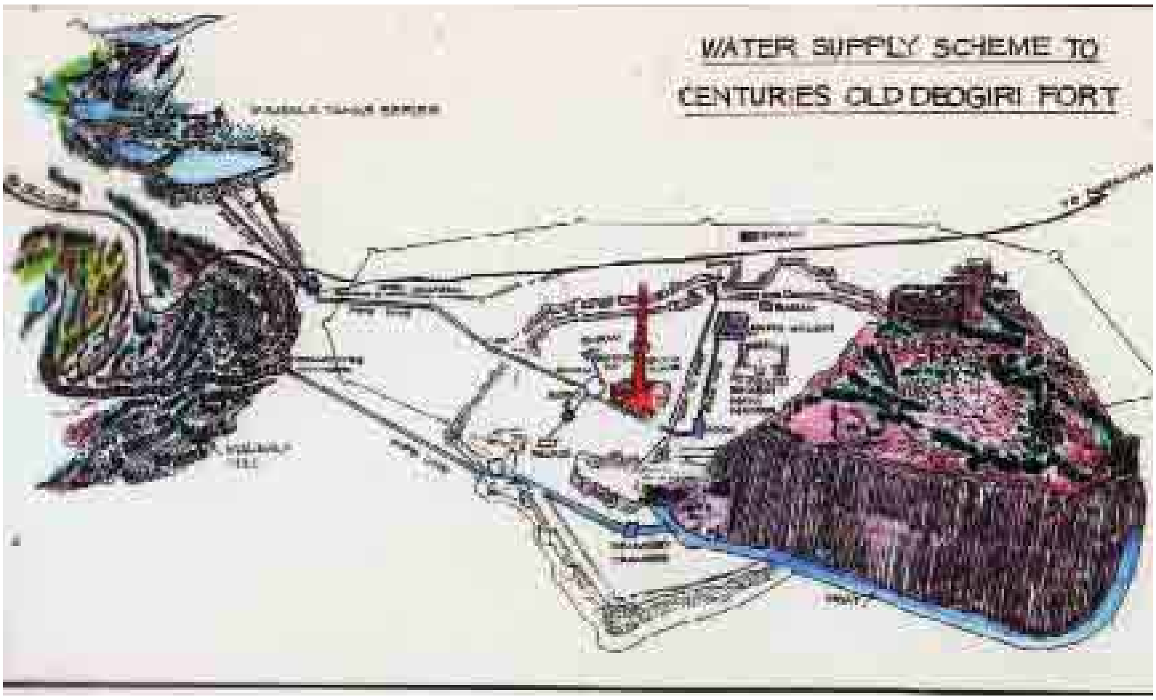
WATER SUPPLY DURING NIZAM'S PERIOD

Nizam was the successor of Bahamani. Malik-Amber was the prim minister of Nizam. Malik was a born hydraulic genius. His knowledge of hydraulics was matchless., Daulatabad was made the state capital in his working period. This resulted into abnormal increase in population. Under the guidance of Malik, the forte was again reinforced. He constructed a magnificent palace at the top of the hill as an emergency resort. He provided all types of royal amenities at the high altitude. He excavated a ditch around the circuit of the hill and isolated the hill from the rest of the area. He continued the excavation deep in to the ground and provided an artificial moat of thirty feet wide and sixty feet deep all around the hill[4]. A withdraw-able bridge over the mote was provided to have link between the central isolated hill and rest of the area.

The area limited by the escarpment on one side and fortification wall [kalakota] on the other side was reserved for the royal Darbar. Large numbers of palaces including Divan-E-Khas were constructed along the escarpment.

The area between Kalakota and Mahakota was reserved for residence. This area was divided in to two sectors. The north sector was earmarked for VIPs and south sector was distributed among the bureaucrats and ministerial staff. A great fortification wall known as Amberkota with number of strong gates, battlements, bastions, was constructed in this period.

As far as the source of water supply is concerned there were two reservoirs in the northern valley but were at low level. Therefore it was not possible to carry water from these reservoirs in to the fort. For making arrangement of water supply to the high level based fort, Malik had constructed a number of new water supply schemes. The details are given below.



RAINWATER HARVESTING[5]:

FIRST LINE OF WATER SUPPLY

This scheme was designed only for the water supply to the royal-complexes. On the opposite and northern side of the fort, there is a hill known as Mausala hill. For collecting the rainwater coming from the top, he constructed a ditch and a small masonry bund at the foot, parallel to the length of the hill. The width of the bund was 450mm, height 750mm, and length was measured as 2000m. A gentle slope was given to the ditch. At the end of the ditch a collection-filtration chamber was constructed. This chamber incorporated two filtering units one below the other. The upper unite is in brick and lime mortar while the lower one is in dressed stones. The lower unit has two openings. One opening has diameter 200mm and other having 400mm diameter. From these openings two conduits were takes off. Stone grills were fixed at the mouth of the two opening for filtering the water.

A second chamber was constructed near the moat and at the top of a tower, inside the fort. The level difference between the two chambers was kept as 10m. The conduits taking off from the first chamber ends in to the second. The 200mm-diameter conduit was made up of terracotta. And the 400mm-diameter conduit was made up of stone. Both these conduits were laid in lime concrete with casing of lime mortar, bricks bats and pebbles. The lengths of the conduits were measured as 1000m.

The water flowing down the hill thus gets collected in to the collection-filtration chamber. The bottom R.L. of this chamber is measured as 514.820 meter. After filtration the filtered water enters in to the conduits and conveyed to the second chamber. The second chamber was constructed at the top of a tower, near the escarpment. It was also functioning as a distribution chamber. The bottom R.L. of this second chamber is found to be 503.570 meter. The level difference between the two chambers was sufficient to carry the water by gravity. A moat section of 200 meter long, 10 meter deep and 20 meter wide were separated from the rest. For that purpose of two diaphragms at 200m distances were kept while cutting the moat below the surface level. The water -storing capacity of this moat section is 40000 cubic meters. A hole at a specific height was provided in each diaphragm for letting out the excess water and stored in the remaining part of the moat. At two convenient places provision of lifting water were made. With the help of the Bullocks water was lifted in to an elevated tank. From this tank terracotta pipelines were provide to supply water to the desired palace complex.

SECOND LINE OF WATER SUPPLY

To meet increasing need of water supply he implemented number of other schemes. To provide water between the fortification walls Kalakota and Mahakota, a new scheme of water supply was provided. On the north side of the fort there is one valley. In this valley there were three reservoirs. A controlled outlet, to let out the water was provided in the topmost dam. The water released from the out let gets collected in to a rock cut cistern, which was constructed, on the down stream side of the dam-wall. This reservoir was named as Hauz-E-Qutlaq. A conduit of 200 mm diameter was taking off form the above rock cut cistern. This conduit line carries water and let in to a water distribution chamber, in side the fort. From this chamber several terracotta pipelines takes off, leading water to various sectors. One of these pipelines conveys water to Hati-hauz [a huge water tank]. The tank is of size 38m x 38m x 6.6m size. It has storing capacity of 10000 cubic meters. It is below ground level. And walls are smoothly plastered from inside. Steps were provided on the three sides to reach to the bottom of the tank. The water stored in this tank was then utilized as and when needed. This water could be fulfilling the annual need of 20000 people.

THIRD LINE OF WATER SUPPLY

A chamber was constructed, on the down streamside of the second reservoir [middle level reservoir] and at the foot of the left side hill of the valley. A ditch was excavated and a bund was constructed parallel to the length of this hill, in such a way that, the rainwater, fowling down the hill gets collected in the above chamber. A conduit takes water from this chamber, crosses the valley and releases water in to an open channel. This open channel runs along the northwestern boundary of the lower most third weir

[Ab-Pash-Darra]. A control out let was fixed in the dam wall of the third reservoir. From which water can be released in to the above channel as and when required. This channel ends in to a filtration chamber. This chamber was constructed near the Ellora-gate. After filtration, the clear water was conveyed inside the fort with the help of 200mm diameter terracotta conduits. Numbers of pressure relief towers were fixed on this conduit line. This conduit again ends in to a distribution chamber. From this chamber water was distributed to desired locations.

FORTH LINE OF WATER SUPPLY

For providing water to general habitation, a separate scheme was executed. Water from the third reservoir was released in to a separate open channel. This channel was constructed in stone and lime mortars. This channel was conveying water to a filtration chamber. After filtration, with the help of conduits, the water was supplied to the area of general habitation.

FOUNTAIN

Generally the conduits end in a tank [small or big], and mostly it is connected to a fountain fixed at the center of the tank. Arrangements were made to collect the excess water after filling the tank. The excess water was then conveyed to the garden with the help of small channels.

For beautification of the garden the tanks were made in various shape such as hexagonal, octagonal, lotus shape etc. The use of water for entertainment is the outstanding contribution of this phase.

LOCKING SYSTEM

The water so brought to the distribution system was controlled by means of locking of pipes. The system was very simple. A conical piece of over burnt brick was used to fix in side the pipe. Using this piece the flow could be controlled.

CONCLUSION

The habitation inside the fort can be divided in to following region.

1] To meet the scarcity of water various schemes of water supply are implemented during different phase of occupation. The schemes can be groped as permanent and seasonal. The seasonal devices were based on rainwater harvesting. Reservoirs constructed in the northern valley were used as permanent water source.

2] Stone and earthen conduits, filtration chambers, pressure relief towers and distribution pipelines were the characteristic features of the supply schemes.

3] Water is conveyed by means of gravity.

4] Without any engineering contrivance, they calculated the relative levels and designed and executed the schemes.

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SOME INCOMPARABLE ASPECTS OF IRRIGATION ART IN ANCIENT IRAN

Bijan Farhangi[1]

ABSTRACT

The ancient land of Iran, with its enduring civilization, is recognized by the world as a cradle of culture and civilization. Her intellectuals founded, over the centuries, great traditions of philosophy, science, art and craft, as well as establishing moral values that led to a long-lasting and harmonious relationship between the individual and society. It is self-evident that in the development of an ideology based on the three pillars of "auspicious thoughts, actions, and dialogues", there exists and implicit set of magnificent spiritual guidelines.

The purpose of compiling this Paper is presentation of the historical values of the ancient hydro-structures of Iran. In the following aspects:

Water mills, an Iranian architectural initiative in the expoitation of Hydropower.

- Water supply and physical water treatment in 3300 years old Choqa-Zanbil Ziggurat-A brilliant example the Iranian's ingenuity.

Ancient weirs in Iran.

Qanats (subterranean caral,an eternal saga of man defying aggressive elements, of nature in desert.

Water mills, one of the skills of ancient Iranians was to make use of the water's hidden power to rotate the stones of the watermills.

The watermills were powered by the river currents, springs or Qanats. A conduit just before the mill shaft would act as a bypass when the mill was not in operation. The mill shaft semi conical in shape and its diameter reduces from top to bottom. This shaft can be plugged by a wooden device which is accessible through a narrow gallery from inside the mill.

Water supply and physical water treatment in in choqazanbil Ziggurat, The Elamite temple of Choqa-Zanbil, otherwise known as Dur-Tash, is located on a Dur-un rash

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high mound on the bank of the river Dez, a tributary of the Karun, and was built in 1250 B.C. (ie. 3300 years ago) by the Elamite king Untash-Gal for the Elamite deity "Inshushinak".

By the order of Dur-Untash Gal, the Elamite king (1245-1265 B.C.) a 50 km long canal was excavated to transfer water from the Karkheh River, on the west of Susa, to a sedimentation basin and then the town itself.

The remains of a large excavated reservoir and a basin can be seen outside the exterior walls of the Dur-Untash town. The water used to be de-silted in the reservoir and then transferred via a series of canals to the basin where it, could be taken by the people.

Ancient weirs in Iran, Scientific studies carried out have indicated that early Iranians were particularly concerned with three factors: dam location, characteristics of the dam foundation, and construction materials. In all the locations where ancient weirs were built, technical aspects including location and type have been well considered. Factors such as the nature of topography, river flows, availability of construction materials and the method of river diversion during weir construction were always taken into account.

Qanats, The Qanat, or chain-well, was a Persian hydraulic technique par excellence. It is a method for tapping deep groundwater without the use of lifting devices, by sinking a series of wells and linking them underground. The technique found widespread use in ancient times to serve urban water supply systems.

The Iranian artisan, by adapting himself to his surrounding environment, managed to obtain the water, he needed to have a prosperous life. Many villages were built because of the Qanat. The Qanat is thus a memento in the heart of the desert as a symbol of the eternal battle of Man with his harsh surrounding environment.

INTRODUCTION

The ancient land of Iran, with its enduring civilization, is recognized by the world as a cradle of culture and civilization. Her intellectuals founded, over the centuries, great traditions of philosophy, science, art and craft, as well as establishing moral values that led to a long-lasting and harmonious relationship between the individual and society. It is self-evident that in the development of an ideology based on the three pillars of "auspicious thoughts, actions, and dialogues", there exists and implicit set of magnificent spiritual guidelines.

Throughout its long history, Iran has contributed its contribution to the world's treasure-house of civilization, both at the material and spiritual levels. The country's contribution to this treasure-house falls into two distinct pars, one being from its own people, and the other from the intermingling of these people with those of neighboring nations.

Ancient tradition rests on three pillars: ancient texts, contributions of scholars, and archaeological relics. These are essential for studying the culture and evaluating the birthplace of every nations.

The Goddess Mithra was the symbol of belief, honesty, affection and the Iranian psyche; in Avesta she is described as the mediator of darkness and light. The Goddess Nahid was the symbol of wind, clouds, and rain.

The study of the archeological relics is another source of judging the richness of any culture and civilization. Almost all of the archeologists after discovering and evaluating the relics of "Sialk of Kashan", the plain field in the south of Tehran, concluded that this location was the oldest place where man had lived as a community. Artefacts of the settlement of primitive man, such as demolished clay walls, food stores and the remains of the somke-coloured earthenware vessels and engraved jugs all are signs of this long lasting civilization.

Professor Ghrishman, in studying the remains of Sialk, has distinguished three stages of habitation: the cave-dwelling stage, the hut dwelling-stage (building houses with sun-dried bricks) and village and town dwelling stage using rectangular clay bricks and fabricating vessels. Iranian architecture was founded at that time and in such a way.

Iran is located in an arid, semi-arid region. Due to the unfavorable distribution of surface water, to fulfill water demands and fluctuation of yearly seasonal streams, people have never ceased their endeavors to provide a better condition for utilization of water as a vital matter.

The mean annual precipitation of our country is about 250mm which is less than the mean precipitation of Asia and about one third of that of the world. The different kinds of climates, topographic and geographic conditions, uneven distribution of surface streams, both in space and time are the hydrological features in many parts of the country.

The archaeological surveys suggest that Iranians enjoyed advanced culture and civilization some 7000 years ago. The civilization in the western part of the Iranian plateau flourished 5000 years ago and they invented cuneiform writing. Discoveries prove that Iranians were peaceful and ingenious people in the second and third millennium BC who cultivated land and raised crops.

The value and credit of historical Iranian architecture is the variety, as well as its enriched spaces and at the same time its practicality of use, value of structural geometry and fascinating decoration. Based on such architecture, the hydro-architecture of Iran has a unique characteristic that makes it different from any other historical monuments, and this is especially attractive.

Civil works such as water mills, underground water reservoirs, ice ditches (chambers), Qanats (subterranean canals) and ancient dykes, all have logical, regular and simple function and at the same time demonstrate ingenuity and originality in every detail.

Dam construction in Iran dates back to the ancient times. Kebar Dam, one of the oldest arch dams in the world has a height of 26m, a crest length of 55m and a thickness 5m with an arch radius of 38m which proves the skills of Iranians in dam construction. Saveh arch dam and Durudzan fill dam are 2 modern structures that have been built very close to the old dam sites.

Iranian are credited for invention subterranean canals (Qanats) which is well-known in the world. According to Herodotus the Greek historian, Qanat digging technique was documented and practiced in the Achaemenids era (550-330 BC) 2500 years ago, Qanat was a characreristic Iranian initiative and the only means of water supply for agriculture and development, giving life to and quenching the thirsty plains, bringing into existence the villages, towns and eventually great civilization of this country.

Such construction master pieces, that is to say the excavation of tunnel-wells underground with a length of 10 times the equator were realized with the sacred aim of supplying the basic needs and more important, well being of the people.

Remains of reservoirs have been discovered along with water intakes, spillways and outlets and event the sewage systems belonging to pre-Achaemenids and Assyrians (600-1500 BC).

The dams made at the time of king Shapur I (Sassanian era) are 1300-1700 years old. A regulating dam and a bridge-diversion dam (500 meters long with 40 spans) in Shushtar are among these dams. Amir dam was constructed by Buyids dynasty 35km north of Shiraz is 1000 years old. This three-purpose dam (irrigation, bridge and mill) still exists and functions.

During the Safavids empire (1501-1739) water engineering developed significantly and many storage and diversion dams and bridges were constructed in Isfahan and Mashhad cities of which some still exist.

Irrigation principles have therefore been attended to, since the ancient times and viewed as “Irrigation Art”. The importance of irrigation is pronounced in Iranian ceremonies, traditions and religious beliefs. Water has been depicted in many Zoroasterian hymns and Anahit was believed as the Goddess of water.

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Qanats (subterranean caral,an eternal saga of man defying aggressive elements, of nature in desert.

WATER MILLS, AN IRANIAN ARCHITECTURAL INITIATIVE

One of the skills of ancient Iranians was to make use of the water’s hidden power to rotate the stones of the watermills. The roof of a watermill building was usually a dome. Light and air were supplied through a door. The combination of roof’s geometry, along with the geometrical patterns of the decorated courtyard and the prevailing poetic atmosphere, in which only the sound of water flowing from the mill shaft onto the rotating paddles could be heard, gave this place a solemn atmosphere.

The watermills were powered by the river currents, springs or Qanats. The Gar-Gar and Amir Watermills were powered by the reservoir water. Kashan town's Fin-garden watermill was rotated by a spring, whereas the Du-Sangi watermill of Mohammed-Abad in Meibod, ancient watermill of Ashkezar, 15 km away from Yazd, and the two hundred year old Taft watermill were all, powered by the neighboring Qanats. These mills were connected to the water sources by canals. A conduit just before the mill shaft would act as a bypass when the mill was not in operation. The mill shaft I semi conical in shape and its diameter reduces from top to bottom. This shaft can be plugged by a wooden device which is accessible through a narrow gallery from inside the mill. The wooden turbine consists of a wooden axle, the diameter of which increases gradually from top to bottom. It has a lower iron tip housed in a pit in the lower millstone, acting as the turbine support. The upper iron tip of the axle is fixed in the upper millstone. This axle is surrounded by some paddles and the whole system is known as the turbine wheel (Fig.1). When a water jet impinges forcefully on the turbine wheel, it rotates, and this in turn causes the upper millstone to be turned. The lower millstone is stationary and the rotation of the upper stone on the lower grinds the grain. There is a hole in the middle of the upper stone, which discharges the grain into the space between the two stones. The two millstones are not truly horizontal, but are slightly inclined which helps the flour to be discharged into the flour bags.

Figure (1) : Watermill paddles , Taft – Yazd province

GRAIN SILOS AND THE WOODEN HOPPER

The grains are stored in a silo located at the top of the watermill and are discharged through a wooden hopper into the hole dugout in the upper stone. By the rotation of the upper stone and the continuous strokes on the hopper, the grains in the silo discharge down. The water is guided out through a conduit built below the watermill.

THE ROOFED AREA OF THE MILL

Some parts of the roofed mill compound are designated for the cleaning and screening of the grains and flour production. A space is also foreseen to lodge the animals, which are used to transport the flour bags. The astonishing aspect of the operation of the watermills is their simplicity, which is the proof of ancient Iranian artisan's practicality.

DU-SANGI WATERMILL OF MOHAMMED-ABAD IN MEIBOD (IN YAZD PROVINCE)

This is a very rare example of watermill, which was constructed at a depth of 40 m on the water passage of Ghotb-Abad Qanat. No construction material was used to build it and the mill is excavated in a clay formation. Some well, also 40 m deep, supply light and air to it. Excavation of this mill dates back 150 years. It has supplied flour to numerous near and distant villages. The passageway to the mill has a high roof so that it was convenient for camels to pass through. A rest champer was also provided for the animals which were used to transport the grains or flour bags. This mill is located 50 km from Yazd city and 8 km from Mohammed-Abad village in Meibod (Fig.2).

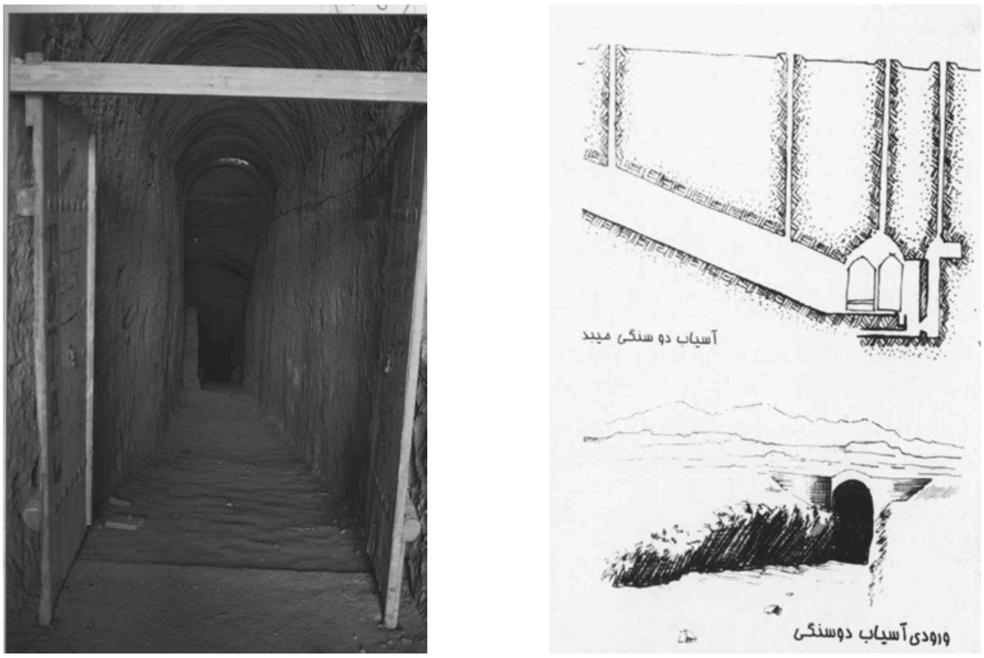

Figure (2) : Entrance of du sangi watermill at the depth of 40m, Meibod–Yazd province

WATER SUPPLY AND PHYSICAL WATER TREATMENT IN 3300 YEARS OLD IN CHOQAZANBIL ZIGGURAT

The Elamite temple of Choqa-Zanbil, otherwise known as Dur-Tash, is located on a Dur-un rash high mound on the bank of the river Dez, a tributary of the Karun, and was built in 1250 B.C. (ie. 3300 years ago) by the Elamite king Untash-Gal for the Elamite deity “Inshushinak”. It is about 25 m high and has an area of four square kilometers and consists of several storeys, made of mud brick and furnished with kiln fired bricks. The Ziggurat has a quadrangular base and its original height is believed to have been about 50m.

Choqa-Zanbil has three walls one inside the other, and the Ziggurat is located at its centre. It was a well known town, competing with Susa, and was the centre of political activities. Untash-Gal, with its numerous paved streets, palaces, and water supply installations was a symbol of Elamite civilization, culture and flourishing arts.

The water supply system to the palaces and the town of Dur-Untash was of equal importance to the construction of the temple and the palaces to its architect.

WATER SUPPLY SYSTEM

By the order of Dur-Untash Gal, the Elamite king (1245-1265 B.C.) a 50 km long canal was excavated to transfer water from the Karkheh River, on the west of Susa, to a sedimentation basin and then the town itself.

HYDRO-STRUCTURES

The remains of a large excavated reservoir and a basin can be seen outside the exterior walls of the Dur-Untash town. The water used to be de-silted in the reservoir and then transferred via a series of canals to the basin where it, could be taken by the people.

The reservoir with the dimensions of 70.10 m (length), 7.25m (width) and 44.35m (depth) has a volume of about 350m^3 and its base floor was made with kiln-fired bricks and lime mortar.

The two side walls were also made with the same materials and rest on the base floor. It seems that the water used to be conveyed via an open canal from one side. The wall, on the fourth side was also made with kiln-fired bricks and lime mortar. This wall at its lowest elevation, had nine openings (0.80m by 0.15m) which were spaced at 0.80m intervals from one another. These intakes were made with two layers of kiln-fired bricks and one layer of rubble masonry and all of the joints were sealed with bitumen.

The sharp inner corners of the reservoir were smoothed out by lime mortar.

Each one of the nine intake gates of the basin, situated under the ancient city's wall, were made of two oblique surfaces and a vertical part with the height of 1.60 m. The first oblique surface which starts at the reservoir floor level is 1.80 m in length, whereas the second surface has a length of 3.75m. The elevation difference between the bottoms of the reservoir and the basin is about 1.02 m. The basin with the dimensions of 9 m (length) × 7.6m (width) × 0.60m depth has a volume of about 4.30 m^3. The spaces behind the basin walls were filled with kiln-fired bricks and lime mortar which is 4 m thick on the northeastern side, 1.5m thick on the southern and 6m thick on other sides. This peripheral platform around the basin is rooted 2.5m deep into the ground.

From the existing evidence it could be concluded that, once the reservoir was filled to its maximum, the physically treated and de-silted water flowed in to the basin (located at a higher elevation), via the nine mentioned conduits, which then could be used by the people (Fig.3).

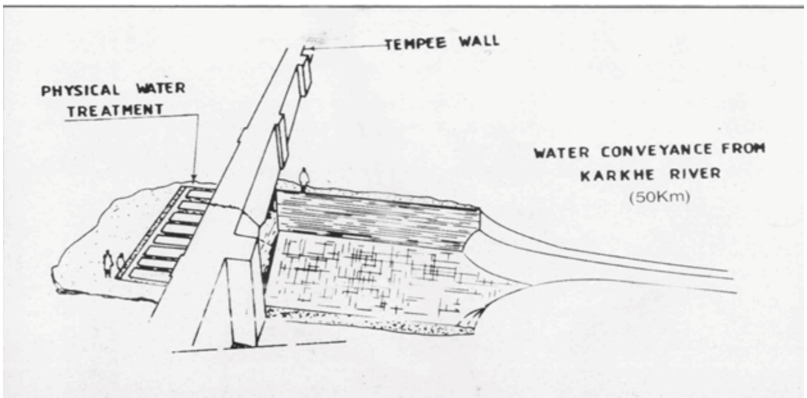

Figure (3) : Choqazanbil – physical water treatment basin (plan & section)

ANCIENT WEIRS IN IRAN

GENERAL CHARACTERISTICS OF THE ANCIENT WEIRS IN IRAN

Scientific studies carried out have indicated that early Iranians were particularly concerned with three factors: dam location, characteristics of the dam foundation, and construction materials. In all the locations where ancient weirs were built, technical aspects including location and type have been well considered. Factors such as the nature of topography, river flows, availability of construction materials and the method of river diversion during weir construction were always taken into account.

TYPE OF IRANIAN ANCIENT WEIRS

The ancient Iranian weirs which were made of masonry may be categorized as follows :

GRAVITY WEIRS

Studies have shown that all the major parameters which are nowadays taken into account for the design of such structures were well noted by the early Iranians, and this fact is evidenced by the construction of the 700 year old Saveh weir and the 900 year old Sheshteraz dam (Fig.4 & 5).

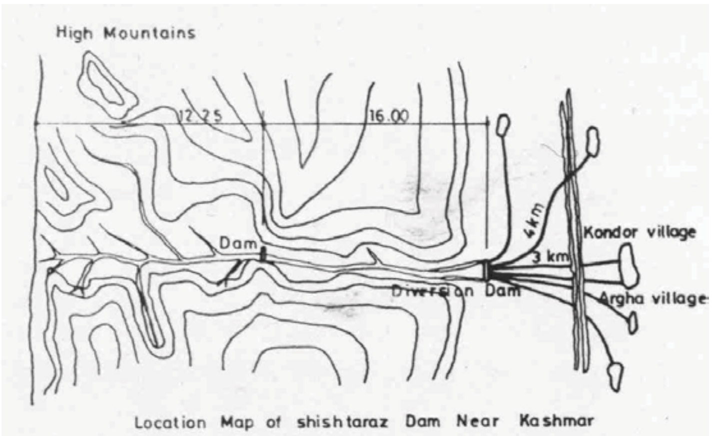

Figure (4) : Location map of Shishtaraz dam near Kashmar

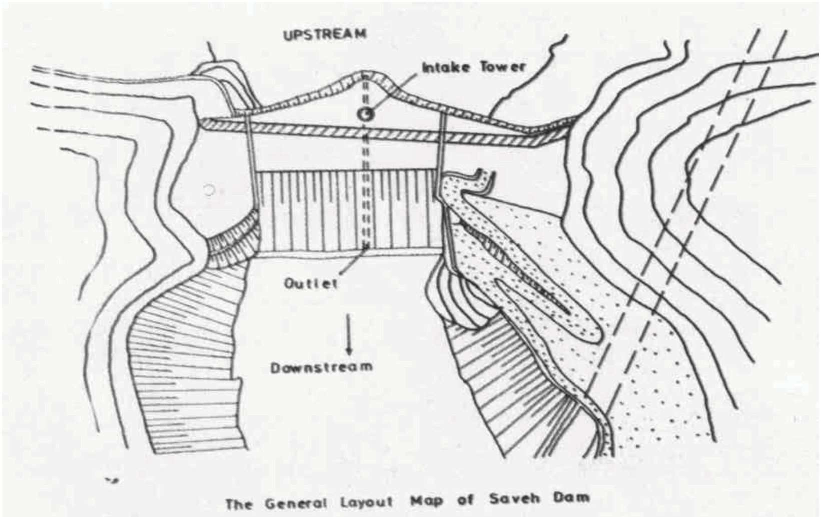

Figure (5) : The general Layout map of Saveh dam

CURVED WEIRS

Early Iranians, even before the Romans, were well acquainted with the load-carrying capacity of arched structures. Typical examples are the Kebar weir, which is more than 700 years old, and the 400 year old Kerrit arch dam.

BUTTRESS WEIRS

The Akhlemad weir, with a crest length of about 230m, a height of 12m and a reservoir volume of 3 MCM, and the 400 year old Fariman weir, which is still in operation, are of this type. The dam construction industry in the Sassanid epoch, particularly during King Shapur I's reign, was at its peak and flourishing. The ages of the dams remaining from this period range from 1300 to 1700 years. Outstanding examples of such structures remain from this era, including : Mizan weir in Shushtar, and the 40 span bridge-weir of Shushtar, with a length of 500m . The Amir historical bridge-weir, located 35km north of Shiraz, which was built on the Kur River in the Buyid epoch, is about 1000 years old. This weir still serves the three purposes of irrigation, bridging over the river and milling. The archaeological excavations carried out around this weir lead to the discovery of numerous relics and remains of intake structures, spillways, conduits and even waste water disposal networks (sewerage systems) which date back to the pre-Achaemenian epoch ie, the Elamite and Assyriass epochs (1500-600 B.C.). In the late middle ages, ie, in the Safavid epoch (1469-1699 A.D.) a new era of hydro engineering began. It was during this time that the numerous weirs and bridges of Mashhad and Isfahan were constructed and diversion weirs and large storage dams were built which remain standing today.

QANATS (SUBTERRANEAN CANAL)

The Qanat, or chain-well, was a Persian hydraulic technique par excellence. It is a method for tapping deep groundwater without the use of lifting devices, by sinking a series of wells and linking them underground. The technique found widespread use in ancient times to serve urban water supply systems.

The Qanat was the result of efforts put forward by the hard working artisans to dig out the desert and to convey every possible drop of water to the fertile farmlands and thus enrich the desert they used to live in.

The Iranian artisan, by adapting himself to his surrounding environment, managed to obtain the water, he needed to have a prosperous life. Many villages were built because of the Qanat. The Qanat is thus a memento in the heart of the desert as a symbol of the eternal battle of Man with his harsh surrounding environment.

The central part of Iran, up to very recently (1960), used to be irrigated by Qanats, and most of the water in this region was supplied from groundwater. Qanats stretched from the foothills of mountains to the plain fields and their lengths varied from one to several kilometers. A good example is the Gonabad region in the northeast of Iran, where the length of the Qanats constructed ranges from 24 km to 32 km. In the same region, there is a 70 km-long Qanat. Dulat-Abad Qanat, close to the Yazd city, about 54 km long. There is also an exceptional Qanant in this region with a length of about 120km. The depth of the main well of this Qanat is 116m. The depth of the main wells which were excavated in the Achaemeniam epoch, are as great as 450m. There are more than 37,588 chain-wells in Iran.

THE DISTANCE BETWEEN THE TWO NEIGHBORING QANAT SHAFTS AND THE MAXIMUM DEPTH OF EACH

The depths of the Qanat shafts vary from zero, at the exit, to a maximum in the main shaft which is situated in the saturated strata. The deepest well excavated in Iran is about 400 m. The distance between the wells usually varies from 15 to 20m, but in some cases, due to the existence of some exceptional natural features it may even reach up to 200m.

DIMENSIONS OF THE HORIZONTAL WELL AND VERTICAL SHAFTS

The dimensions of the horizontal well are about 60×120cm, whereas the vertical shaft (wells) have a diameter of about 80 to 90cm. These dimensions were chosen to reduce the amount of the excavation.

COVER OF THE INNER SURFACE OF THE HORIZONTAL TUNNEL

The geological structure of Iranian Plateau is such that there was no need to take any special measures for protection of the inner surface of the Qanat. During the course of time, as the Qanat's inner surface was constantly in contact with water, it became covered with a layer of lime, which from the presence in the water formed an impermeable protection. In weak and collapsible ground formations, the Qanats were lined with elliptical clayey segments known as Kool, which was large enough for a person to pass through.

QANAT LENGTH

The length of a Qanat depended on the natural condition of the ground on its path, i.e, the ground slope and the depth of the main wall. The longest Qanat is known to be excavated near the town of Gonabad, in Khorasan province, which has a length of about 120km.

METHOD OF EXCAVATION OF A QANAT

The excavation tools for a Qanat, due to their simplicity, have probably not changed much through the ages.

The first step was to excavate some reconnaissance wells in the selected region, to make sure of the presence of groundwater. The number of these exploratory wells could sometimes be as many as three, and then the water flows would be measured and studied. Having been satisfied with the result, the Qanat artisans would then use surveying equipment to determine the ground slope and the appropriate intervals for the wells, down to the Qanat outlet. Qanat artisans based on a few thousand years of experience, were so skilled that Qanat excavation was like their second nature, and they could start the work simply by carrying out a site appraisal. Generally, excavation of a Qanat starts from the outlet and ends at the water source. Two adjacent wells are excavated first, and then connected to each other by a horizontal well. This method is continues to the end.

EXCAVATION EQUIPMENTS FOR THE QANATS

The equipment used for excavation of Qanats consisted of a wheeled machine, supported horizontally by two vertical poles at some distance above ground level, with a thick rope attached to it. At the other end of the rope, a bucket was tied which carried the equipment down the well and removed excavated material.

CLOTHING

In the earlier period, special care had to be taken as regards the clothing of the people working deep in the wells. Based on observations made by Karaji (6), one thousand years ago, when the well-sinker encountered water seepage, he would put on sheep's leather clothing waxed with ox fat. A large hat with would have protected his head against dripping water.

PROBLEMS WHICH COULD BE ENCOUNTERED

Numerous problems could be encountered during the Qanat excavation and the followings are just a few examples :

ENCOUNTERING A LARGE BOULDER

If a well-sinker encountered a large boulder, he would either break it into pieces with a chisel and hammer, or bypass it. Sometimes, in the case of the existence of numerous boulders, he would lose his orientation, and an open polygon would be made in the horizontal well and transferred to the ground surface, and thus the horizontal well's alignment could be determined.

AERATION OF THE WELL

So that the bottom of the deep wells could be aerated, which was e difficult task, the numbers of the wells were increased, or air would simply be blown into the wells by using apparatus similar to that of a blacksmith (bellows) and a leather trunk. Using lamps in the wells was inevitable, which would produce carbonic gases and therefore selection of the type of lamp fuel was important.

"Existence of heavy air or air polluted with gas inside a well is due to several reasons such as : the large depth of the well, the sulphurous nature of the ground or even the collapse of the horizontal well at the inlet. The sign of a polluted well, which a noon time becomes extremely bad, is that a lamp could not be kept on. The oil-lamp which can be most effective is the one which uses pig, cow or sheep fat as its fuel. After these, olive oil or similar are the best. Kerosene, due to the fumes which it produces, is not suitable at all".

VERTICAL SHAFTS (WELLS) IN LOOSE SAND

The excavation of wells in loose and non-cohesive sandy formation is carried out using wooden formworks the internal dimensions of which are equivalent to the well diameter plus the well-liner thickness. As the well deepens, more formwork is added at the top of the lower one, which is sliding down. Collapse of the well once the wooden boxes rott away, is inevitable.

The next best alternative is using resilient elliptical clayey or concrete loops (Tanbushe) with a minimum diameter of 70cm, i.e, a convenient dimension to allow for manual excavation be carried out. By the removal of the loose sand, the loops would sink down under their own weight. The rate of sinking of the loops depends on their peripheral friction with the adjacent ground material.

STRAIGHT ALIGNMENT UNDERGROUND

People are always faced with the question of how the Qanat artisans could orientate themselves below the ground and proceed in the right direction.

Nowadays, a compass is used for this purpose. It is worthwhile noting that the ancient people of Iran were familiar with the magnet. Kharazmi (9) in his book defines the magnet as : "a store which attracts iron".

The people who used to excavate Qanat were in possession of a campass or similar apparatus in order to be able to proceed in a straight line during their underground excavations. Karaji explains that :

Once two adjacent wells were found to be in alignment with the horizontal conduit, then the well-sinkers, using of a string, would set out this direction on the ground surface. After excavating the two wells to the appropriate depth, string plumb lines were hung down from the centers at the top of the wells. By aiming these two vertical plumb lines, the direction of the rest of the horizontal well could be set out.

The experience of Qanat excavation during the past millennia gave enough confidence to the well-sinkers to carry out their work without resorting to a compass, strings or any other kind of apparatus.

SUBTERRANEAN ORIENTATION

In cases when the route of a horizontal well did not coincide with the straight line in between tow vertical wells, or due to some other reasons because of a zigzag in the work, the well-sinker would lose his orientation.

Then according to what Karaji had proposed, he would set out an open polygon inside the horizontal well, and by measuring the length and angles of this polygon, he would try to duplicate it on the ground surface, and in such a way the well-sinker could pinpoint his route under the ground (Fig.6 & 7).

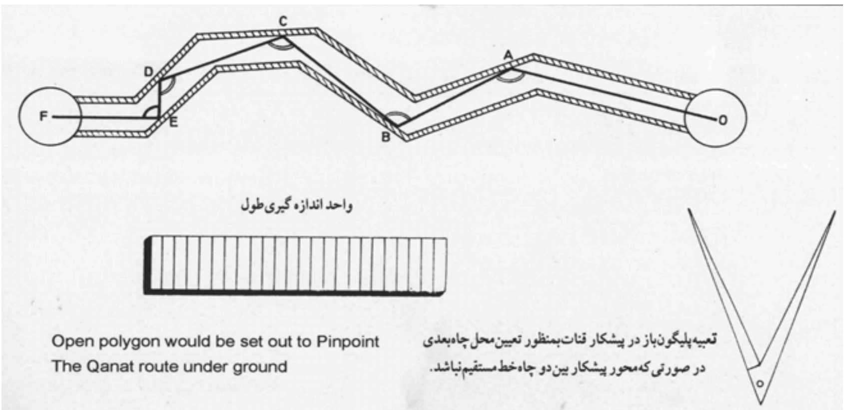

Figure (6) : Open polygon would be set out to pinpoint the Qanat route under ground

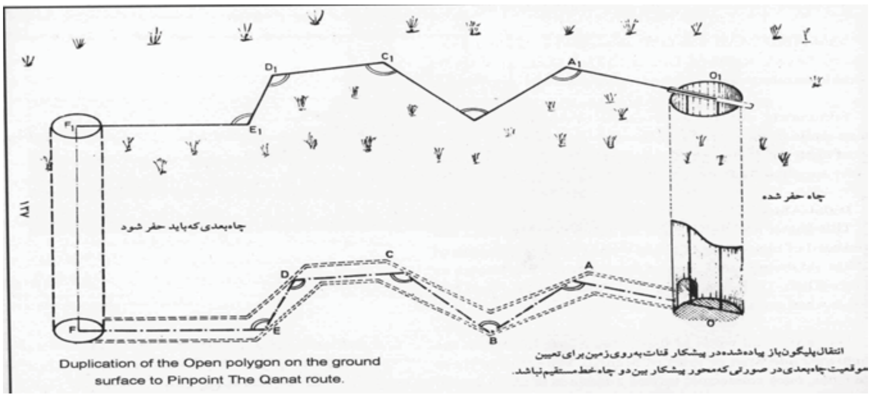

Figure (7) : Duplication of the open polygon on the ground surface to pinpoint the Qanat route

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TRADITIONAL WAY OF PARTICIPATORY IRRIGATION MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

Mrs.Charu Bhavsar[1], Pradeep Bhalge[2],

ABSTRACT

Ancient civilization developed along the banks of rivers and water bodies. The ancestors had a great wisdom to harness the gift of nature. Several periods of prosperity are quite discernible on the history of India. History revels that the prosperity at that time was depend upon well conceived water planning and wisdom in water management. Numerous documentary and field evidences are extent in different part of India. The country was ruled by various dynasties and all of them were very much particular in promoting the Rain water harvesting and irrigation development. They were providing financial aids for construction of water harvesting devices for holding water both on ground surface and under ground surface. The water management and Ownership was lies with the community. Repairs and water management were totally in the hands of the community. The ancestors were far ahead in field water management. They were taking almost care for equitable distribution of water harvested and stored in water bodies. Therefore the techniques and the system were last for centuries to gather. Unearthing the wise principle can give guide lines to the water user in the present period also. This paper deals with one of the best methods of participatory approach and wise full irrigation management used by the ancestors in arid part of the county.

Keywords: Diversion Weir, irrigation, water management, Water distribution policy, Farmers participation, equitable distribution, crop management

1. INTRODUCTION

The history of India has left a considerably large legacy in the sector of water conservation and wise full management of available water resources. The dictum "wherever there is water, there will be a habitation" is the very beginning of the legacy. Innumerable inspiring examples such as the millennium-old canales off taking from Kavari river near Tanjavar in Tamilnadu state, The water supply system existing in the empire of Vijayanagar Kingdom, The phad irrigation system ensuring equitable distribution of water in Khandesh area of Maharashtra state are spread all over India. Water management system of ancient and medieval period had been in the operation for

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thousand of years on nominal financial provision. Even today at some of places out of those, the life of the peoples is dependent solely on theses very system. In this paper we are discussing the thousand years old community managed Phad irrigation system, which is prevalent in northwest Maharashtra i.e. part of Dhule and Nasik districts. The system is in operation in the three rivers basins. The rivers are Panjhra, Mosam, Kan and Aram. They originate from the Sahyadri hill ranges. In their first reach they travel to wards the east. Then they meet to the Tapi River. Tapi River is the major and west flowing river. Series of weir were well built across these rivers. These weirs are called as Bandharas. Weirs were constructed to divert the river water for agriculture use. Each independent Phad system comprises of a diversion weir, a canal on the bank and distributaries for irrigation.

2. AVERAGE RAINFALL

The average rainfall in this area is 674 mm. Most of them receive in between June to September. The temperature in summer days is very hot. The day time temperature some time touches to 45 degree centigrade, and winter days are not very cold. The lands are fertile.

3. PHAD IRRIGATION SYSTEM

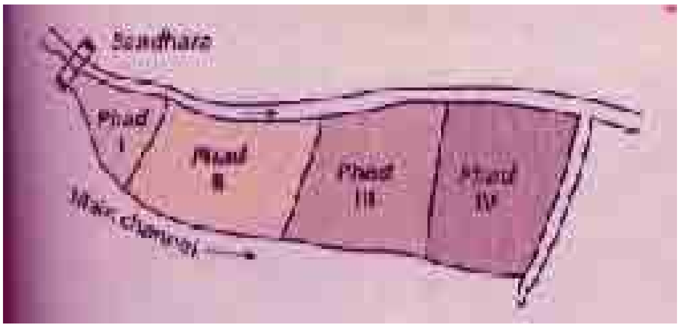
Surface irrigation is boon for this area. A Weir/Bandhara may supplies water to more than one village. The right to water has been fixed by tradition, which is strictly adhering to. Each system consists of one diversion weir, canals, distributaries, field channels, and the command area. King or Ruler supported the capital costs for construction of weirs. The distribution network is to be prepared by the irrigators. The maintenance works were the collective responsibility of the irrigators. And they had performed in such a way that the system runs years to gather. The wisdom in the management is very attractive.

4. DIVERSION WEIR: The strata in this region are percolating type. After the rainy season, the underground water gets accumulated in the river. Thus the rivers were having flow throughout the year. To take the benefits of this Geographic situation, there was a tradition to construct weirs across the perennially flowing rives. The technique of construction of weirs and diverting the river water for irrigation were developed form the dynast Morya's period (300 BC). Construction of the weir was the communal activity.

Diversion weirs were raised at different locations. The river water is diverted in to the canal. Diverted water is brought to the filed through canal and distributaries. Length of the canal varied from 2 -12 km. Each canal has a uniform discharge capacity of about 450 litres/second. Distributaries are built to feed water from canal to different area of Phad. Field channels are built to carry water from distributaries to individual field. Escapes are provided along the canal and distributaries to drain away the excess water.

5. MANAGEMENT OF IRRIGATION

The irrigation management of the available water in the weir is said as one of the best system of management. The water distribution practice and the management rules are so framed that they sustains for a long period.



The command area is divided in to four parts. Each part is called as Phad. The size of the Phad may vary from 10 to 200 ha. Each Phad has number of beneficiaries. But only one type of crop is grown in each Phad, in a season.

5.1. WISDOM IN PHAD MANAGEMENT

Every village has an effective system of management. A village level committee is formed by the irrigators. The members of the committee are elected mostly by consensus in the general body meeting. The elections are generally held once in every two to four years. The general body also chose the chair person. The chair person may continue for several years. The number of committee members not fixed. It varies from place to place to place and village to village.

5.1.1. Functions of Committee

- They have to Protect, Supervise, and Administrate the irrigation system.
- They have to employ supervisors, Canal inspectors and water guards for irrigation.
- They have to solve the dispute and impose fine to the offenders.
- They have to decide the cropping pattern

- They have to decide sequence of irrigation of the field in a Phad.
- They have to call an annual general body meeting. Generally this meeting is held on Akshy tritiya i.e. in the month of March/April.

5.1.2. Functions of Irrigators

- They have to elect the committee members and decide the chairperson.
- They have to maintain the field channels and distributaries.
- They have to take part in collective annual maintenance of the irrigation canal.
- The operations like tillage, sowing, removing weeds from the fields, applying fertilizers, applying pesticides and harvesting are to be done by the irrigators.
- They have to sow that type of crop as decided by the committee.
- They have not to interfere in the working of the irrigation staff.
- They are not allowed to decide the quantity of water for irrigation to be applied to their field.

5.1.3. Function of Supervisor

- He has to supervise the work of canal inspectors and water guards.
- Timely inform the farmers about the period of tilling, sowing, applying fertilizers and pesticides, removing weeds, and harvesting etc.
- He has to maintain the contact with the farmers and inform them about the condition of the crops.
- Inform the farmers about the cleaning of field channels and distributaries.

5.1.4. Functions of Canal inspectors

- He has to petrol and up keeps the canal.
- He has to ensure timely supply of water.
- He has to attend the minor repair of the canal.
- He has to remove the grass and accumulated silt from the canal.
- He has to inform the committee about the general condition of the canal, water flows and seepages to ensure speedy remedial actions.

5.1.5. Functions of Water guards

- He has to irrigate the crops.
- He has to ensure water flow from one field to other as per the schedule given by the committee.
- He has to insure that all the area in the field gets sufficient irrigation to optimize the yield.
- He has to guards the crop.
- He has to inform the supervisor in case of any problems pertaining to water flow or field channel.

5.1.6. Payments to the staff

The staffs engaged are paid in cash and kind. Wages are calculated on the basis of number of irrigators per unit area of land and by crop season. They also get share in the produce from each individual field. More the yield more will be their share. This type of incentive makes them to work hard and maximize the yield in every field.

5.2. LAND OWNER SHIP

The average land holding is about 0.22 hector. In previous days all the irrigators were having their land in the entire four Phads. Thus they were equally interested in the entire Phad.

5.2.1. Working of the system

Irrigators have to pay maintenance charges as decided by the committee. The committee directs the staff regarding water distribution. Many times disputes occur. The committee has to settle the disputes. The committee may collect fine from the defaulter. The amount may range from Rs. 100 to 200 in a year. However fines are not the preferred way to maintain the disciplines. Special pressure is usually used against the offenders. The conflicts are few. The committee sells the grass in the area of common interest. The amount of the fines, selling of the grass and maintenance charges collected is to be put in front of the general body meeting. Every farmer is free to check the account at any time. Irrigators can not order or influence the staff expect through the committee. The complain both from the irrigators and the staff are entertains by the committee. It meets once in two to three months to discuss the administrative problems like water distribution, enforcement of discipline, Water supply, Grazing by animals, and tapping of water by upstream villages.The committee on Akshya Tritiya i.e. in March/April calls a meeting of all the irrigators, once in a year. Announcement of the date for the annual farmer’s assembly is made by beating the drums. Usually a major item of the agenda is to decide upon the crops to be grown, for which the availability of water in the next season is taken in to account.

5.2.2. Crop management in Phad

The command area of a diversion weir is divided in to four equal parts, called as Phad. Each Phad has to grow only one type of crop in a season. Cropping pattern is decided so wisely that a)It helps in utilizing the available water efficiently. b) Equality in water distribution is maintained. c) Productivity of land is maintained. d) No water logging though under long run irrigation. e) No salinity of the land. f) Easy to farmers. h) Sustainable use of land.

5.2.3. Crop rotation in Phad

The first Phad may have a perennial crop, Second may have a two seasonal crop, Third may have a one seasonal crop and forth may be follow or may have a crop if water is available. Each Phad has a provision to raise perennial crop in every four years. The crops in the Phad are kept rotating one after the other. The rotation of the crops is given in the table below.

Year (Rabi)	Phad no one	Phad no two	Phad no three	Phad no four
I	Wheat	cotton	Gram	Fallow
II	Fallow	Wheat	cotton	Gram
II	Gram	Fallow	Wheat	Cotton
III	cotton	Gram	Fallow	Wheat

From the above table it is observed that every Phad has an opportunity to grow all types of crops by rotation. The composition of the committee increased or decreased according to the needs and dedication of the members. The committee memberships are renewed regularly. The new members generally have dynamic relationship with the village power structure. The staff performs irrigation operations and farmers are not allowed to interfere. The farmers need not to worry about the irrigation and guarding the crops in their field. The irrigation staffs do their best, as they have to get share from the individual field produce. Maintenance is a group function. All farmers contribute equally both in labor and eldership. Discipline is strictly enforced. The Phad system has continued to survive in spite of political changes taken places during the last three centuries. The system shows government influences is not necessary for making self-management possible.

6. CONCLUSION

The Phad system shows that small farmers can organize themselves and can form a sustainable irrigation system. The system ensures equitable distribution of available water resources among the beneficiaries. The water management is very easy with fewer complications. There is no need of Government to interfere in the water distribution. Watering to a field is not a headache to a farmer. The crops are rotated from one Phad to another and frequently one Phad is kept follow in rotation. Because of frequent non-irrigation and crop rotation the lands neither get water logged nor get saline. Thus fertility of the lands is maintained. Crop yields are optimized. Water is used efficiently.

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INSTITUTIONAL ARRANGEMENT AND WATER RIGHTS IN AFLAJ SYSTEM IN THE SULTANATE OF OMAN

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ABSTRACT

The scarcity of water in Oman has let to the development of a system of water allocation very different from that which exists in regions graced with more rainfall that is abundant. Omanis have perfected the art of exploiting available water resources to the best advantage over the centuries. An example of this is the falaj system (plurar aflaj), which was introduced into Oman about a thousand years ago. Water rights are treated similarly to rights to real property, which is they can be inherited, sold, rent, and encumbered in the same manner, all independently of the land on which the water originates, or on which it is used

The important of water rights arrangement and location can be attributed to the following factors. First, the economic development has been strongly influenced by the ability of a society to control its water resources and to use them effectively and sustainably. Second, water allocations should support long-term goals and investment and also incorporate a renewal mechanism for future generations. Third, water allocation mechanism is highly linked to the society's objectives, that is, if the society wishes to govern land use to meet say poverty alleviation or increase productivity of certain crops, then this becomes a water allocation objective. In this paper review of such system in terms of water rights institutional arrangement have been undertaken. Several important finding have been revealed. For instance, historical link exist between certain instrumental aspects of aflaj water rights and well-social coding. In addition, economic instrument like water market have been established for centuries.

1. INTRODUCTION

Throughout the world, water has always been an important resource. This is because water considered as economic development tool that is needed for crops, mining and other economic activity (Merret, 1997). In addition, from social and religious point of view, water is of great important, as Muslims and Judaism uses it for cleansing and purifying. Almost all Churches or sects have an initiation ritual involving the use of

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water (Abrams, 1996). Therefore, and for that reason it is very well recognized that water, as one of the natural elements, has proven to be a difficult subject matter to regulate. Furthermore, water is regarded as a scarce and highly prized commodity especially in the dry settlement regions. Thus, there are multiple governmental and nongovernmental actors who work to influence and implement policy in a decentralized political system. It seems that developed and developing countries have struggled to formulate an acceptable institutional and managerial framework that regulates water distribution, as pointed out by Frederiksen (1993) that a nation's institutions and the manner in which they are applied, determined how the nation manages it water resources. He added that the existing institutions together with the conditions of the resources and the economy combine to create the important issues confronting a country.

There are many different views about water right law and institutions arrangement. Frederiksen (1993) regarded national institution including laws, customs, organization and all that is associated, as the framework within which society functions, He added that they constitute the framework for every action from group relations to commercial activities. Teerink and Nakashima (1993) stated that water is a renewable resource that may be in limited supply and, therefore, its regulation, control and use is invested in sovereign authority of the nation or its subdivision. The important of water rights arrangement and location can be attributed to the following factors. First, the economic development has been strongly influenced by the ability of a society to control its water resources and to use them effectively and sustainably. Second, water allocations should support long-term goals and investment and also incorporate a renewal mechanism for future generations. Third, water allocation mechanism is highly linked to the society's objectives, that is, if the society wishes to govern land use to meet say poverty alleviation or increase productivity of certain crops, then this becomes a water allocation objective.

The scarcity of water in Oman has let to the development of a system of water allocation very different from that which exists in regions graced with more abundant rainfall. The art of exploiting available water resources to the best advantage has been perfected by Omanis over the centuries. An example of this is the falaj system, which was introduced into Oman about a thousand years ago (Wilkinson, 1977; Sutton, 1984). Water rights are treated similarly to rights to real property, which is they can be inherited, sold, rent, and encumbered in the same manner, all independently of the land on which the water originates, or on which it is used.

We know much about the role that aflaj have played in the history of dry land settlement, engineering construction that went into building these qanals and how water is distributed, but little is mentioned about water rights institutional framework and most importantly what are the policy instruments that behind the success of the system.

The sheet quantity of falaj in Oman has enticed scholars to produce a number of detailed studies for the falaj, but most of these studies focused on the physical and administrative structures. Therefore, the nature of these studies have left gap in our knowledge concerning water rights and their institutional framework. The following paper presents a more detailed illustration of the issue of water rights and institutional framework that used to manage traditional irrigation water in Oman. The principles set forth in this paper draw from several sources, mostly from earlier studies, together with fresh information extracted from author own observation. It is not intended as a comprehensive treatment of the subject, but as illustration of an old traditional system that can provide valuable contribution to the existing literature.

2. AN INTERNATIONAL PERSPECTIVE- THE LITERATURE

Water rights have long been studied by scholars from western countries and Muslim states. Comparison of water rights among these two main institutional sources highlights some of the differences between legal traditional.

In general, public water defined as the water derived from rainfall, streams and lakes. Access to such water varies from country to country, as very much influenced by the doctorial and institutional framework they follow. In the literatures, it seems there are two-main-water doctoring types. The western doctoring that mainly influenced by the English Common Law and the Muslims doctoring based on the Islamic law.

2.1. WESTERN WATER DOCTRINE

Witting (2005) point out that as one of the natural elements, water has proved to be a difficult subject matter to regulate. He then illustrated how common concepts have been formed by stated "the courts have relied largely upon a hybrid of land and tort doctrines in their regulation of water. These doctrines have developed haphazardly and have been subject to changes in philosophical leanings and to a substantial foreign influence. For instance, Teerink and Nakashima (1993) pointed out that allocation of water and development of water rights law in the United States is based on doctrines influenced by European laws.

Reviewing the literature, there are three basic approaches have been developed for establishing water rights. These include:

- The common law system of riparian that is defined as water rights of property vested in the owner of land that abuts a watercourse. Teerink and Nakashima (1993) Another definition was provided by Frederick (1993) stated " riparian rights gives owners of the land bordering a water body rights to use the water in ways that do not unduly inconvenience other riparian owners. There are three main principal features for the riparian doctrine. First, water use is limited to riparian lands. Second, a riparian land owner can use water at any time as long as the use is reasonable. Third, water shortages are shared by all riparian owners.
- Second, permit system that considers water to be a public resource that only can be used with the permission of the government.
- Third, prior appropriation awards water rights according to the principle of "first in time, first in right".

2.2. MUSLIM WATER DOCTRINE

Most Muslim countries based water law under the Sharia or Islamic law doctorial. Thus, Muslim's scholars consider water as public property that cannot be owned. They based their argument on the prophet Mohammmed statement "mankinds are co-owners in three things: water, fire and pasture (Buckari). However, Maktari (1971) classifies water under three headings according to its sources; as river water, well water, and spring water. His classification and discussion can be summarized as follows. First, the water of the great rivers, such as Tigirs and Euphrates in Iraq, must be allowed free access, since such water supply has no case or dispute. Second, the water of small river or spring, which is in sufficient quantity, must only allow to those who dwell in its vicinity. Third, the water of artificial rival or spring is held in common by those who dug the channel. In short, Islamic law in general term consider water as public assets but as effort of mankind and expanses involved then access must be restricted to those who have played part.

Based from the above discussion one can consider water from falaj becomes the property of the people who built the structure. Its use is governed by mutual agreement between the users. A protective area around the falaj or well, referred as falaj protective zone, is created (about 25 m around structure). A community of people with water rights was organized around a falaj, with right being established in proportion to the participation of each in the construction of the falaj. A Similar view, expressed by Al Ghafri at al (2001) stated that after the construction of falaj, farmers create a committee of experienced people to distribute falaj water shares among falaj owners.

BACKGROUND OF THE AFALJ SYSTEM

A number of definitions have been provided for the afalj system in Oman. In general, falaj system is mainly a channel constructed a long more 2 to 5 km at a gradient stated from the mother well to the village. Such channel has a unique construction design, in a way allows seepage of rainfall water accumulated in the oasis to enter through channels rocks, this have resulted in a continuous water flow by gravity. In the literature, geologist, agriculturist, legislative and economiest have studied aflaj systems and provided different definitions. For instance, Norman et ad (1998) Dull (1989), as they analyzed them from agricultural point of view, described falaj as community-managed systems that access ground water by gravity flow from underground galleries. Birks (1984) and Wilkinson (1977) (geologists) defined aflaj as a tunnel (many kilometers long) which taps water where it concentrates in the ground and leads it to the surface. Finally Sutton (1984) and Haydar and Omezzine (1996) see from legal and institutional framework that used social well-managed codes and regulation that kept the system running for over a thousand years.

It is well recognized that in order to appreciate afalj definition and get detailed and full understanding, is of great important to define it according to the three daudi, aini and ghaili. These types differ in terms of physical structure and institutional arrangement.

- ***Ghaili falaj***: physical structure consists of a perennial flow in the surface gravels of the wadi or river. The flow is diverted into a man made channel either by a flow bund, or through a short collector gallery. Sometimes, Ghaili falaj are simple diversion channels that bring the water directly from the wadi to the nearby gardens (Wilkinson, 1977).
- Daudi falaj. Physical structure is characterized by the fact that water is dug from underground aquifer. Then it conveyed to the village by an underground tunnel that may reach up to 17 km. Also these types are

characterized by relatively high flow of water discharge and have the most stable water flow rate around the year compared to the two other types of falaj.

- For Aini falaj water draws from one or more natural springs. Like Daudi, the water is transported from the springs by a channel up to the agricultural land MRMEW (2002).

Table one summarize the inventory result that conducted by Ministry of Regional Municipality, Environment and Water (MRMEW) in the period from 1997 to 1999. It can be observed from the table that the majority of the aflaj, of a total number of 4112, fall under the Ghaili type, 48 percent followed by Aini 28 percent. Despite the fact that Ghaili falaj form the highest percentage, 54 percent of them are dead. This can be attributed to the fact that these, as pointed by al Rawas (2000), are usually seasonal due to their dependence on shallow subterranean source that disappear during dry seasons. It is important to understand that water collects from over the mountains and through the wadis until it forms a reservoir, and the water is conveyed through a channel, which is normally rectangular in cross-section. In contrast, the source of Aini and Daudi falaj water is from underground aquifer. Thus, one would expect that the flow of water is more consistence than Ghaili type. In fact, Major falj in Oman like Melki in Iski, Daris in Nizwa and Mafjoor in Ibri are of Daudi type.

			Falaj Type, No.			
Region	Estimated Water Demand (mm^3/year)	Total irrigated Area (Hectare)	Daudi	Aini	Ghaili	Total
Al Batinah	104	6458	193	443	925	1561
Al Sharqiyah	115	5819	318	238	290	846
Interial	135	8132	279	196	275	750
Al Dhahirah	79	4626	152	145	419	716
Muscat	26	1463	25	130	84	239
Total	459	26498	967	1152	1993	4112
Percent		37.4	24	28	48	
Active %			21	33	46	
Dead %			31	15	54	

AFALJ WATER RIGHT AND INSTITUTIONAL ARRANGEMENT

As pointed out by Wilkinson (1977) that the systems of shareholding and the ways in which falaj water is distributed are complex. Therefore, using a sample of falaj selected among different regions is very important component in order to examine water right in

Oman and to appreciate the basis principles upon which each village develops its individual system of water organization. According to proto-historical theory, a community of people with water rights was organized around a falaj, with right being established in proportion to the participation of each in the construction of the falaj. However, the current appropriation of water from the falaj is not always linked to the construction of the gallery but it is rather expressed based on the historical balance of power between the local population and tribes. Furthermore, the method of organization introduced around the falaj is part of the Omani law and therefore follows a number of rules, based either on Muslim or customary. In short, historically, falaj water rights arrangements have been influenced by several fundemantal water rights institutional arrangement based on: community tribal structure, Muslim and customary legislation and well-social codes arrangements.

TRIBAL INFLUENCE

It is important to recognized that in practice, the current appropriation of water from the falaj is not always linked to the construction of the gallery, but is the expression of a historic balance of power between the local population and tribes and families, which were and are still expressed in the form of transactions concerning the ownership and use of water.

MAF Study (1993) indicated that there is a great variation among the twelve aflaj studied, in terms of water rights concentration. The twelve aflaj studied can be divided, in term of water right concentration, into two main categories. First categories are those aflaj that characterized of having high concentration of ownership. That is a high proportion of the rights are on the hand of few tribes. An example of such flaj are Abu Thaled (Rustaq) falj and Mafjoor (Ibri) falj. The water rights of the former are hold by 20 tribes among 64 water owners, but only three tribes that control more than 50 percent of the private rights. The Al Hinaii tribe is the most numerous (32 percent). Similary, Mafjoor water rights are spread among 22 tribes, 10 main tribes possess major water rights, with a total of about 260 water owners. The most important tribes is Yakoubi, which control 34 percent of the water rights. The second tribe in terms of importance is Chenadide which hold 31 percent of the rights. The second catogeries is charachterized of having less concentration of ownership. For example, El Malki in Izki, Daries in Nizwa and Al Hamra in Al Hamra. Water rights of these falj are among two to three tribes.

In short, the fragmentation of water rights among many tribes reflects the intensie trading and population movements that have taken place over the years. That is if intense repurchasing of the water rights occurred, a fragmentation of rights among many tribes may occur. This clearly can be seen in the Al Maiser Falj where 36 main tribes are in fact represented in the 167 private owners along these tribes there is sub-groups, that is a total of 50 tribes affiliation. Another example can be seen in the Hali Falj which its water rights are represented among 40 tribes. The most important is the Ruwali, which possesse 14 percent of the private held rights, followed very closely by the Kassabi.

MUSLIM AND CUSTOMARY LEGISLATION

The method of organization introduced around the falaj is part of Omani law and thus follows a number of rules, based either on Muslim or customary law. Custom defined by Islamic Encyclopaedia (2000) as frequency draw on as a material source of law. Muslim jurists included custom in the law because of the principle that any lawful force. For it could be said that custom is no more than an agreement among a large number of people whence the common maxim. Historically, custom were practiced during the Ottoman Empire in the sixteen century. Modern scholars of Muslim law generally devote a chapter on custom along with their writing on the classic sources. In general, customs applied by community in order to organize their social like, marriage, divorce, with strong connection to Islamic law. However, it should be added that many professions also had their own specialised custom. The best-known example is the body of customary law that control water distribution in the aflaj system.

Author own observation revealed that many falaj water rights are not registered in books, they rather well known by falaj Management Community and water right owner. Sometime they know number of anthers own more than knowing their cultivated land size. This have resulted in well-social arrangement link among the villagers. As Nath (2002) clearly indicated that law is simplest sense is based on customs and traditional rather than written codes, He attributed that to the fact that received customs represent the collective norms of the group and contain rules of behavior considered essential to the well being of the community, societies tend to feel bound to observe them.

Another point to link custom law with the role of Wakil.. In fact, many writers defined Wakil's role in various ways depending on the managerial point of view. Sutton (1984) view wakil role as the overall administrator, who responsible for the organization of falaj affairs. MAF (1993) report pointed out that wakil manages of the falaj budget, consisting of the sale of water shares. Gafri at al (2001) added that Wakil solve water conflicts between farmers. The different view stated above can be explained by the fact that the word Wakil in the root of the Arabic classic linked with Islamic law contains more details. As stated by Ibn Rushed (1996) the principle of Wakil is to take the constitution agency by someone absent, who exercises authority over their own affairs. This principle has been taken in practice by the role of the falaj Wakil. All the water rights holders give full authority to the Wakil in trading, solving conflicts, taking decision on emergency matters and so on.

Generally speaking, public water defined as the water derived from rainfall, streams and lakes. However, there is fundamental Islamic principles concerning the appropriation and use of water. These can be summarized as follows. First, water is free to all. However, it may be appropriated provided that the conservative law is respected. Second, water from falaj becomes the property of the people who built the structure . Its use is governed by mutual agreement between the users. A protective area around the falaj or well, referred as falaj protective zone, is created (about 25 m around structure).

The above-mentioned aflaj water right institutional arrangements have resulted in certain essential instrumental aspects that helped falaj operation for centuries with miner conflicts among water holders. The following instrument can be illustrated as unique feature of the Omani experience in water management.

MARKETS FOR WATER RIGHTS

Aflaj Water rights marketing in Oman are active and span on several centuries. Observation revealed that these markets can be divided into two main categories. There is a market for the sale of water rights (sometime referred as market for permanent water rights) and another market for short-term rental rights. The latter administered by FMC to rent or lease falaj common water rights in order to generate income for maintenance.

AUCTION OF PERMEATE WATER RIGHTS

Most water markets in Oman fall under the form of auctions. Sale of water rights rarely happens, and usually takes place in case of death of the owner and when inheritors want to sell the water rights.

The sale of water rights is done by auctions. An auctioneer or caller conducts the auction, usually in the village main market. The caller announces the auction. Once the caller considers that enough potential buyers have collected, he starts the bidding asking for quotes. At any stage during the auction, the prospective seller can withdraw either because he feels that insufficient people are present or because he considers the final price is not as expected. Generally, however, attempts to persuade him to accept the arrived-at price will be made not only by the buyer but by the caller as well. When the seller accepts the auction price, it is recorded along with the names of the seller and the buyer. Once the deal is made it is the responsibility of the caller to make sure that the seller receives his money and that the buyer pays. Payment is usually made in cash.

AUCTION OF THE RENTED WATER RIGHTS

Short term markets are based on auctions too. Rented water rights' auctions deal with falaj common property rights. These are usually expressed as a time share of the resource on a week or any other basis depending on the turn of water. Common property rights are the main source of income for falaj maintenance. These water shares are usually auctioned by lots of an ather.

Short term auctions are usually conducted in the same common place at village level, and at an agreed on time, normally on Friday afternoon, a rest day in Oman. The auction assembles the sellers, represented by Wakeel (administrative agent), buyers or farmers who are willing to pay for extra water to irrigate their crops (mostly date-palms), the caller, who seats in the middle of the buyers to bid and the recorder, who is responsible to record the buyers names and the final bidding price. Every falaj does have a book serving to register the water leases' prices, buyers as well as the date and duration of each lease.

WATER DISTRIBUTION AND USAGE

Table 2: Water disytibution through the use of rotation (cycle) among different aflaj in Oman

Falaj name	No. of turns	No. of days	No. of athar
Al Maisre (Rustaq)	13	13	1248
Abu-Thaleb (Rustaq)	11	11	528
Mafjoor (Ibri)	11	4/16	384
Mabooth (Ibri)	14	5/20	480
Al Malki (Izki)	9	19	912
Al Hamra	8	7.5	360
Daris (Nizwa)	9	8.75	420
Al Hali (Smail)	18	18	864
Al Mudhaibi	19	16.5	792
Hamad	2	9.5	456

Water rights are often quite separate from land ownership. However, a water right may be attached to a particular plot. This consists of a proportion of the total volume of water flowing in the falaj over a certain period (Day/cycle). An autonomous measuring system has been drawn up, and is converted into units of time for purposes of convenience.

The most important unit is the badda. In general, a badda can be a day or half day. In fact, as pointed out by Al Ghaifri at al (2000) that normally day has two baddas, dat badda and night badda. This mean that each badda will have 24 athars, since ather usually corresponds to a half hour. In past, as pointed out by Wilkinson (1977) that the length of the two baddas is obviously governed by the rising and setting of the sun. While those of the night are measured by the movement of the stars. However, most farmers nowadays using modern watches.

Table 2 summarizes water turns and the corresponding total athers registered in each falaj. As mentioned previously that ather for each owner of the water right is the bases of which irrigation cycle is calculated. For example, if we take falaj Melki in Iski which hold 912 athers. First number of athers divided by two (for the day and night turns or badda) equal to 456 hours then we divide this by 24 hours to convert hours into days then the result is 19. Thus, we say that this falaj has an irrigation cycle of 19 days. However, not all falaj in Oman structured using such methodology. A number of considerations are essentially important in order to clarify things. These can be summarized as follows. First, the water cycle varies depending on the availability of water, which may vary enormously from one year to another, and from one season to another within the year. It is based on 16 units (Badda), each lasting 6, 12 or 24 hours depending on the quantity of flow available. The cycle may thus last 4, 8, or 16 days, with an average 8 days for 16 badda of 12 hours each. For example, falaj mafjoor in Ibri hold 384 athers, with 8 irrigation cycle. However, due to water flow it can be short as 4 days or log as 16 days. Second,

Water distribution is based on two different principles. One is based on time and the other on the volume of water. That based on time is common, but in many mountain villages with large variation in flow, the unit of distribution is that of a full cistern rather than of flow over a given period. Where time is the basis, the four that are followed are shown in Table 1.

Table 1: Equivalence of Terms Used in Irrigation.

Term	Meaning
Badda	12 hours
Rabiya	3 hours
Ather	½ hour
Qama	7½ minutes

These additional units are based on a shadow's length, and are, therefore, not exactly equivalent to chronometer time. For example, The term "*ather"* means the shadow of a man while he is standing during daytime. As daytime passes with accordance to the sun movement, different shadow can be obtained and thus time can be measured. Originally, water flow was measured by the increase in the length of a man's shadow, and at night by the movement of the stars.

The unit on which the distribution is found depends on the size of the falaj. The smallest uses whole *baddas*, the largest *qamas*, with *rabiyas* and *athers* the commonest. These units of time are all part of total time cycle of water application to a particular plot. This varies in length from village to village. The main system of shareholding is the *Dawran*, i.e., the rotation or cycle by which the *fala*j water is distributed to individual farms every 7-10 days. The cycle (*Dawran*) starts from Friday to Thursday and each shareholder will obtain his share once a week on the average. However, During drought periods, when the flow of water is low, some of the shareholders will have their share after 12 days. It is important to note here the significant of using time unit (ather) rather than volume, as an unit used to measure water right. The fact that if volume were used, means that during draught period or low flow rate some people will have less water than others. But the use of time unit give more fearless in the system i.e. change occur in the length of the cycle rather than volume of water distributed.

CONCLUSION

The overall picture drawn from general examination of water rights on the traditional aflaj system in Oman reveals a number of characteristics. These can be summarized as follows. First, the basic water needs is free to all. However, it may be appropriated provided that the above law is respected. Thus, water from falaj becomes the property of the people who built the structure. Its use is governed by mutual agreement between the users. Second, Ownership of water is often independent of land ownership in falaj in Oman. The objective of this separation is to allow water to be exchanged freely. Third, falaj water rights are recognized at the national level and have the same legal aspects as any other private asset. Thus, a water right may be sold, inherited, or instituted as Waqf. Fourth, rights for each owner are measured on time basis. The measurement of time most commonly used for individual rights is the Ather, which lasts about half an hour.

One of our finding reveal that water rights in aflaj irrigation system may be classified into three categories.

- Private water rights. These can be either explicit water rights with property licenses or implicit without written licenses owned by individuals. The difference between the two categories is mainly the opportunity to trade water. In fact, for the implicit water rights, the right is exclusively a use right that could be inherited but in no case traded or even rented, it is tied to land property.
- Common water rights. These are water rights owned by falaj community members. These rights are mainly established to generate income for falaj maintenance and operation expenditures. The common water rights are rented weekly, half yearly, or on an annual basis through water lease auctions. This type of common water rights is of great importance since it aims to prevent the free riding problem in relation to the cost recovery of maintenance of the water system. By pooling together a set of water rights, based on a percentage of individual shares into a common property right owned and rented by falaj's manager it provides a continuous monetary flow. It is important to note that this is the particular originality of the Omani falaj system management in comparison with similar water system such the ones in North Africa and Asia Minor called Klettara, Foggara and Qanats (Garduno-Velasco, 2001).
- Quasi public water rights owned by charity institutions, now under state control.. The returns from right's rents are used to finance mosques, schools and needy people. These water rights are managed in the same way as common water right that is by falaj manager. The quasi public water rights could not be sold but could be only leased in short term markets. Consequently these water rights may increase by donations of private water rights, but never decrease.

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HISTORICAL ANALYSIS OF IRRIGATION AND ENVIRONMENT IN TWO ARID REGIONS IN SOUTH AMERICA

Maurits Ertsen and Joanne van der Spek[1]

ABSTRACT

Much historical research conceptualizes irrigation technology as artefacts "without history", as if artefacts enter society in a final shape. For example, many scholars assume that large ancient irrigation works were constructed in one phase, requiring strong central state supervision (based on the well-known hydraulic thesis of Wittfogel). It is more likely, however, that irrigation works emerged from purposeful but uncoordinated (series of) human activities. The two cases discussed in this paper illustrate these nuances of the Wittfogelian thesis. The case of the Pampa de Chaparrí (pre-Columbian Peru) shows that it is perfectly feasible that adaptations to water availability on scheme level were realized by individual farmers. The case of the Proyecto Río Dulce shows that large-scale irrigation development in this area needs to be understood in terms of series of actions by smaller groups of stakeholders within a context of changing positions of central state authority. This paper suggests that development (of management) of irrigation infrastructure needs to be understood as a longer term process, in which irrigation infrastructure becomes concrete through human action in continuous use, design and construction. Irrigation systems are result of actions and the material context of new actions. An historical perspective not only provides the data for optimization of models, but also helps to increase our understanding of the nature of the relations between water availability and human intervention within natural environments.

Key words: Peru, Argentina, irrigation, hydrology, arid environment

INTRODUCTION

Human beings are rather unique among other living organisms in that their adaptive specialization lies not in some physical form or skill specific to a ecological niche, but in identification with the process of adaptation itself. Human survival depends on our ability to adapt, not just in the reactive sense, but also in the proactive sense of shaping the environment. A major instrument for human society to adapt (to) the environment is the development of technology. Technology conceptualizes a relation between

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artifacts/instruments, (human) actions and (human) goals. It is employed to support instrumental actions of human actors. Technical (and dull) irrigation may appear at first, its development is the story of the history of mankind. A most fascinating aspect of irrigation is the close connection between human civilization, natural environment and irrigation, as many of the important civilizations in world history had to use irrigation to feed their growing population. The manipulation of water flows, thereby adapting the availability of water in both time and space, by constructing irrigation systems, permits both the intensification of land use, for instance through double or multiple cropping, and the spatial expansion of arable land (Carlstein 1982). This intensified expansion provides a relatively secure food source for a larger population as it enables the peasant population to produce a surplus to support the non-peasant population. Food security enabled development of urban kingdoms occurred in a number of regions: Mesopotamia (after 3500 BC), Egypt (after 3400 BC), the Indus-valley (2500 BC), China (1800 BC), Mexico (500 BC) and coastal Peru (300 BC).

The importance of hydrology and ecology comes to the front when studying the formation of these civilizations. All of them are located in hydrological distressed regions, usually arid plains with a single (rain dependent) large river running through them. Within such an agricultural landscape, water is the natural variable par excellence. Thus, irrigation has played a crucial role in cultural development, and in the formation of these states. In the (semi-) arid regions of early civilizations with their large rivers water is not only highly mobile, but also quite bulky. This bulkiness relates to mass organization; as such a large quantity of water is supposed to be channelled and kept within bounds only by the use of mass labour. Although he was certainly not the first to stress the importance of irrigation and water control in societal development, Wittfogel was the first to develop a general theory about this importance. Wittfogel appears to advocate a deterministic role for the influence that water management played in early states, arguing that state controlled bureaucracies evolved as a consequence of expanding irrigation systems (Scarborough and Isaac 1993).

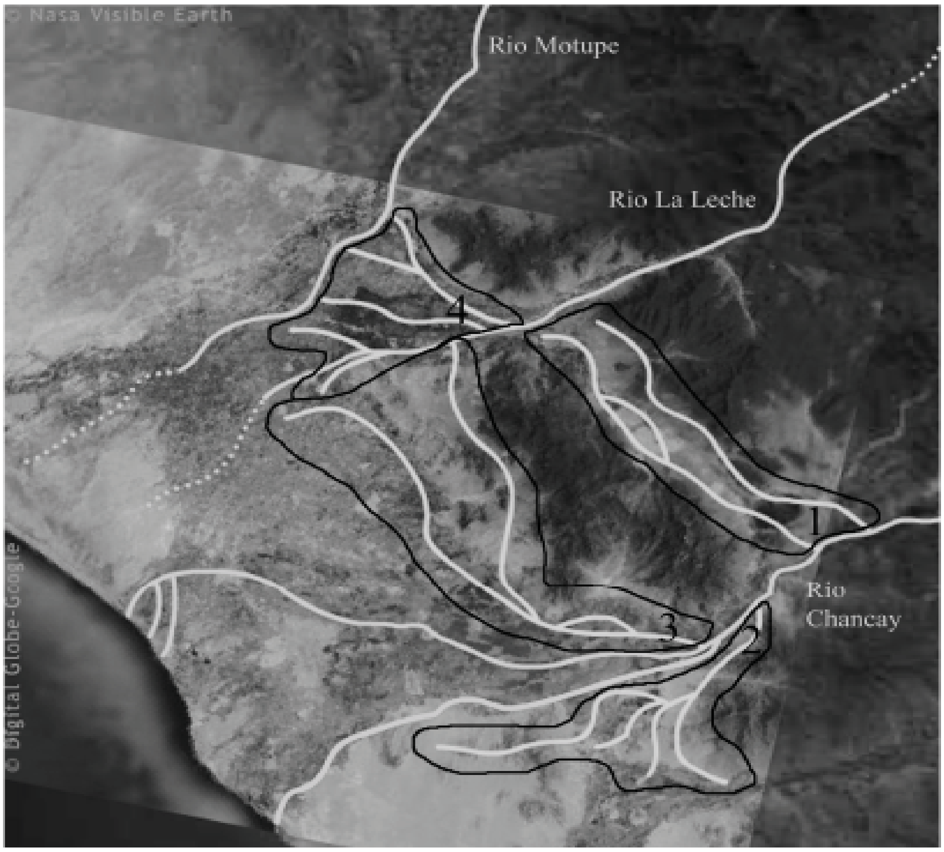
A crucial argument of Wittfogel is that the required mass labour must be coordinated and disciplined: it must subordinate itself to a directing authority. "*Primitive man has known water-deficient regions since time immemorial; but while he depended on gathering, hunting, and fishing, he had little need for planned water control. Only after he learned to utilize the reproductive processes of plant life did he begin to appreciate the agricultural possibilities of dry areas, which contained sources of water supply other than on-the-spot rainfall. Only then did he begin to manipulate the newly discovered qualities of the old setting through small-scale irrigation farming (hydro-agriculture) and/or large-scale and government-directed farming (hydraulic agriculture). Only then did the opportunity arise for despotic patterns of government and society.*" (Wittfogel 1957). Small-scale irrigation farming involves a high intensity of cultivation on irrigated fields too, but Wittfogel preserves central control for situations when large quantities of water have to be manipulated: "*Too little or too much water does not necessarily lead to governmental water control; nor does governmental water control necessarily imply despotic methods of statecraft. It is only above the level of an extractive subsistence economy, beyond the influence of strong centers of rainfall agriculture, and below the level of a property-based industrial civilization that man, reacting specifically to the water-deficient landscape, moves toward a specific hydraulic order of life.*" (Wittfogel 1957).

Up to today, many scholars studying development of large irrigation works in ancient civilizations assume, in the spirit of Wittfogel, that these irrigation works always were constructed in one phase. This would require a strong institution (a central state) to supervise and organize such massive work. It is quite likely, however, that larger systems are the result of many smaller scale actions in a longer time period (Ur 2002). Furthermore, "large scale" does not necessarily mean "strong central authority" (Hunt and Hunt 1976; Hunt 1988). In two cases these issues will be discussed in further detail. The first case presents the Pampa de Chaparrí (pre-Columbian Peru), the second case focuses on the Proyecto Río Dulce in Argentina.

PAMPA DE CHAPARRÍ, PERU

The Pampa de Chaparrí is located on the arid Peruvian north coast (figure 1). Despite its harsh and arid environment pre-Colombian civilizations have prospered, at least partly because the rivers provide the fertile coastal plains with irrigation water from the Andean mountains. The irrigation system of the Pampa de Chaparrí has been dated as being used between 900 AD and 1532 AD. It has been used by the Sicán, Chimú and Inca civilizations (Nordt e.a., 2004). In the 16th century the system was abandoned. Several publications on the Pampa are available on different issues. Téllez and Hayashida (2004) conclude that canals and walled fields on the Pampa were constructed with organized labour replacing taxes. Nordt et al (2004) discuss soil fertility and show that infiltration capacities of the coastal soils and low salinity levels in the irrigation water would have given no problems related to salinization. What has been less intensely studied is how the irrigation systems have functioned both in terms of hydraulic behaviour (in relation to canal operation and management) and hydrology (water demand in relation to availability). What is clear is that irrigated agriculture must have depended heavily on the strongly varying discharge of the Río Chancay, caused by rainfall in the Andean mountains.

Figure 1 shows that three areas had to be irrigated from the Rio Chancay. Area 1 in the figure is the Pampa de Chaparrí. A fourth irrigated area derived water from the Rio La Leche north of the Chancay. Water from the Chancay river was diverted to the Rio La Leche when it was not used in the Pampa de Chaparrí. Assuming proportionality between water use and surface area between the three areas taking water directly from the Chancay river the Pampa de Chaparrí would have derived maximally about 1/3 of the discharge. 30% would be a reasonable target value (as is explained below). What amount of land was planted is an uncertain factor: the more cropped area, the higher the risk of insufficient water availability to irrigate all crops later in the season. When crops were planted is not easily determined either, although the main cropping season would have fallen within the Peruvian summer (January – April) when river discharges are generally highest. Obviously, measurements and observations of pre-Colombian river discharges are unavailable. In modern times, after 1960, several tunnels have been constructed which linked several rivers in the Andes. Therefore river discharge figures after 1959 are not usable for our purpose. However, it is not unreasonable to assume that the discharges before 1960 are representative for the period of interest. Therefore available discharge data for the period 1914 – 1959 were used (figure 2, upper left and middle).



River **Canal** Area 1 is the Pampa de Chaparrí. Map based on www.tiwanakuarcheo.net/7_flash/irrig/irrig_lambay.html.

Figure 1. Irrigated areas along the Rio Chancay and Rio La Leche

River discharges were generally high in January and stayed high enough in most years to provide sufficient irrigation water for the crops. Crops cultivated on the Pampa de Chaparrí will have included cotton, beans, mais and potatoes. The growing season of cotton is about two months longer than of the other crops. Assuming that cotton was planted in January and the other crops some months later would give an end of the growing season on July. Basic crop water requirements calculations showed that such a cropping scheme made higher relative demands later in the season (May to July) on the lower river flows than if cropping would start in December (figure 2; upper right). Planting in December would furthermore yield less water shortages in the growing season than planting in January would yield. The December scheme water shortages would be more severe, however, and more often in the middle of the growing season when crops are generally more vulnerable for water shortages. Furthermore, discharge fluctuations in the period between November and February are much higher than later in the season. Thus, predicting river flows in December would have been somewhat more difficult too compared to January. Figure 2 illustrates that predicting river flows of the Río Chancay was already quite difficult, even in January. It can be seen that water shortages are not just caused by generally dry years (lower right). Years with average flows could still cause water shortages in some months, because the distribution of flows within the (normal) season was irregular (lower left). Another possibility was that the rains in the mountains stopped early and river discharges dropped earlier than normal (lower middle). Calculations showed that in case the irrigators at the Pampa de Chaparrí would plant their cotton in January they would have suffered more water shortages in the 45 year period simulated, but these shortages would occur always at the end of the growing season, when crop damage is less severe (upper right).

Several indicative calculations relating to number of events (in terms of months per year) in which water shortages were to be expected were made (figure 3). Months or years with water shortage were defined as periods during which crop water requirements exceeded the 30% share of the river water (set as the water right for the Pampa earlier in this paper) plus an extra 5% to take into account uncertainties in the crop water requirement calculations (particularly with respect to the actual water demand of antique crop varieties). Assuming planting in January, the calculations showed that shortages always occurred in the period May – July. With respect to the percentage of the available area under cultivation, a value of 70% of the area resulted in 6 years showing (mainly) less severe water shortages (for example in July) out of a total of 45 years, a reasonable value. In case about 80% of the surface would have been cultivated, about 8 years out of 45 years would have shown water shortages (from 1 to 3 months). With 100% of the area irrigated this would increase to 11 years, with larger amounts and longer periods of shortages. It is not unreasonable to assume that values of 1 dry year per 4 years would be relatively high. Therefore the assumption of 70% cultivation seems fair.

All calculations discussed so far do not cover the issue of irrigation management. How the irrigation systems were controlled (in social and technical terms) needs further study. It is not unreasonable to assume that on main system level potential control over water flows was minimal, given the technology available at the time and the extremely fluctuating river flows. What the calculations do show, however, is that with relatively simple measures the central issue of water availability could be dealt with locally (on field or farmer group level) through adapting cultivated surfaces to hydrological circumstances.

The results presented above are the first from the Pampa de Chaparrí area, which is one of the case areas within of a larger research project focusing on the development of larger irrigation systems in semi-arid regions of South America. In modern historical times, the changes in this Peruvian region have been enormous, including construction of tunnels, reservoirs and lined canals; these need to be studied further, however. In the next case study, however, similar enormous changes towards (what has become known as) modernization will be discussed. This case shifts attention to the semi-arid northwest region of Argentina.

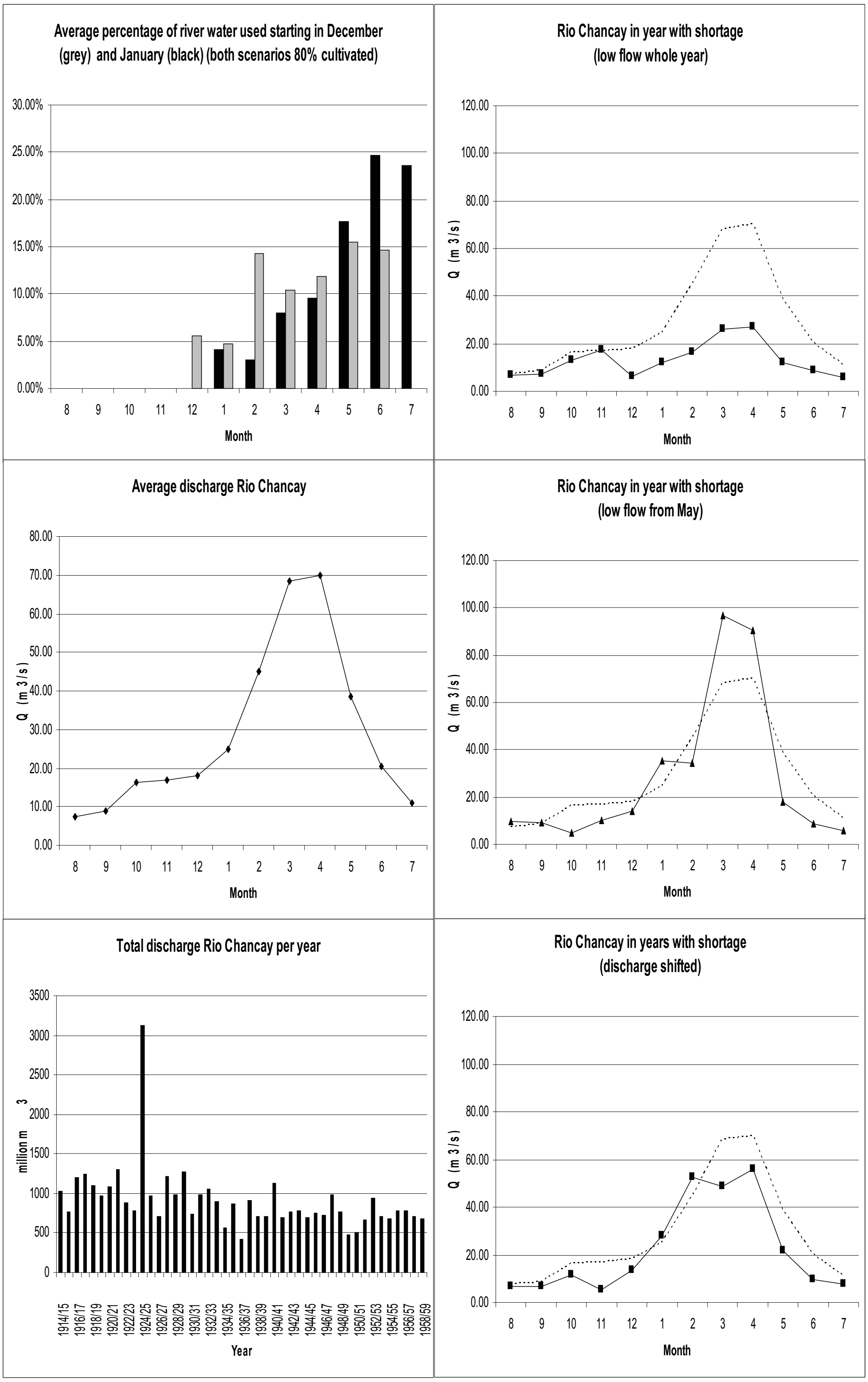


Figure 2. Average river discharge, yearly discharges, water shortage scenarios and percentage of river water used for irrigation for two starting dates

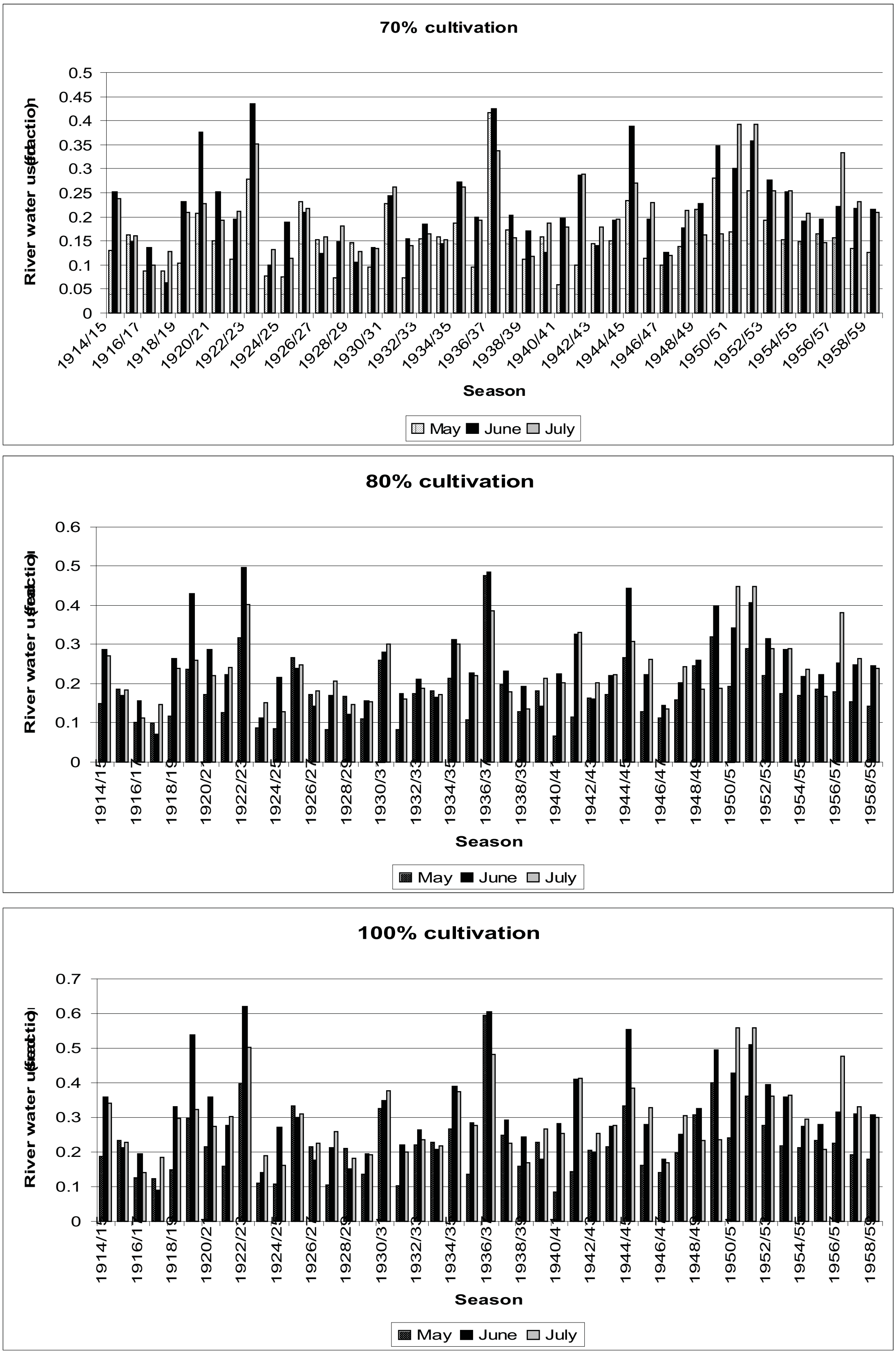


Figure 3. Indicative water shortages for different scenarios

PROYECTO RÍO DULCE, ARGENTINA

It is precisely this unpredictability which has been the drive for major changes in the Río Dulce irrigated area in Argentina. The Dulce River basin covers about 100,000 km^2. Within the basin, the area known as the Proyecto Río Dulce (PRD, irrigable area 122,000 hectares in a command area of around 350,000 hectares) is one of the largest irrigation schemes of the country and the most important irrigated area in the province of Santiago del Estero. This second case study discusses a common reaction of societies to water availability fluctuation described above: increasing control over water flows. Petts (1990) describes the relationship between water, engineering and landscape as a three-phase development. These phases are illustrative for developments in Santiago del Estero (figure 4; description below based on Michaud 1942 and Prieto 2006). The first phase, management of perennial water sources for local agriculture and domestic supplies and the opportunistic use of seasonal floods and rains for agriculture, extends until about 1875 in Santiago del Estero. In 1577, Spanish settlers built their first irrigation ditch (*acequia*) in Santiago del Estero. In 1583 this reached a length of 5 kilometres. In 1680 an irrigator's register was established. In 1873, 73 acequias existed. These canals were not the small ditches one would perhaps expect: most were longer than 10 kilometres, some extending even up to 50 kilometres with a width of 6 meters. Officially about 8,000 hectares were irrigated by the canals, but in practice this figure would have been higher.

In 1878 canal *La Cuarteada* was built, which starts a second phase, involving the management of rivers for informal regulation of seasonal floods for irrigation agriculture and drainage of wetlands. In 1886 an intake structure was constructed for La Cuarteada, which was renewed in 1898. In 1905 the existing irrigation infrastructure was further extended. From then on, the intake diverted water to a main canal, at the end of which (*La Darsena*) *Canal Norte*, *Canal Sud* and Canal La Cuarteada branched off. This was the first public irrigation system in Santiago del Estero, irrigating about 38,500 hectares (with 14,500 hectares being irrigated from private acequias). In 1913 a communal canal on the right bank was constructed: *Canal San Martín*, with a length of 64 kilometres. In 1947 the federal organization for water affairs *Agua y Energía Eléctrica* (AyEE) began building a permanent diversion weir in the river, the *Dique Los Quiroga*. San Martín continued to derive water directly from the river, as did the remaining private acequias. However, these canals downstream of Los Quiroga had difficulties getting water, in particular during periods of low flow, since almost the full flow was diverted to the La Cuarteada system on the left bank. Again, assistance from the National Government was looked for. As a solution, the San Martín system was connected to La Matriz through a siphon around 1954.

Dique Los Quiroga already marked a first step in the direction of a third phase, during which rivers have been regulated by large structures, often as part of a complex basin or inter-basin development, for hydro-electric power generation, water supply and flood control. In the Río Dulce basin, this period extends fully from 1968 onwards with the construction of a reservoir in northwest Santiago, the *Embalse del Río Hondo*. AyEE presented plans in 1957 and the reservoir was completed in 1968. The reservoir has shaped the potential for irrigation all year round, although its capacity is insufficient to provide more than annual regulation. Data from the PRD show that inflows per hectare are significantly higher after 1968 (the third period) compared to the second period, especially before Los Quiroga was built (and probably also compared to when Los Quiroga was in use, for which we have no data yet) (figure 4).

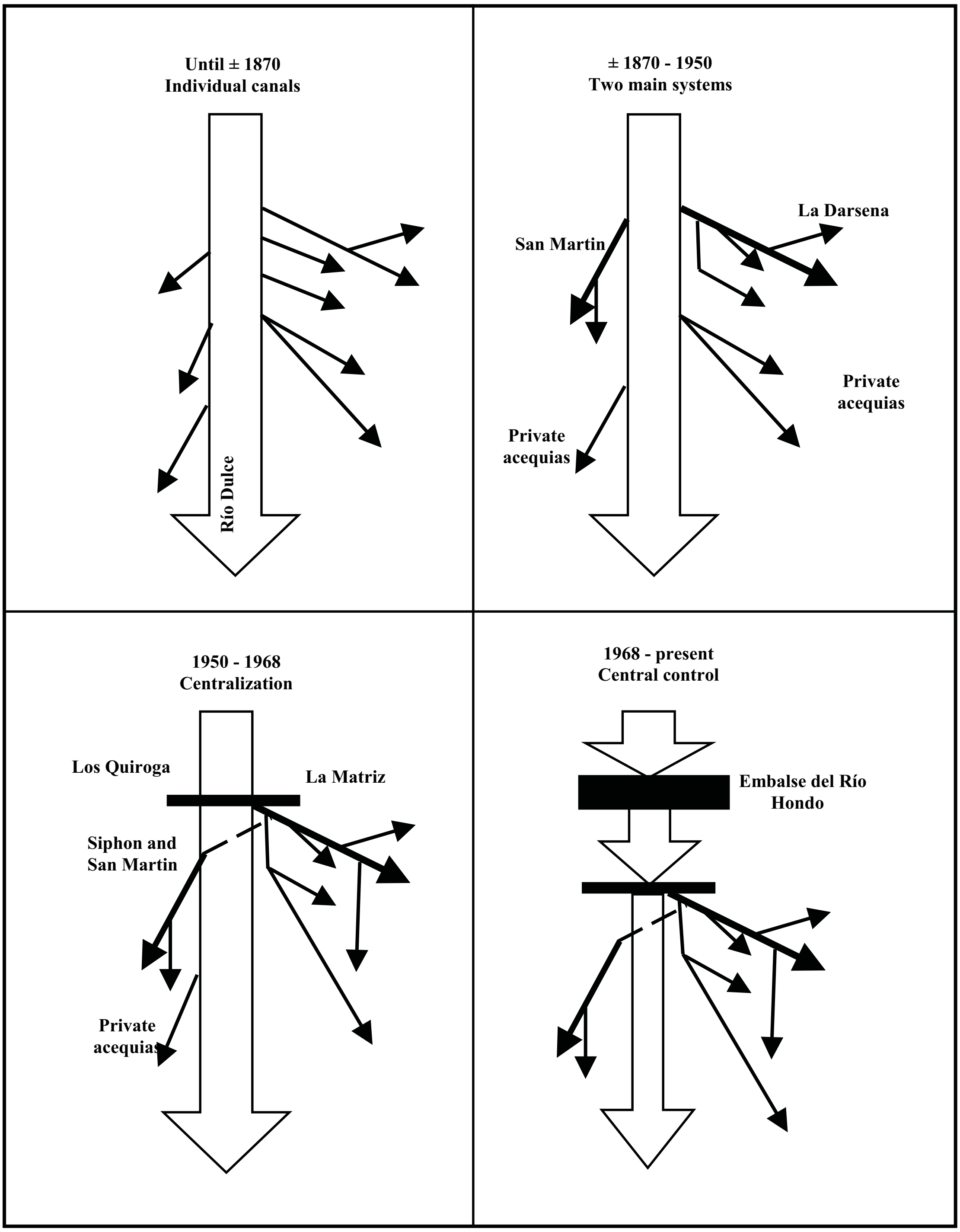


Figure 4. Schematic representation of development phases in the PRD area

In actual practice, smaller farmers irrigate their cotton or alfalfa on average three to four times per year and use about two and a half times more water per turn than allowed (240 mm/event). Smaller farmers reproduce the former distribution schedule from the second period in the development process of the PRD area. Before the reservoir the irrigation infrastructure provided two or three irrigation turns for each farmer in late spring and summer, when water levels in the Río Dulce were sufficiently high. The larger farmers, with more diversified cropping patterns, take advantage of the new potential made possible by the reservoir. They combine the irrigation strategy of the smaller farmers (irrigating crops a few times), but take water during 6 to 8 turns because they irrigate only a fraction of the area available to them each turn. They sometimes irrigate a larger area than officially allowed. (Prieto 2006)

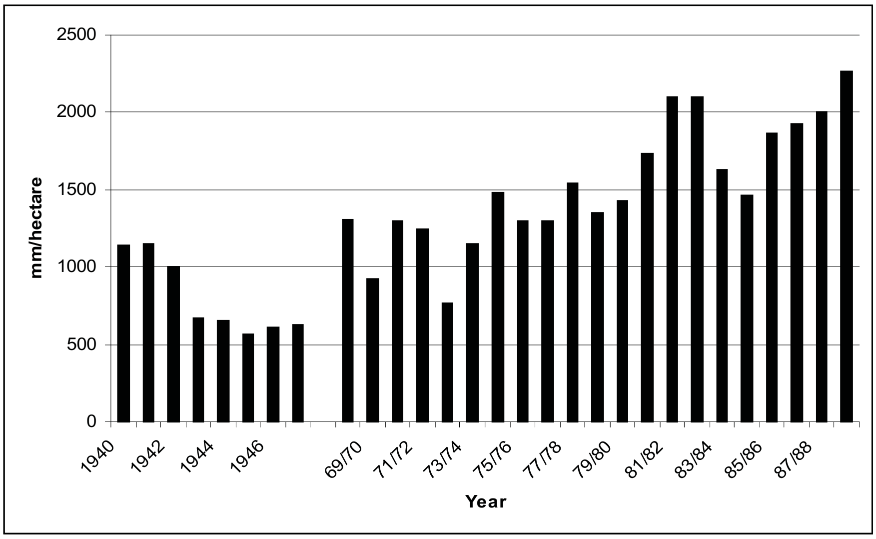


Figure 5. Water use in the PRD area in different years (data used from Ertsen et al 2004; Prieto et al 1994)

CONCLUSIVE REMARKS

An important issue in irrigation is the nature of unstable water availability during seasons and over the years. Many rivers have an irregular flow pattern, with large fluctuations in and over seasons and very low flows in the dry season. In such a setting it is difficult to match water availability with actual water requirements. Rational water use requires (to a certain extent) knowledge of river flow predictability. This requires both physical and socio-political arrangements: some kind of distribution facility is needed to transport water and some kind of coordination between actors is needed to manage water flows. Both case areas discussed in this paper are located in arid regions with fluctuating rivers in South America. The case of the Pampa de Chaparrí on the arid Peruvian north coast (900 AD - 1500) discussed how irrigators may have dealt with fluctuations in water availability over the years. It shows that it is perfectly feasible that adaptations to water availability on scheme level were realized by individual farmers. The case of the Proyecto Río Dulce shows that large-scale irrigation development in this area needs to be understood in terms of series of actions by smaller groups of stakeholders within a context of changing positions of central state authority. All this has not necessarily resulted in stronger central management. Within the process, irrigators steadily increased their control over similarly fluctuating surface water flows. This has increased incoming flows into the PRD per surface unit.

The cases discussed cannot be fully appreciated if irrigation technology is conceptualized in terms of a “physical network” of “artefacts” without history. Developing and managing irrigation infrastructure is a social practice; irrigation (infra) structures become concrete through human action in (continuous) use, design and construction. Irrigation systems are both result of actions and the (material) context of new actions. Actions and infrastructure together create spatial and temporal patterns of water flows, which are very likely to provoke new actions on either individual and/or collective level, which are constrained by hydraulic properties, etcetera. If we accept that (ancient) irrigation systems emerged from purposeful but uncoordinated (series of) human activities, we need to study their “*structuring properties providing the 'binding' of time and space in social systems.* […] [t] *hese properties can be understood as rules and resources, recursively implicated in the reproduction of social systems.*” (Giddens 1979; 64).

Social and material structures are both medium and outcome of social practices, coined as ‘*structuration*’ by Giddens (1979, 1984; although Giddens does not discuss technological development in detail and probably never intended to apply his structuration thesis to physical structures). In the process of structuration ‘[r]*epetitive activities, located in one context in time and space, have regularized consequences, unintended by those who engage in those activities, in more or less ‘distant’ time-space contexts.*’ (Giddens 1984; 14). The “distantness” of space and time in irrigation systems can be extremely varied. Irrigation systems can be the result of series of actions within longer time frames, as in the PRD where canal building activities before 1700 partly set the constraints of the modern system. On the other hand, a change in gate settings can have consequences for neighbouring gates and/or canals within minutes, hours or days. Because of such short-term actions, canal flows usually show changes in water level and discharge over time (which is defined as non-uniform behaviour). Whatever the timeframe, it is important to take into account that irrigation systems have histories; many modern systems have changed and/or grown over time.

Offering interpretations of the past is a main goal of the historical discipline. Responses from the professional irrigation community, including the continuous dedication to create historical seminars, shows that a historical approach is not only valued by professionals because it offers nice reading in airplanes, but also because historical work provides good case studies for some of the theoretical and practical concerns within the irrigation engineering domain. ‘*History does not repeat itself in detail, but drawing analogies between past and present allows us to see similarities. For this reason, generals study military history, diplomats the history of foreign affairs, and politicians recall past campaigns. As creatures in a human-built world, we should better understand its evolution.*’ (Hughes 2004). In the present time, irrigation still is one of the key resources for many groups in the world. The irrigation systems encountered today, the practices of actors involved and the different institutions surrounding them are the product of history. ‘[…] *knowledge of the past is necessary to understand the fundamental structures of, and the background to, established patterns of water use. Knowledge of how the past weights on the present is a precondition for escaping the power of history.*’ (Tvedt 2004). Although success is not guaranteed, one would expect that engineering interventions will improve when the irrigation context in which these interventions need to take place is better understood.

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QANAT; IRANIAN'S MOST REMARKABLE ANCIENT IRRIGATION SYSTEM

Omid Esfandiari[1]

ABSTRACT

Modern civilization, as we knew it today, is not the product of the genius of one sole nation. In fact, to achieve what we have today, the legacies and contributions of many nations have played their part. We can, indeed, liken the present civilization to a pot into which almost every nation of the world, whether extinct or alive, has thrown its share.

Iran being situated in the middle of the old world before the discovery of the Americas and the growth of Europe was an active member of the world and had to take part in almost every historical and worldwide upheaval or disturbance. It had to shed its intolerance very early in its long history, which is full of glorious periods and disturbed episodes. In this position Iran contributed continuously to the enrichment of civilization, it not only placed its own inventive genius at the disposal of the pot, but gleaned what it could from the East and West, transformed and transmitted it.

In the sphere of agriculture, Iran has helped the development of agriculture in two ways; first by controlling the forces of nature and domesticating animals and plants existing in the wild state in the plateau, and secondly by inventing ways and means of procuring water from the places where it could be found and diverting it to the places where it was needed for irrigation; by inventing various agricultural implements, Qanats, water-mills and windmills and storing the wheat, by creating gardens and using manure to restore to the land what had been lost through uninterrupted cultivation.

Iranians have devised a number of ingenious methods for preserving and obtaining, where and when it is wanted, enough water to grow sufficient food. Irrigation was considered a good deed in the eyes of Ahura-Mazda in the Avesta, the sacred book of the ancient Persians. The Achaemenids Kings granted exemption from land tax for five generations to any man who made a tract of desert land cultivable through the construction of an irrigation system.

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Technically, irrigation water may be obtained from dams (Band, Band-e Ab, and Sadd), underground channels (Qanats), and wells (Chah). Describing the water supply in this way is the traditional Islamic classification.

The Qanat system was invented by the people of the plateau of Iran. It is unique to Iran and a typical feature of Iranian scenery. It is used all over the plateau including Baluchistan and Afghanistan. In the Eastern parts of Iran where the Qanat is constructed, it is often called Kahriz which is a double word (Kah=straw and Riz=throw), because they used to through kah into the Qanats for purpose of seeing how rapid the movement of water in the wells is and for repair works, the straw used would fill some of the gaps in the side of the subterranean channel. From this derived the word Qah-riz . In Western parts of Iran, Kahriz is called Qanat.

The Qanat system was introduced by the Iranians to Transoxania, Fergana, Soghianna and still farther East to Qara Khoja and Turfan as far as the Chinese oasis settlements of East Turkistan. They bore in all these areas the Persian name Kah-riz. Westwards the Qanat system was adopted by the Assyrians. We know that the Assyria King Sargon II (722-705 B.C.) claims that he learned the secret of tapping underground water during his campaign against the old country of Urartu around Lake Urumieh in Northwest Iran.

Although the Persian Qanat system is of such venerable age, it is by far the most reliable source for obtaining water, Up to 20 years ago, the 75% of all water used in Iran came from Qanats. W. Benisson, an authority in this subject is convinced that Qanat system undoubtedly is the "most extraordinary method to develop ground water". C.F. Tolman, in his book called "The Greatest Water Works of the Ancients", calls Qanats "one of the greatest achievements for obtaining water in the ancient times."

INTRODUCTION:

Modern civilization, as we knew it today, is not the product of the genius of one sole nation. In fact, to achieve what we have today, the legacies and contributions of many nations have played their part. We can, indeed, liken the present civilization to a pot into which almost every nation of the world, whether extinct or alive, has thrown its share.

These contributions, of course, are not equal. Some of these nations lived for a span of time, threw something into the pot and then died completely vanishing from the face of the earth. Others gave a share for a short period and then stopped making any new contributions, while yet others started very early and still continue to be fully alive and active in helping the pot to grow in size and content. Some of these nations live in the middle of the arena and some on the edge. While some have had to take an active port in the world's turbulent upheavals, others could stand apart and aloof, continuing their own way of like uninterrupted by these changes, each nation's outlook depends upon its geographical position and the inborn characteristics of its people. Some, especially those situated on the edge who could afford to remain aloof, became conservative and abhorring all innovations and change, and believing only in their own historical legacy, tended to grow very intolerant. Such intolerance is also the result of ignorance or immaturity.

Iran being situated in the middle of the old world before the discovery of the Americas and the growth of Europe was an active member of the world and had to take part in almost every historical and worldwide upheaval or disturbance. It had to shed its intolerance very early in its long history, which is full of glorious periods and disturbed episodes. In this position Iran contributed continuously to the enrichment of civilization, it not only placed its own inventive genius at the disposal of the pot, but gleaned what it could from the East and West, transformed and transmitted it.

"From the earliest and in all branched of art Persian has shown a combination of two capacities, apparently mutually contradictory but together productive of great achievements. On the one hand there is an undeniable creative genius, on the other, great facility in assimilating foreign cultural contributions."

The Survey of Persian Art - Leo Bronstein

What Dr. Bronstein says about art is also true in the domain of ideas, whether religious, philosophic, scientific or administrative. In the opinion of quite a number of scholars who have either studied or taken part in the discoveries made in the last two or three decades, the plateau of Iran is indeed the cradle of our present civilization. According to Dr. Ernest Hertzfeld and Sir Arthur Keith, the mode of living which came to fruition on the banks of the Indus, the Euphrates and Tigris, was preceded by a phase first elaborated by upland peoples living in the valleys of the Caspian plateau. The two eminent scholars believe that the people of the plateau of Iran were the original agriculturists, and that the knowledge of agriculture spread from the plateau of Iran over the three adjoining alluvial plains of the Indus, the Amu and Syr-Darya, and the Tigris and Euphrates. This opinion has been corroborated by the finds of the last two decades in the plateau of Iran. It is also an accepted fact, now, that the smelting of minerals, irrigation systems, weaving, pottery bricks, the potter's wheel, wheeled vehicles and quite a number of other first rate inventions were originated by the people of this plateau. These discovering, pregnant with revolutionary consequences, were all made in the 5th and 4th millennium B.C. and by 3000 B.C. these achievement s were being diffused at least as far as the Aegean Sea in the west and Turkistan and India in the East. After a further thousand years or so they had reached China and Britain.

According to some scholars, The Sumerians belonged to the same racial stock as the people of the plateau of Iran. The Sumerians were a non-Indo-European, non Semitic people, whose presence in the alluvial province created by the lower Tigris and Euphrates is attested historically from the beginning of the 3rd millennium B.C. onwards.

The Iranian Plateau is indeed East of Mesopotamia, proving thereby the origin of the Sumerians and the origin of the civilization that, according to Sir Leonard Wooley, they already possessed when they arrived in Mesopotamia. In his words,"Sumerians believed that before coming to the alluvial plains of Mesopotamia they had a civilization of their own and had knowledge about agriculture, architecture and metallurgy."

According to Prof. A.U. Pope "Agriculture , Metallurgy and the initial religious and philosophical ideas as well as the art of writing and the science of numbers and astrology and mathematics originated in the lands that today we call Middle East, and the origin of many of these cultural elements is the plateau of Iran."

As Dr. Ghirshman puts it: "Iran was a highway for the movement of people and for the transmission of ideas. From the pre-historic period onwards, and for 1,000 years more, it held this important position as an intermediary between East and West. In return for what it received it never ceased to give; its role was to receive, to recreate, and then to transmit."

Iran is one of the few ancient civilizations that, owing to its genuineness, have survived the onslaught of time and circumstance. Many other countries have appeared in the orbit for varying lengths of time, eventually to disappear forever form the face of the earth. Iran, owing to its vitality, started earlier than many and yet still continues to survive and keep intact its traditions and legacy for future generations.

Iran, by right, should be properly introduced to the West, and its magnificent and prodigious contributions to the present world civilization should be recognized. It is the object of this short essay to show, a most remarkable system of bringing water from its sources in the mountains to the lower plains for irrigation and consumption by Iranians, in order to show the Iran's proper share in the present civilization, for what Iran and Iranians actually were, rather that as they have been represented by 19th century scholars who were under complete tutelage of Greece and Rome or the Church.

AGRICULTURE AND IRRIGATION

In the sphere of agriculture, Iran has helped the development of agriculture in two ways; first by controlling the forces of nature and domesticating animals and plants existing in the wild state in the plateau, and secondly by inventing ways and means of procuring water from the places where it could be found and diverting it to the places where it was needed for irrigation; by inventing various agricultural implements, Qanats, water-mills and windmills and storing the wheat, by creating gardens and using manure to restore to the land what had been lost through uninterrupted cultivation.

Iranians have devised a number of ingenious methods for preserving and obtaining, where and when it is wanted, enough water to grow sufficient food. Irrigation was considered a good deed in the eyes of Ahura-Mazda in the Avesta, the sacred book of the ancient Persians. The Achaemenids Kings granted exemption from land tax for five generations to any man who made a tract of desert land cultivable through the construction of an irrigation system.

Technically, irrigation water may be obtained from dams (Band, Band-e Ab, and Sadd), underground channels (Qanats), and wells (Chah). Describing the water supply in this way is the traditional Islamic classification.

THE QANAT SYSTEM

The Qanat system was invented by the people of the plateau of Iran. It is unique to Iran and a typical feature of Iranian scenery. It is used all over the plateau including Baluchistan and Afghanistan. In the Eastern parts of Iran where the Qanat is constructed, it is often called Kahriz which is a double word (Kah=straw and Riz=throw), because they used to through kah into the Qanats for purpose of seeing how rapid the movement of water in the wells is and for repair works, the straw used would fill some of the gaps in the side of the subterranean channel. From this derived the word Qah-riz . In Western parts of Iran, Kahriz is called Qanat.

The Qanat system was introduced by the Iranians to Transoxania, Fergana, Soghianna and still farther East to Qara Khoja and Turfan as far as the Chinese oasis settlements of East Turkistan. They bore in all these areas the Persian name Kah-riz. Westwards the Qanat system was adopted by the Assyrians. We know that the Assyria King Sargon II (722-705 B.C.) claims that he learned the secret of tapping underground water during his campaign against the old country of Urartu around Lake Urumieh in Northwest Iran.

His son, King Sennakherrib (705-681 B.C.) undertook a great irrigation scheme around Nineveh which included underground conduits according to the commemoration plaque at the end. The same king built a real Qanat system for the water supply of Arbela. According to a stela recently translated is revealed that the Persian general Scylax by order of Darius I introduced the Persian method of irrigation by means of underground conduits fed by water from the strata of sandstone where it collected in faults. From then on the Egyptians were no longer hostile to the conquerors and built a temple of Ammon, and conferred the title of Pharaoh on Darius. Polbius gives some more details about the Qanat in his description of the war between Antiochus the Great and Parthian King Arsaces III (212-205 B.C.) as follows: “For in that tract of Media there is no water appearing on the surface, though there are many subterranean channels (hyponomani) which have shafts sunk in the, at spots in the desert unknown to persons unacquainted with the district. “

The Greek geographer Megasthens saw the system in operation in North India where government overseers inspected the conduits, ordered maintenance work and supervised water distribution. The first historian on technology, Vitruvius 980 B.C.) gives much technical detail in the Qanat system.

When Caliph Hisham in 795 A.D. built a garden palace some distance away form Baghdad, water for it was obtained through a Qanat. Abdullah B. Tahir (828-844 A.D.), governor of Khorasan, found that the traditions of Prophet did not refer to the Qanat system and the distribution of water, and so he asked the jurists of the province to write a book on the subject. Qanats were introduced by Iranians as we saw, into Iraq and Syria where they were known under the name Fugara. In Arabia and Yemen it is called

Shariz (from the Persian word Kariz). The system spread from the Near-East to North Africa, Spain and Sicily in Roman times, followed by a second wave of introduction after the Arab conquests. In Tunisia and Algeria a number of oasis settlements are still irrigated by these fugaras; in Sahara region of Taut alone 1,200 miles of them are in full working condition. The Qanats are known as "Persian work "to the Touares who live on the southern fringes of the Sahara.

QANAT CONSTRUCTION

The ancient Iranians were skillful in digging Qanats and many hand-books on the subject were available. They knew all about subterranean waters and the manner of extracting it. They give very exact and detailed instructions for digging Qanats and Mughanis (Qanat diggers) and water-founders follow the principles they had laid down. A technical treatise on the subject written by Mohammed Ibn-al-Hassan al Hasib Karaji in about 1000 A.D. has fortunately survived, Karaji who was born in Karaj near Tehran gives very food detail on the finding of water level instruments for surveying protection against decay and instructions for digging Qanats and ways of keeping the, in working order by clearing and maintaining the, Karaj mentions many books in existence in his time, which were written by the ancients, but unfortunately he does not give a detailed list of such books most of these are no longer available.

Qanats are underground channels dug into the alluvial fans raising from the valleys toward the slopes of the mountains. A head-well (Madar-Chah) or a gallery of them tap the aquifer (Ab-deh) at a depth between 5- and 300 feet and , by using less slope for the conduit tunnel (Pusteh) than that of the surface of the fan, water is eventually led to the open (the lengthy of such a Qanat from the head well to the outlet may be only a mile or two; often it is 10 miles and occasionally much more, e.g. the Qanat form Mahan to Kerman in South-West of Iran is 18.3 miles long. The diggers, who do this rather large job work with very simple tools- a pick, a shovel, a leather bucket, a wooden windlass, a plumb-bob on a long string and a little lamp. Also, they know by generations of experience, their duties in the dark and cold environment. It may take 20 to 30 years to dig a new Qanat. Qanats are expansive to dig, and expensive to maintain. But, until now they have been worth it, for they bring the water to places when it is needed in a way which no other means can equal.

The Qanats have been there for so long that it is said special forms of life have developed in them; Blind white fish, for example, and the Creature form the Qanat, which held a whole village in terror for several days only a few years ago. It was probably an otter. Legends and mysteries have grown up around the Qanats, and the diggers who make and look after them are the people set a little apart from the rest of the community. Qanats have owners ranging from one to many numbers of Qanats, to his responsibility is to balance the costs of maintaining and renewing the system against the profits that the produce will bring him.

Although the Persian Qanat system is of such venerable age, it is by far the most reliable source for obtaining water, Up to 20 years ago, the 75% of all water used in

Iran came from Qanats. W. Benisson, an authority in this subject is convinced that Qanat system undoubtedly is the “most extraordinary method to develop ground water”. C.F. Tolman, in his book called “The Greatest Water Works of the Ancients”, calls Qanats “one of the greatest achievements for obtaining water in the ancient times.”

For a detailed explanation about Qanats and their construction one can refer to various books in the subject.

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EVALUATION OF HISTORICAL WATER WORKS IN TURKEY FROM HYDRAULIC ENGINEERING POINT OF VIEW

Akif Ozkaldi[1], Huseyin Akbas[2], Koksal B. Celik[3]

ABSTRACT

The main objective of this article is to analyze the primary historical water works constructed in Turkey throughout the four thousand years from hydraulic engineering point of view. Since the subject is too extensive, the article is only focused on historical waterworks in Turkey from Hittite, Urartu, Hellenistic, Roman, Seldjukide, and Ottoman periods.

In the first part of the study hydraulic structures from Hittite period are presented. The earliest remains of water works in Turkey dated from the Hittite period, primarily the second millenium B.C. It is believed that the most ancient dam in Anatolia (a part of modern Turkey) is Karakuyu dam constructed for irrigation purpose.

In the second part of the article water works from Urartians are discussed. The Urartians (one of an early eastern civilizations) was an early leader in complex irrigation networks. The most important water works of the Urartians is Samram irrigation canal, dating from 800 BC.

Hellenistic, Roman and Byzantine water works are presented in the following part of the article. Water conveyance systems to Side, Pergamon, Ephesus, Aspendos, Laodecia, Perge, Istanbul etc. exhibit great richness, variety and important engineering skills.

In the last part, water structures of Seldjukide and Ottoman periods are investigated. Bridges of Seldjukide period are important engineering and architectural structures. Halkali, Kirkcesme, Uskudar, Taksim water ways of Istanbul, Taslımusellim waterway of Edirne, dams of Istanbul, flood protection canals, aqueducts, water mills, water balance towers of Ottoman period respect special attention from hydraulic engineering point of view.

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1. INTRODUCTION

Turkey, the cradle of civilization throughout the mankind history, deserves special attention because of its historical hydraulic structures. Numerous pipelines (terra-cotta, stone, lead), canals, tunnels, inverted siphons, aqueducts, galleries, reservoirs, settling tanks, wells, cisterns, and dams of Turkey exhibit a fine sense of the hydraulic technology of their times.

2. WATER WORKS DATED FROM HITTITE PERIOD

Hittites constructed several hydraulic storage structures in central Anatolia since water resources were scarce in the region.

After a serious drought period Hittite King Tudhaliya IV ordered numerous dams to be built in Anatolia in 1240 BC. One of them is the dam in Alacahoyuk, Corum called Golpinar Dam. The water source is inside of the dam's reservoir. The Hittites used this dam to provide irrigation and tap water. In Hittite period tap water from this dam was collected in a sediment settlement pool, after the pool they conveyed water by using a two km long pipeline. After a recent restoration it stores 15000 m^3 of water and is still used for irrigation.

Karakuyu, the most ancient dam in Anatolia, was constructed for irrigation of Uzunyayla region. The U-shaped crest of the dam has a total lenght of 400 m. The upstream slope of the dam appears to be covered with a stone pavement (Ozis, 1999). Eflatunpinar Dam near Beysehir, Koylutolu Dam near Ilgin, Golpinar Dam near Corum, Guneykale Dam at Bogazkale, spring collection chamber in Bogazköy are the other important Hittite hydraulic structures. Hittites also constructed terra-cotta water conveyance pipelines especially in Bogazkoy. The lenghts of the terra-cotta pipes vary from 0.60 m to 0.96 m. Their diameters gradually vary from 20–22 cm to 11–15 cm having conical shapes.

3. WATER WORKS DATED FROM URARTU PERIOD

The first irrigation canals, reservoirs and dams in eastern Turkey (which lies in a region subject to violent sismic activity) were constructed by Urartians in the first half of the first millenium BC. Urartian hydraulic engineers had precautions to build eartquake resistant structures some of them are still in relatively good condition after thousand years.

Tushpa (Tuspa), shore of Lake Van became the capital of Urartu Kingdom about 830 BC. Since the water of Lake Van is not suitable for drinking (because of high sodium carbonate concentration) they built a conveyance canal from Engil (Hosap) Creek to Tushpa for the water supply of the city and agricultural purposes (Garbrecht, 1985).

The oldest large-scaled conveyance system in the world seems to be the Urartian Menua channel which was constructed around 800 BC by King Menua (810-786 BC) (Fahlbusch, 2000). This 56 km long water canal conveyed 2-3 m^3/s of water from Engil (Hosap) creek springs to Tushpa (Vankale) region. The widht of the canal varies from

3.5 to 4 m and the depth of the canal varies from 1.5 to 2 m. The source of the canal lies at an altitude of 1760 m, and the altitude of the downstream of the canal is around 1700 m.

A level route for the Menua canal has been created by building high retaining walls along valleys and low depressions. The retaining walls of Gulo Bogazi and Kadembasti have 11-12 m heights. Nearly half of the Menua Canal (23-25 km of its total lenght) has been carved out of rock. (Belli, 1997).

Another remarkable example of the Urartian's hydraulic engineering skill is Ferhat Canal, which has been supplying irrigation water in the vicinity for 2700 years without interruption. The width of the canal varies from 2 to 2.5 m and the depth of the canal varies from 1 to 1.5 m. Its capacity is lower than Menua Canal but it has been cut into the bedrock in planes where the terrain forms an obstacle like Menua Canal.

In order to supply water to the later Urartian capital city, Rusahinili (Toprakkale) the storage capacity of Rusa (Kesis) Lake has been increased by the construction of two dams around 700 BC (Ozis, 1999).

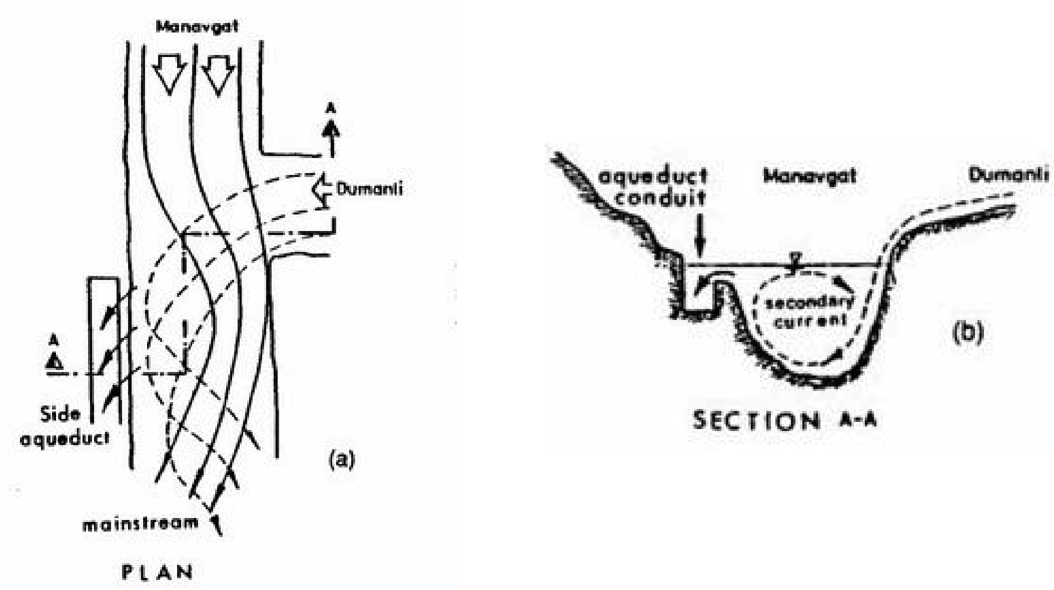
4. WATER WORKS DATED FROM HELLENISTIC, ROMAN, AND BYZANTINE PERIODS

4.1. SİDE WATERWAY

Side Waterway is an important example of antique hydraulic engineering. This water conveyance system is especially unique because of the engineering technic had been used on intake structure.

Roman engineers supplied water from Manavgat (Melas) River right after Dumanli-Manavgat River junction (35-40 m downstream of the junction) by the help of a side weir situated opposite side of the junction (Hodge, 1992).

Dumanli Spring is a steep sloped river with a mean discharge of 50 m^3/s. Roman engineers prefered this location for side weir in order to derive high quality water of Dumanli Spring. They diverted 400-500 lt/s of discharge by means of this hydraulic structure. The side weir typed intake structure is a good example of the Roman engineers observing river currents and profiting from them. Following the side weir typed intake structure the 25.3 km long Side water conveyance system includes 24 aqueducts, several tunnels, galleries, and inspection manholes. Tunnels have widths of 2.05-2.70 m and heights of 1.85-2.05. Closed canals at the beginning have widths of 1.10-1.30 m. The slope of the conduit is around 0.1 %. 19th km of the system there was a branch for irrigation. Antique Side city had also used groundwater and precipitation water by the help of cisterns and wells besides the Side water conveyance system.



Figure–1: Side side weir (Hodge, 1992).

4.2. EPHESUS WATER CONVEYANCE SYSTEMS

Ephesus city deserves special place in the history of water resource engineering. Ephesus has been supplied by water through four important water conveyance systems, two of them were exceeding 40 km lenght. These are Sirince, Derbentdere (Marnas), Degirmendere (Kenchrios), Kayapinar (Kaystros) water conveyance systems.

The Sirince water conveyance system consisted of terra-cotta (baked clay) pipes. Total lenght of the system is 8 km long. The inner diameters vary between 10 and 16 cm, and outer diameters vary between 12 and 22 cm. It mainly collects the groundwater. It is probably dated to 6th century BC but it had several repairs throughout the centuries.

Derbentbere (Marnas) water conveyance system is 6 km long, conveying springwater from southeast of Ephesus through three parallel terra-cotta pipelines. The first pipeline crossed the Marnas valley over the Sextilius Pollio aqueduct. The two storied aqueduct had a total height of 16 m. It is also the oldest roman aqueduct in Turkey.

Degirmendere (Kenchrios) water conveyance system is 43 km long, conveying the water of Degirmendere Springs. It is probably dated from the first century AD.

The Kayapinar (Kaystros) water conveyance system is 40 km long. It conveyed the water of Kayapinar spring by means of a masonry conduit. It was probably built in second century AD. It was built between Kayapinar and northeast of Ephesus.

Figure–2: Sextilius Pollio aqueduct over Marnas Valley.

In addition to these water conveyance systems Ephesus' water needs were also supplied by local cisterns and wells. A dense terra-cotta pipe network, some of them still visible in situ, distributed water to the fountains, baths, and other buildings. Ephesus city had also an important sewerage network under the main street of the city discharging to the harbour.

Figure–3: The lead pipe with marble joints on display at Ephesus Museum.

Artemis Temple near Ephesus (one of the seven wonders of ancient world) was met its water needs by an inverted siphon. The inverted siphon was formed by lead pipes with marble joints. Inner diameter of the lead pipe is 8 cm, the wall thickness is 4.5 cm and the lenght of the lead pipe is 60 cm. The marble joints have 18 cm inside and 35 cm outer diameters. A sample of these pipes is on display at the Ephesus Museum. It is dated to 5th century BC. A similar marble joint resisted to 51 atmosphere internal pressure based on a laboratory test made in Australia (Ozis, 1994).

4.3. PERGAMON WATER SUPPLY SYSTEMS

The water supply of the Pergamon city was based originally on some fountains and cisterns of the city.

The first pipeline of Pergamon is probably dated to second half of the 3rd century BC leading water from eastern slope of Bergama (Selinus) River to the city. There were two water conveyance systems from Selinus river. One of them was a single terra-cotta pipeline with a water capacity of 3 l/s and the other system were consisted of two parallel terra-cotta pipelines with a total water capacity of 27 l/s and they had a lenght of more than 15 km. Both systems include inverted siphons with an internal pressure of 25-30 m.

Water conveyance system from Madradag to Pergamon consisted of three 45 km long parallel terra-cotta pipelines. After flowing through a double section settling basin water was conveyed to the Pergamon acropolis by means of an inverted siphon of single line lead pipes under a 190 m internal pressure (Ozis, 1996). Pergamon lead pipe inverted siphon had the highest pressure in the world of the hellenistic period (Fahlbusch, 1997).

Pergamon also had some other important water conveyance systems from the springs of Kaikos River and Geyiklidag. The completely ruined Ilyas River aqueduct belongs to Kaikos River conveyance system had 40 m height and 550 m lenght. It was one of the most noteworthy aqueducts in the world (Ozis, 1996).

4.4. ISTANBUL WATER SUPPLY SYSTEMS

The earliest known water supply line to Istanbul city was built in the time of Emperor Hadrian (117–138). It conveyed the water from west of the city to Sultanahmet Square. This water supply line was extended during the reign of Theodosius II (408–450). The second important water supply line was built durign the reign of the Emperor Constantine (324–337) and supplied water from the Istranca Mountains west of the city to the south of Edirnekapı. It was the longest of all water supply lines constructed by the Romans. The upstream point of this system is 6 km west of Vize and its total lenght was 242 km (Cecen,1996). Istanbul's third major water supply line was constructed in the time of Emperor Valens in 373. The water line, which was renovated and enlarged during the reigns of Justinian (527–565) and Constantine V (720–740), supplied the Achilleus Baths and Yerebatan (Basilica) Cistern. The fourth water line belongs to romans carried water from the Belgrad forest to the nortwest part of the city was probably built by Theodosius I (379–395). Epreror Justinian had large cistern constructed in the 6th century also repaired the Hadrian waterline.

When wells, cisterns and water resources of the city became inadequate because of population grew, the existing water supply lines and distribution networks inside the city were expanded and new sources added to existing systems. In the periods of Constantine V (741-775), Romanus III (1028-1034), and Manuel I (1143-1180) only repaired the existing systems. From tenth century deterioration of the old Roman water system as a result of sieges and eartquakes, prompted the Byzantines to make extensive use of cisterns. Small conduits were added to existing systems for water distribution from reservoirs and cisterns. They built new cisterns instead of supplying water from distant sources.

After the Latin occupation the water system of Istanbul became unusable. As soon as the conquest of Istanbul by the Turks in 1453, the restoration and reconstraction works of water systems had begun (Cecen, 1996). Roman period aqueducts dated from the 4th century, the Bozdogan (Valens), Mazulkemer, Karakemer, and Turuncluk, are still in good condition.

4.5. OTHER IMPORTANT WATER WORKS DATED FROM HELLENISTIC AND ROMAN PERIODS

Aspendos triple inverted siphon, two parallel stone pipe inverted siphons of Laodecia, stone pipe inverted siphon of Izmir under a 155 m internal pressure, Cevlik Dam near Antakya, Cavdarhisar Dam near Kutahya, Orukaya Dam near Corum, Boget Dam near Nigde, Ildir Dam near Cesme, three Dara Dams near Mardin, Lostugun Dam near Malatya, Sihke, Sultan and Faruk Dams near Van, Perge water conveyance and sewerage systems, Priene water conveyance and sewerage systems, and Cevlik diversion tunnel systems are some other important water works dated from Hellenistic and Roman periods.

5. WATER WORKS DATED FROM SELDJUKIDE PERIOD

The Seljukides constructed numerous passive water structures, like bridges throughout Anatolia. Malabadi Bridge with a 39 m single span width is the largest masonry bridge in the world. The flexible wooden foundation systems and sharp edge shaped piers of Seldjukide bridges exhibit high engineering skills. They built water mills and irrigation systems, fountains during their 10th-13th century period in Anatolia. They also have constructed several dams in Turkey, Iran and Turkmenistan (Ozis,1999).

Figure–4: Malabadi Bridge with a 39 m single span width.

6. WATER WORKS DATED FROM OTTOMAN PERIODS

6.1. ISTANBUL WATER SUPPLY SYSTEMS

After the caption of Istanbul in 1453 Ottoman Sultans gave special attentions to the water works of Istanbul. Halkali, Kırkcesme, Uskudar, Taksim water ways are some of the important water conveyance systems of Istanbul.

Halkali Water Conveyance System consisted of 16 different water conveyance lines with a total lenght of 130 km. This system had been constructed between 1453 and 1755. The names and construction dates of these conveyance lines are Fatih (1453-1481), Turunclu (1453-1481), Mahmutpasa (1453-1473) and Laleli (1454-1474), Bayazit (1481-1512), Kocamustafapasa (1511-12), Suleymaniye (before 1557), Mihirmah (before 1565), Ebussuut (before 1545-1574), Cerrahpasa (1598-1599), Sultan Ahmet (1603-1617), Saray Fountains (1623-1640), Koprulu (1656-1661), Miri (Beylik) (1730-1754), Hekimoglu Alipasa (1732-1750), Kasimaga, Nuriosmaniye (1748-1755) (Ozis,1996).

Kırkcesme Water Supply System was built by Architecht Sinan between 1554 and 1560. It includes many aqueducts, settling basins, water intake systems, sand traps, water measuring structures, city networks, fountains etc. Some parts of the system had a restoration because of a huge flood. The whole system had been completed in 1563 after the restoration. This system is still in use without any failure after more than 400 years. It fed the Rumeli side of Istanbul and was derived from the sources located north of the city. It has a total lenght of 55 km. It has four significant aqueducts. These are; Uzun Aqueduct (26 m height and 710 m length), Egri Aqueduct (35 m height and 342 m length), Maglova (35 m height and 258 m length), and Guzelce Aqueduct (32 m height and 165 m length). Topuz, Buyuk, Kirazlı and Ayvat Dams were added to system between 1620 and 1818 in order to ensure the seasonal flows regulation. Kırkcesme Water Supply System is a monumental water work totaly belongs to Architect Sinan.

Figure–5: Maglova (Muglava) aqueduct with 35 m height and 258 m length was constructed by Architect Sinan on the Kırkcesme water conveyance system (Cecen, 1996).

Figure–6: Guzelce (Gozluce) aqueduct with 32 m height and 165 m length was constructed by Architect Sinan on the Kırkcesme water conveyance system (Cecen, 1996).

Uskudar Water Supply System was constructed between late 16th century and 19th century. It contains numerous water balance towers. Water balance towers used on water supply systems of the cities like Pompei in Roman period but they extensively used by Ottomans. The aims of the water towers were changing the direction of flow, branching the flows, discharging the trapped air in the pipelines, controlling the defective sections, opening the pipeline to the atmosphere, and limiting the internal pressure of the pipelines.

Taksim Water Supply System was constructed in 1731 by Sultan Mahmut I. It has a total lenght of 23 km. Buyukdere aqueduct, Derbent inverted siphon, Topuzlu, Valide and Yeni Dams are the important features of the system. Hamidiye water conveyance system was constructed primarily for drinking water in the 19th century.

6.2. EDIRNE-TASLIMUSELLIM WATER SUPPLY SYSTEMS

Taslimusellim Waterways was also constructed by Architect Sinan. It has two branches called Sinankoy and Taslimusellim. Total lenght of the system is 50 km, total discharge capacity is 35 l/s and the system is still partly in service.

6.3. OTHER IMPORTANT WATER WORKS DATED FROM OTTOMAN PERIOD

Ottomans were also built several water structures like dams, flood protection canals, water mills, irrigation canals, aqueducts, water balance towers, and fountains in Turkey.

7. CONCLUSION

Turkey has been the crossroads of many civilization throughout the human being's history. During the last 4000 years, many civilizations left remarkable remains of water supply systems including pipelines (stone, terra-cotta, lead), irrigation canals, tunnels, galleries, inverted siphons, aqueducts, reservoirs, cisterns, flood protection canals, water mills, water balance towers and dams in the country. Present paper evaluated the various historical water works belong to Hittite, Urartu, Hellenistic, Roman, Byzantine, Seldjukide and Otoman periods in Turkey from hydraulic engineering point of view. The ancient hydraulic structures in Turkey convey a fine sense of hydraulic engineering knowledge even for today's hydraulic engineer's thought. The historical water structures in Turkey clearly prove that the predecessors of modern engineers knew the main rules of both open channel flow and pressurized flow.

Moreover based on a four thousand year hydraulic engineering tradition, Turkey is still constructing large-scale irrigation projects, dams and hydroelectric power plants.

Finally, it is hopefully anticipated that international and national interests both in the ancient water works of Turkey from the Hittite, Urartu, Hellenistic, Roman, Byzantine, Seldjukide, Ottoman periods and modern water works from Republic of Turkey period will continue to increase.

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TRADITIONAL WATER MANAGEMENT; AN INSPIRATION FOR SUSTAINABLE IRRIGATED AGRICULTURE IN CENTRAL IRAN

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ABSTRACT

Central Iran is an arid area where all agricultural systems as well as human civilizations have always depended on the groundwater mostly obtained through *qanats*, but lack of an integrated management has thrown our groundwater resources into disorder. This paper investigates the ways through which we can incorporate some traditional methods into our modern water management. In fact there are two important things we might learn from the tradition:

1- accurate systems for division of water
2- preservation of groundwater resources

In central Iran, traditional knowledge provides informal education on water management that is passed from generation to generation. It concerns knowledge on division of water, maintenance of qanats and preservation of groundwater resources. This gives hope for the future, where both tradition and modernity can live side by side to promote our new water management.

Key words: Traditional water management, modernity, division of water, preservation of water, water resources, qanat, sustainable agriculture

INTRODUCTION

Central Iran is an arid area, so that its average rainfall does not exceed 250 millimeters a year. Therefore in central Iran all agricultural systems as well as human civilizations have always depended on the groundwater mostly obtained through qanats[2], some

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2- There are 32164 qanats in Iran and an estimated the total length of their galleries is about 310800 kilometers (Papoli Yazdi & Labbaf Khaneiki, 2003). A qanat consists of a long horizontal tunnel which directs water toward the surface as well as lots of shaft wells in order to ventilate the tunnel and provide a way through which the excavated materials can be pulled up. To construct a qanat, first of all, an area near a mountain slope is usually chosen in order to dig the first well. The qanat practitioners continue to dig the first well as long as they come across the aquifer seeping into the bottom of the well. Then they stop digging the well because of the level of water coming up, but start digging a long tunnel crossing bottoms of all the wells, from the surface of earth to the last and deepest well. The tunnel is roughly horizontal, with a slop to allow water to drain out. The discharge rate of a qanat depends on its extent in the aquifer. Qanat has been an important part of a sustainable productive system, consistent with the environment of Iran, and used during the past centuries without damaging aquifer reserves.

gently sloping subterranean conduits, which tap a water-bearing zone at a higher elevation than cultivated lands. But lack of an integrated management has thrown our groundwater resources into disorder. About fifty years ago, the total discharge rate of the qanats was approximately 18 billion cubic meters a year, which was 2 times more than the present amount. This problematic decline is attributable to the extensive pump extraction of groundwater and many wells drilled in the past few decades. Without regulation on water resources management this practice often depletes aquifers. The pumps are threatening our groundwater in central Iran and putting some economical-social systems in a real crisis, which make us think of other ways to improve our water management.

This paper investigates the ways through which we can incorporate some traditional methods into our modern water management. In central Iran, traditional knowledge provides informal education on water management that is passed from generation to generation. It concerns knowledge on division of water, maintenance of qanats and preservation of groundwater resources. This gives hope for the future, where both tradition and modernity can live side by side without doing any damage to our water resources. Before getting to the point, I would like to bring the historical aspects of water management to the readers' attention.

THE HISTORY OF WATER MANAGEMENT IN IRAN

Since the dawn of the Iranian civilization, water division system has played an important role and often lain behind the social and political processes. According to Wittfogel's theory, the water division system led to oriental despotism. In this arid region which has always been short of precipitation, people had to irrigate their lands, because they could not leave their cultivated lands only to such a little rainfall. On the other hand, the amount of water obtained through either rivers or qanats might not be quite sufficient for everyone to use without any need to economize on it. Therefore, some individuals gradually emerged to regulate water consumption and took charge of other water related affairs. In this region, whoever could take control over water would be able to gain a high social position and finally power to organize a political dictatorship or oriental despotism somehow.(Naghib zadeh A. 2000)

One can place a great importance on water division system during the history of Iran. As an instance, water authorities or water organizations trace back to Sasani era, about 1900 to 1400 years ago. That ancient water authority was responsible for managing water ownership, recording water shares, and calculating the amount of tax the farmers had to pay for their shares of water. Later, Abbasid caliphs reestablished the same water authority named *Divan al-Ma'*, and assigned some experts named *hassab/accountant* to all water related affairs (Papoli Yazdi M. and Labbaf Khaneiki M. 1998). All the Iranian governments used to place a high value on water, so they tried to do their best to look after water affairs. The more perfect water distribution and management, the more profit the governments could make. I would like to draw your attention to the fact that in some cases the taxes were only calculated based on the amount of water (Khosravi Khosrow. 1969), because our historical governments had derived from a traditional economical context which was quite different from the recent one resulting in some political systems that often fasten their hopes on some natural resources like oil. In the past, the Iranian governments used to intervene in water management to avoid any disorder in agricultural production systems which had something to do with the amount of taxes the government expected to charge people. Aboodalaf, an Arab historian, reports a fascinating dam in Damghan (in central Iran) constructed by Sasani kings in order to divide water into 120 shares each of which belonged to a village, then he admits that "he has never seen such a clever and accurate technique to manage water". (Aboodalaf. 1975) Also, what Maqdasi, an Arab geographer, reports on the Marv dam, in fact shows how much the Iranian governments were concerned about the irrigation systems and water management. According to Maqdasi's report the Marv dam was run by a staff of ten thousand persons who were hired to protect the dam or be in charge of its water management. To measure the amount of water, the dam had a special tablet in a standing posture with some horizontal lines cut into it. Should the level of dam water could reach the sixtieth line, it would imply that the coming year would be so wet and fruitful that the staff of dam no longer needed to be quite strict about the water division. But, it could be a bad omen predicting an upcoming drought, if the level of water could not exceed the sixth line. There were some main outlets in the dam each of which belonged to a separate village to distribute water among them as fairly as possible, and then there were other outlets in every village to divide water among the quarters, and more outlets in every quarter, so on. If the dam would become short of water, the staff would do their best to decrease all the shares alike (Meftah E. 1992). Note that whatever we know about the water related techniques or management in the course of history come from only the existing historical records that in a way seem exaggerating. For example it is mentioned that there was such a huge dam able to supply water to 120 villages in Damghan an arid region where today the existence of such an amount of water is incredible. Also Maqdasi refers to a staff of ten thousand running the dam of Marv, but it may flash through everybody’s mind that such a staff is out of proportion to the population of a medieval city like Marv. Meanwhile, we have no idea how they could predict the scarcity of water just by means of a tablet, and do not know anything more about the scientific basis of such a prediction what is so difficult and complicated even with the aid of modern technological devices. Here I do not want to track down the mechanism of the dam of Marv or to find out whether the number of ten thousand is true or not. My purpose is to indicate that how important water management has been in the Iranian political-economical structures attracting the attention of those rulers and writers, even though the historical records are partly exaggerating.

Sometimes rulers and writers teamed up to find a remedy for water related problem. For example a book entitled “extraction of hidden waters” was written by Aboobakr Mohammad Al-Karaji whose patron was the minister of Manoochihr Voshmgir. Al-Karaji states in his preface that he had referred to various books by earlier writers on the exploitation of subterranean water (Lambton A. K. S. 1989). In fact if any problem threw the water division systems into disorder, the government was also in charge of solving it, as king Tahir did about 1000 years ago. A terrible earthquake struck Khorasan province and destroyed many qanats so that their flow completely ceased. After renovation of the qanats, some serious disputes broke out between the owners of the qanats for more shares of water. Finally king Tahir mediated between the owners and settled the problem by means of calling in all the clergymen and lawyers from all over Khorasan to compile a book on the water division and water related laws (Salimi M. S. 2000).

Bearing in mind the importance of water management in Iran, it was only for king or his minister to confirm and sign the official proofs regarding the water division systems of big rivers. For example the proofs of Karaj River should have been authorized by Amir Kabir, Nasereddin Shah's famous minister (Enayatollah R. 1971). So, it would not be an exaggeration to say that most of the socio - political structures of Iran are still rooted in the history of water management.

Needless to say water management systems did not exist only at the level of state, but even more complicated systems were (are) practiced in rural regions. The following part examines the remains of these local systems that can be an inspiration for our new water management systems.

TRADITIONAL WATER MANAGEMENT

Here, traditional water management means all the actions the local farmers take in order to regulate water division, irrigation related subjects and preservation of water resources. They have traditionally established some complicated systems in order to divide water among the farmers or the shareholders of a water resource, and irrigation rights are based on landownership or time shares within a certain period of rotation. This water division system can match up with all likely changes in the volume of water during a year, while satisfying the farmers' irrigation needs. To measure the time every shareholder has for irrigation, they have invented a special type of water clock or clepsydra. Their clepsydra consists of two bowls made of copper one of which is so small that could freely float on the surface of water in the large one. The floating bowl has a tiny hole at its bottom through which water can enter the bowl and gradually fill it up. After being filled which may take a certain time, the small bowl sinks in the water and bumps into the bottom of the large bowl. As soon as the bump would be heard, a unit of time would be over, so the time between the two bumps equals a certain unit of time. One can also find some marks cut into the inner side of the small bowl which divide the certain unit of time into the shorter fragments. The time it may take the small bowl to be filled and sink varies from area to area in the central plateau of Iran. I examined some different types of clepsydra in some areas and summarized all the results in the following table.

Location	Time (hour: minute: second)
Kol-e Birjand	00: 24: 00
Shahik-e Qayen	00: 22: 30
Khor-e Birjand	00: 17: 00
Kadekan	00: 15: 00
Sarbisheh, Zirkooh-e Qayen, Darmian-e Birjand	00: 12: 00
Yazd	00: 11: 15
Zoozan, Boshrooyeh	00: 10: 00
Fakhrabad-e Bajestan, Eshgh abad-e Tabas	00: 09: 00
Bilond-e Gonabad	00: 08: 30
Gonabad	00: 08: 24
Dihook-e Tabas	00: 08: 00
Khanik-e Gonabad	00: 07: 30
Abiz-e Qayen	00: 07: 00
Aboojafari-e Boshrooye, Kakhk	00: 06: 00
Khosro Jerd-e Sabzevar	00: 05: 00
Serend-e Ferdows	00: 04: 44
Bajestan	00: 04: 36
Tabas	00: 04: 00
Ferdows	00: 03: 00

Sometimes, in a certain area, the unit of time may vary with the season and the period of rotation within which the irrigation rights have been defined. As an instance, In Bajestan area, the unit of time varies from 2.3 to 17.2 minutes between the months of March and February. In this area, there are three qanats named Mohammad abad, Golbid and nowkariz. Bearing in mind the location of farms and the distance between the qanats and the farms, each farmer may use either one of the three qanats or two/three of them mixed together. The joint flow of the qanats of Golbid and nowkariz is only considered as the standard flow to which all the official proofs refer. For example, if someone claims that he/she possesses ten shares of water, in fact he/she is entitled to irrigating his/her land for 46 minutes because every unit of time equals 4.6 minutes on the condition that the flows of Golbid and nowkariz are together. On the other hand, the rotation of irrigation rights may be based on 21, 14 or 10 days during a year. Within a period of rotation based on 21 days, every shareholder is allowed to irrigate only once every 21 days and so on.

Meanwhile, the length of the period rotation varies from season to season in order to adapt the available water to the existing climate condition. Therefore, there are 15 units of time all of which depend on the period of rotation and the source of water, as you can see in the following matrix. The gray part of this matrix shows 15 possibilities for unit of time from 2.3 to 17.2 minutes. As an example, the unit of time would equal 4.6 minutes, if the rotation of irrigation rights would be based on 14 days as well as both the qanats of Golbid and nowkariz would be taken into account.

10	14	21	period of rotation / source of water
2.3	3.2	4.8	Mohammad abad+Golbid+nowkariz
3.2	**4.6**	6.9	Golbid+ nowkariz
8.2	11.5	17.2	Mohammad abad
8.2	11.5	17.2	Golbid
5.5	7.8	11.7	Nowkariz

Due to the complexity of the water division, there are some professionals named *mirab* who are in charge of distribution of water among the farms, and are paid a definite salary by all the shareholders. While giving water to a shareholder, *mirab* also has to consider the time it may take the qanat flow to get to the given farm. For example, if someone has a right of 46 minutes irrigation, and if it takes the flow of water 4 minutes to arrive in his/her farm, then he/she should be allowed to use the water for 50 minutes. Therefore, *mirab* does his best to distribute the water among the farms in a way that as less water as possible would be wasted in the ditches. Doing so, *mirab* should be quite familiar with the locations and characteristics of all the ditches leading water to the farms. *Mirab* has a notebook too, including all the irrigation rights in detail, so if the shareholders want to sell or buy any right they should let *mirab* know about any transaction. Unfortunately nowadays this profession is fading but nothing is replacing it, so we witness some recent conflicts over water in rural areas these years.

Preservation of groundwater resources is also a good example of traditional Water Management which could be up for discussion here. Iranians traditionally used to live in harmony with their environment, so their techniques to supply water did not end up in the annihilation of groundwater resources. They used qanats as a sustainable technique to extract groundwater, which was recharged in winters by some special dams constructed by the farmers. To prevent damaging aquifer, they designated the vicinity of qanat, which was the area defined surrounding the qanat and comprised between 1 and 3 km depending on the local conditions. The aforementioned dam is nothing but a pile of soil in upstream above the first and deepest well of qanat so that it can catch the floods in winter behind itself. The water accumulated behind the dam can gradually penetrate the earth and then seep into aquifer, so an increase in the discharge of qanat as well as the lack of erosion are two of the advantages of such dams. Nowadays, most of the dam are leveled and then cultivated with the help of pumping deep wells drilled in the vicinity of qanat. The fertile deposits of the dams tempted some farmers to change the dams into the farms at any cost, even though the qanat would dry up. As an instance, in Yazd a qanat named Chahok-e Nir was recharged by four dams which were located in the bound of another village named Pandar. The habitants of Pandar had some shares from this qanat, so not only they put up with the presence of dams in the middle of their lands, but also they helped the main owners of the qanat with renovating and protecting the four dams. After the Islamic revolution, the farmers of Pandar started selling their shares, and after a while they completely destroyed the dams and drilled some pumping wells in order to cultivate the whole area. The lack of those dams caused the qanat to drizzle. But fortunately such traditional dams could provide inspiration for the Yazd Regional Water Authority which is very concerned about improving the groundwater resources in Yazd province. Doing so, they recently implemented some great projects to help recharge aquifer such as building 18 mud dams being able to inject more than 17 million cubic meters seasonal flood into aquifer. This gives hope for the future, where we would be equipped with both tradition and modernity to guarantee a sustainable agricultural system, though after the land reform program and the advent of modern devices, these traditional water management systems started to fade out.

Figure 1- a traditional structure named Maqsam for dividing water into four shares each of which goes to a particular village. (the province of Yazd)

Figure 2- calculating water shares by means of a traditional clepsydra

WATER MANAGEMENT IN THE REALM OF MODERNITY

Among the package of the modern reformation of the former Shah in 1963, the redistribution of agricultural lands which sheared the traditional landed elites of much of their influence has the most significant effect on water management systems in Iran. Before the land reform, most of the Iranian population resided in rural regions. Each village consisted of some agricultural units named *boneh*, cultivated by 8 to 12 farmers (share-croppers). The duty of each farmer was perfectly specialized. Two farmers were usually in charge of plowing and preparing the field, two other farmers were responsible only for irrigation, and the rest of them were involved in seeding, protecting and harvesting. Everybody worked and lived under the management and authority of a lord, who owned the whole village. According to the Law of Land Reform, the villages were purchased from the lords by the government one after another, and then were sold to a few farmers in the same village by installments.

The land reform law was finally carried out, without caring about the majority of the villagers who had no share in the agricultural units (*boneh*), not profiting from the land reform at all, and without caring about the complicated relationships between the production systems, environment and water management in Iran. So, the land reform law could lead to annihilation of many qanats which were only resources to supply water to central Iran, by means of a blind mechanization and confusing water management systems. Even if the motive for the land reform was making the lords' capitals move to the principal cities to be invested in the industrial section, the government should not have distributed the lands between the peasants yet. But, it was better for the government to retain the purchased lands and reconfigure the traditional management in a modern context by means of setting up some organizations in the rural regions being able to take the landlords' place. Doing so, the agricultural units *(boneh)* which could optimize irrigation so perfectly that sometimes the irrigated fields could be extended 1.5 times (Safinejad. 1989), would be left untouched.

In fact the land reform removed the lord’s traditional position, because those agricultural systems carrying such a position were ruined, but anyone or any kind of organization did not exactly replace the lord’s role. Therefore many qanats were abandoned for a while or even for ever. Because, within the agricultural system of *boneh*, the lord used to look after his qanat, and if a qanat would need to be repaired, the lord did not hesitate to call in the qanat practitioners and finance the whole project. After the land reform, the qanat practitioners could no longer work for any lord who used to finance the qanat and give them an opportunity to earn a living, so they were encouraged to immigrate to the cities or other regions. In central Iran, qanat practitioners were a professional community having no right to work on the lord’s lands as some official and permanent farmers. In the rural regions, the society was divided into two casts locally named *Nasaqdar* and *Khoshneshin*. *Nasaqdar* meant the groups who had the right to work for the lord as his farmers on his fields, so they had priority over the second cast (*Khoshneshin*) who had nothing to do with the agricultural activities, and their jobs would only satisfy the other needs of the rural community such as masonry, carpentry, handicrafts and qanat-related activities. According to the land reform law, the lord’s lands should have been distributed just among the *Nasaqdars* the people who worked on the lord’s fields, so this program did not bring any profits to the qanat practitioners and made them let go of the agricultural areas.

On the other hand, the land reform raised a great demand for irrigation water because of a bad management. Before the land reform, whoever worked in an agricultural unit (*boneh*) was responsible just for a particular job such as plowing, seeding, irrigating or harvesting, and the farmers rarely interfered with each other’s job. Therefore, each farmer could not be as good at all jobs as his own job, so most of them were not capable of irrigating the fields. In a traditional manner, someone who was not expert at irrigation might waste some water in many ways, so after the redistribution of the lands the consumption of water increased, and the demand for water quickly surpassed the supply of qanats mostly due to misusing water. Therefore, the farmers had to drill some deep well to pump the aquifer to provide the required water, doing so lots of qanats fell into decay.

As mentioned, according to the Law of Land Reform, the lords were forced to sell their lands to the government. But mechanized farms were the exception, and having pump extraction was legally considered as a proof of it (Azkia M.. 1994), so some of the lords were encouraged to replace qanat with pump extraction in order to save their own lands. Actually they did not want government to destroy their traditional position in the rural communities by means of removing their economical roots. The lords hurried to dig the well with extractive pump to avoid being included in the land reform law, even if their lands needed no well. Doing so, the number of the deep wells dramatically began to increase. As an instance, the first well with extractive pump, which took place in Neyshaboor region, was drilled in 1958. But the number of such wells reached 14 in 1960 just when the land reform law were approved and announced, and then amounted to 286 in 1970. Massive ground water extraction causes depletion of finite aquifer reserves, and it dramatically reduces the water table of the whole surrounding area. An estimated in Neyshaboor region the water table goes down about 0.2 meters a year on average, because of the massive groundwater extraction (Velayati. 1999). Therefore most qanats were drying one after another, due to the wells and their pumps, which took the water table away from the access of qanats. The comparison of qanat with well (extractive pump) can shed a light on the fact that such wells are not suitable for Iranian agricultural systems in many cases. Extractive pump empties the porous layers of water and cause some subsidence, which do lots of damages to the structure of soil and even buildings. If extractive pump empties karstic holes of water and destroy them, then a circular hollow appears within a radius of 100 meters on the surface of earth. But qanat never makes such a problem. The potential loss of fresh water, which makes salt water move towards up stream, is attributable to extractive pumps, whereas qanats never change the quality of water. According to some information related to Iran, the wells with extractive pumps could not last more than 30 years unlike qanats which last more than 2000 years without any defects. After all, water flows out of qanat only because of the force of gravity that is free of charge, whereas the extractive pumps consume an enormous amount of fuel per year. For example, in Yazd area there are 4340 wells with extractive pumps, which totally consume 205854880 liters gas oil a year in order to obtain 926350000 cubic meters water. But in the same area there are 2948 qanats, which withdraw 329870000 cubic meters water a year without any fuel (Baqeri & Roozbeh. 1999).

This land reform was an example and a bad experience that taught us the fact that development is not a simple concept we can import from the modern world into our own country, without taking our cultural economical and ecological conditions into account. Although the Iranian authorities tried to belittle all the traditional production systems, while carrying out the land reform program, in order to pave the way for a modern model. They believed that our country could never achieve a developed stage, unless we completely let go of the traditional sections of the society that appropriate most of our resources. Therefore, most of the Iranian scholars and politicians tried to exaggerate the technical defects in qanat and traditional water management to justify their own hasty programs and convince farmers to use pump extraction instead of qanat.

As an instance, a report entitled "Economical Development of Soil and Water Resources" prepared in 1966 explains the amount of required water to irrigate an area equal to 10000 square meters or a hectare. Some parts of that report associated with modern techniques estimate the amount of required water for a hectare to be about 10000 cubic meters a year. But another part related to qanat and traditional irrigation makes contradictory statements, so that it estimates the amount of water needed for a hectare to be about 16400 cubic meters a year. In fact there is a thirty percent decrease in the required water in comparison with real estimate when the report explains modern irrigation, and a sixty percent increase when the report engages in qanat and traditional irrigation. Then the report concludes from such wrong estimates that qanat cannot supply the required water to irrigate our farms. Such exaggerating reports resulted in thousands qanats being destroyed. As an instance, only in the plain of Yazd there are more than 70 dried-up qanats, which have caused many villages and about 2500 hectares rich lands to be abandoned (Labbaf Khaneiki M.. 1999). The main reason why *qanats* started drying is that many deep wells were drilled in lower slopes to extract water with pumps depleting aquifer.

The depletion of aquifer not only makes *qanat*s dry, but also causes desertification especially in central Iran in which some plants such as Salsola Spp and Seidlitzia Sp usually grow depending on the water table (Ekhtesasi & Daneshvar. 1999). When I worked for Amirkabir institute in 1996, I came across an awful adventure explaining the role of pump extraction in some water and land management disasters as well as social – economical problems. There were some villages in southern Khorasan lying on the edge of central desert of Iran in which some peasants had settled and traditionally earned their living by camel husbandry. An organization had made a decision to help them start to cultivate their pastures in hopes that they could improve their economical situation. So the organization encouraged them to give up camel husbandry that was supposed to waste their time and energy. They started to drill many deep wells to pump water for the lands allocated to produce pistachio instead of camel husbandry. The extracted water contained some salt, and irrigation water that was not properly drained left a salt residue. The salt built up and finally led to a type of soil unusable for farming. According to the book Blue Gold, salinity has affected a fifth of the world's agricultural land, and each year it forces farmers to abandon a million hectares of farmland (Barlow & Clarke. 2003). As a result, the aforementioned farmers had to stop planting the pistachio trees, because of the salty soil not letting pistachio grow. So they desired to return to the camel husbandry, but the environmental condition had changed so much that no animal could feed on such poor vegetation. In fact the pumps caused depletion of aquifer as far as the roots of some plants such as Alhaji which was the main food to camels could not reach the water. Therefore, there is no enough plant in the field in which their camels were supposed to graze. Unfortunately the farmers lost both agriculture and animal husbandry, and they had to immigrate to some principal cities as a community of poor suburbanites. I believe that after water management broke up in disorder and lost its traditional function, we faced some multidimensional problems which would remain unsolved unless we would modestly learn some lessons from tradition.

CONCLUSION

It is not wise to give up all modern technologies and revive tradition instead, but it is quite wise to adopt the sustainable relationship which has always existed between environment and the elements of the traditional production system. In the traditional agriculture, such an accurate water management perfectly met environmental conditions to make use of every drop of water in cultivating this arid region. Therefore, there are still many things we can learn from traditional water management to promote our new water affairs. Recently, in Iran some governmental centers' attention to traditional water management is tending upward. This gives glad tidings that future is not that disappointing if we learn how to have both tradition and modernity living side by side meeting a unique purpose, and it is the golden key of the sustainable water management.

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KHAZANA BAWALI; HISTORICAL WISDOM NEEDING PROTECTION

Narendra Chapalgaonkar[1]

ABSTRACT

'Khazana Bawali' (Treasure Well) was constructed about four hundred and thirty years back during Nizamshahi rule in western India. Most of the cultivable land in this kingdom was arid and this was probably first public facility for irrigation. Barring negligible small portions irrigated by private wells, agriculture was dependent on insufficient and uncertain rains. Project is said to be once irrigating 1000 acres, but it is gradually on the decrease. Except in the recent past, project was managed by self disciplined beneficiaries. Now, a state department looks it after.

Irrigated land was considered to be prize possession. Transfer of ownership was rare. Dry farming and very few army services were the only vocations. They did not generate enough money for purchase of irrigated land. Now, different means have given sufficient resources for such purchases to many. Original beneficiary families could not now resist temptation of lucrative prices. Lands under this project have changed hands. Vehicular assistance has made it possible to cultivate and supervise lands from a distance. Rich peasantry as a class has become influential in political life. This fact has many-sided effects. There is a tendency to flout rules to great personal benefit. Social ethics has lost its primacy and tendency to grab all benefits has replaced it. It has become difficult to enforce discipline and regulate the use of public amenities. Problems, which are posed by the present state of this project are of general importance and are relevant in consideration of similar projects.

INTRODUCTION:

'Khazana Bawali' (Treasure Well) situated about six kilometers from Beed, a district place in Maharashtra, was constructed about four hundred and thirty years back during Nizamshahi rule in western India. Most of the cultivable land in this region there was arid and this was probably first public facility for irrigation. Barring negligible small

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portions irrigated by private wells, agriculture was then dependent on insufficient and uncertain monsoon. This project is a large well of 20 meters radius in which rain water oozing from nearby hills is brought through underground tunnels and then used for irrigation by taking it through masonry channels under gravity. Ventilators provided at regular distance in this channel allow fresh air helping water purification and space also allows occasional manual cleaning. Underground construction below bed of the river crossing is one of the engineering feats. Project was once irrigating 1000 acres, but it is gradually on the decrease. Record shows that about 500 acres were irrigated thirty-five years back and now it is further reduced to 165 acres. Except in the recent past, project was managed by self disciplined beneficiaries. Now a State Department looks it after.

In the gazetteer published by the government of Maharashtra in 1969, following information is found on page no 659 regarding this well.

" Khazana Bavli : A little over four kilometres (three miles) West of Bid near the village Pali is a large well called the Khazana bavli which was constructed about 1582 A.D. by the then Jagirdar of Bid. There are three inlets, which feed the well and only one outlet. The source of water supply has not yet, been traced. It has channels built for Irrigation purposes, which irrigate over a thousand acres of land. Its water level remains the same at all times of the year. "

Photo 1: View of well from outside

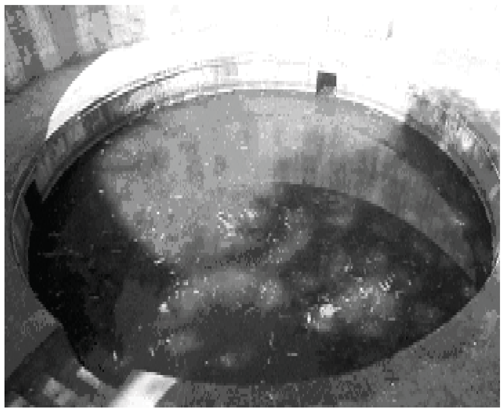

Photo 2: Inside View of Well

Photo 3: Main Well

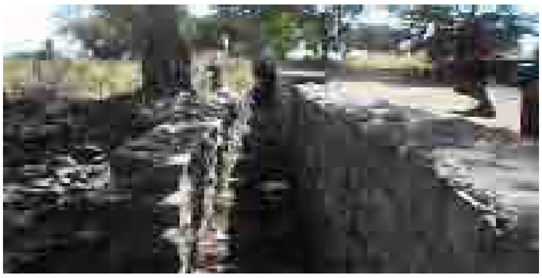

Photo 4: Transformation from Underground Channel to Open Channel

Photo 5: Open Channel

Irrigated land is still considered to be a prize possession in India; it was much more so in historical past. Nobody was prepared to part its ownership. Transfer of ownership was rare. Agriculture, merely dry farming and occasional army service were then only major occupations and were not much remunerative. They did not generate enough money for purchase of irrigated land. Now the situation has changed. Different means have given sufficient resources for such purchases to many. Original beneficiary families could not resist temptation of getting lucrative price. Many lands irrigate under this project have since changed hands. Automobiles have made cultivation of agricultural lands from distance possible.

Rich peasantry as a class has become influential in Indian for political life. Assurance of political support has made at least some of them bold enough to disrespect and ignore rules for personal benefit. Ethic has lost its primacy in social values and tendency to grab all benefits has replaced it. It has become difficult to enforce discipline and regulate the use of public amenities, Secondly; even leaders coming from peasant class are not wedded to interest of small farmers. They have their own preferences. Protection of farmers' interest and facilities available to them is not always a priority with them.

This project is just in the vicinity of Beed town. Process of unregulated urbanization has swallowed thousands of villages near the cities in India and Beed is no exception, which has also swelled in all directions. Once Khazana Bawali was also providing some water for this town besides irrigation. Now that has stopped. Portion of these water channels, siphons and other regulatory mechanics has already been destroyed and rich, fertile irrigated land is put to residential use. About 225 Acres from the beneficiary zone has already been used to build houses. If this continues unabated, result would be that the whole project would be redundant. Maharashtra State has only 16% cultivable land irrigated. Irrigation facility constructed from public money should not be allowed to be rendered useless. It would be criminal waste.

Fate of this project, once a pride for the region, today hangs in uncertainty. If immediate steps are not taken to serve its usefulness, it is likely to remain as a Historical monument witnessing wisdom of the past and callousness of the present. Questions that are posed by this State are of general importance and they are relevant in respect of may other projects. When would we appreciate fully the value and importance of such facility? When wisdom would dawn on and we would stop mad run for urbanization at the cost of our forests and rich fertile lands.

CONCLUSION AND SUGGESTIONS:

If we are to save Khajana Bawali and similar irrigation projects existing in the vicinity of cities and towns, we will have to take some legislative and administrative steps urgently. Some of them are listed below:

A) Legislative Measures:

- Looking to the smaller extent of irrigated land, transfer of irrigated land, particularly owned by small holders should be prohibited.
- Conversion of irrigated agricultural land for any non-agricultural purpose should be prohibited, except for exceptional public purpose.
- Historical irrigation facilities which witness traditional wisdom like dams, reservoirs, wells, channels and controlling towers etc. should be included in and treated as historical monuments and should get protection from legislation protecting them.

B) Administrative Measures

- Equitable distribution of water between entitled beneficiaries should be strictly enforced as per rules and supervised by independent machinery.
- Breach of rule and use of unauthorized water by force should be met with penalty debarring such person from use of water from that project.
- Parts of the channel and mechanism of this project is damaged. There is urgent need to restore them by repairs.

Table showing Year wise Area Irrigated on the Khazana well

Year	Kharif Season	Rabi season	Hot Weather	Total Area Irrigated
1971-72	22.31	167.90	13.07	203.28
1972-73	--	--	--	--
1973-74	13.18	91.37	10.67	115.22
1974-75	33.46	153.07	29.63	216.60
1975-76	45.99	175.07	34.03	255.08
1976-77	82.66	135.38	14.96	233.00
1977-78	54.83	139.03	38.18	232.04
1978-79	65.17	133.30	27.06	255.53
1979-80	22.00	134.91	37.47	194.38
1980-81	59.32	137.90	51.79	249.01
1981-82	05.68	91.92	00.20	97.80
1982-83	00.20	35.04	03.20	38.44
1983-84	--	76.41	12.96	89.37
1984-85	04.72	71.79	03.20	79.71
1985-86	08.96	51.80	--	60.76
1986-87	13.98	40.41	--	54.39
1987-88	--	36.99	--	36.99
1988-89	--	30.48	--	30.48
1989-90	--	62.98	--	62.98
1990-91	--	67.39	--	67.39
1991-92	--	61.88	--	61.88
1992-93	--	32.64	--	32.64
1993-94	--	61.13	--	61.13
1994-95	--	--	--	--
1995-96	--	35.61	--	35.61
1996-97	--	58.18	--	58.18
1997-98	--	60.00	--	60.00
1998-99	--	104.00	--	104.00
Source : Bid Irrigation Circle, Bid, Government of Maharashtra, India.				

THE INDIGENOUS KNOWLEDGE OF ISFAHAN PEASANTS IN THE EXPLOITATION, STORAGE AND INCREASING THE PRODUCTIVITY OF AGRICULTURAL WATER[1]

Siamak Shahabi[2]

ABSTRACT

Iran is one of the countries which its major parts are in dry and semi-arid areas and continually was faced with drought and dryness. Isfahan province is one of the dry provinces in Iran with the average of 116_{mm} for rainfall. In spite of these natural conditions, the agricultural background in these areas comes back to the very past ages of history .Iranian farmers including Isfahan farmers in order to make use of surface and subterranean water sources created appropriate irrigation methods and raise different types of plants. These methods which were used by farmers from a portion of indigenous knowledge of our country in the agricultured shaped and established by passing time and transferred from one generation to the next one. The study and documentation about this knowledge not only prevents it from extinction but also make possible to integrate it with academic knowledge in order to provide a suitable technology either resolve the increasing demands or exploit the limited ground resources. In this study it has been tried to examine the Isfahanian agricultural indigenous knowledge in the field of exploitation storage and increasing the productivity of water. Major methods which are used in this study to collect the data are including field observation, exploratory interview and tapes and photographs.

Key words: Indigenous knowledge, rural areas, drought, Isfahan, province, agricultural water, subterranean canal.

INTRODUCTION

Iran is considered among dry areas throughout the world with average of 252_{mm} annually. About 65 percent expanse of our country is located in dry and semi-arid areas that average rainfall of them is less than 150mm annually.

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Since large parts of the country are located in arid regions. Drought periods are more than rainy years. Isfahan is one of the dry provinces throughout the country with average of 116_{mm} rainfall annually. Isfahan average rainfall is less than half of the average of country and one-sixth of the average of world locating in the neighborhood of desert from north, northeast and east and drought of southern areas cause many limitations for Isfahan province(Ibrahimi,1380/2002)(Map1).

In spite of these natural conditions, Isfahanian farmers in order to make use of surface and underground run off created appropriate watering methods and rose different types of plants. These methods which were used by farmers from a portion of indigenous knowledge of our country in the agricultural real in and established by passing time and transferred from one generation to the next one. Indigenous knowledge of each society is a set of culture, skills and techniques about different aspects of life which evolved through trial and errors of people with natural and social environment during long centuries and some of them are really wonderful. Indigenous knowledge of each nation is a part of its national capital that consists of beliefs, values, knowledge and life tools. This is the same knowledge which one day, World nations provide their food from the surrounding environment, provided their clothing, indigenous knowledge of each nation was able it to provide their needs from natural resources without any extinction. So the collection of world indigenous knowledge is a valuable treasure of methods and tools which are examined during the time and will be used in order to develop the nations.

Unfortunately because of oral nature of this knowledge in the one hand and unawareness and little attention of experts to this knowledge in the other hand are caused to increase the speed of extinction rate of it. The study and documentation about this knowledge not only prevents it from extinction but also make possible to integrate if with academic knowledge in order to provide a suitable technology either resolve the increasing demand or exploit the limited ground resources. In this study it has been tried to examine Isfahanian agricultural indigenous knowledge in the field of exploitation, storage and increasing the productivity of water.

METHODS AND MATERIALS

According to the aim of indigenous knowledge studies including present study which is consist of collection, writing and local experiences, knowledge and compilation. We can call these researches "Extractive Research" which deals with study and documentation of people indigenous Knowledge. Most important methods that are used for this research are including:

FIELD OBSERVATION

Observation is the most important and natural research tools that have a high importance in all sciences such as humanities. Field observation is a kind of observation which happens in natural conditions, it means that occurring in the inner of the society. In this method, researcher observes people, behaviours, tools and their function. In this research one part of findings are collected by attending in the field and observation directly.

EXPLORATORY INTERVIEW

Exploratory interview is one of the methods which are used in this research. In this method, the interviewer explores in the respondent's mind through some kinds of determined subjects and is not limited himself to standard question (Delavar.1380 /2002). In order to collect required data, we interviewed with experts of agricultural Jihad's organization in different parts of Isfahan province and its townships and we used their experience which is gained by working for many years in rural areas. In additional to agricultural Jihad's organization, we interviewed with aware and experienced peasants and they gave very much valuable data to the researcher.

USING TAPES OR CASSETTES AND PHOTOGRAPHS

A cassette player is used to record the conversation and interviews with villagers so that they were concentrated rated and then in an appropriate time were written on the paper. Also to make documentation, a camera is used for some Methods.

DOCUMENTARY METHOD

In this study, documentary method is used to collect some parts of data. This method is one of the easiest ways in social studies and the researcher obtains his necessary data from existing documents such as reports, documents and statistical publications.

RESULTS

In this section, research findings which are including the methods used by peasants exploit, store and increase the productivity of agricultural water, will be explained.

SUBTERRANEAN CANAL AND METHODS FOR INCREASING PRODUCTIVITY OF SUBTERRANEAN CANAL WATER

Subterranean canal has been one of the techniques which were used to provide drinking and agricultural water in dry areas like Isfahan province.

Beside usage of natural underground and surface water like spring, stream and river, well and subterranean canal were most important and artificial forms to exploit from water resources. In this method without any mechanical power and just by gravitational force, the underground waters will transfer to earth's surface. By using this technique it can be possible to collect a considerable amount of underground water and to flow it on earth's surface during the year.

Subterranean canal and its characteristics are as follows: Each subterranean canal contains a main well or mother well ground tunnels, wells and the appearance. The mother well is told to the farthest well toward the source. The mother well in comparison with other wells always is very deeper. The water of subterranean canal is transferred to earth's surface by an underground tunnel. The existing water in the underground layer of earth was led to the tunnel by a mild slope and without using any other mechanical power like electricity power and just by gravitational force. it will flow in direction of underground tunnel. By the reason of this slope, the appearance of subterranean canal will be located lower than mother well. About the most important conditions for digging can mention to the existence of such permanent underground waters, the steep lands and watery parts of the land which are higher than subterranean canal appearance.

The wells which called "mille" were digged along the tunnel direction. These wells are located in an approximate twenty meters distance from each other. Theses wells are used to evacuate the digged soil and to ventilation of tunnel and to repair. The subterranean canal appearance is an opening where the water flows on the ground (Figure1). After the subterranean canal, every tunnel that transfers the water of subterranean canal to the agricultural lands is called "Haranje" or "Madie". Usually the surfaces of irrigating canals are open. The distance between the appearance and those parts of tunnel where the land is dry and not has water is called dry land or "Khoshkekar" and from here to the mother well where the land is wet is called wet land or "Tarekar". The most important methods to increase the amount and the productivity of subterranean canal water are as follows:

PISHKARZADAN OR NOKANI

There are many different ways to increase the amount and the productivity of subterranean canal water and one of them is "Pishkarzadan or Nokari". When the level of underground decreases because of different reasons Such as drought or not compensate the lost water, this method is very useful. It means that a tunnel will be digged and a well will be added in a direction which nearer to underground resources. This work accomplishes in straight right or left direct. Even it is possible to dig in two or tree sides of subterranean canal. This work causes to absorb much underground water and the water transfers to the main subterranean canal. This factor made them too long during the time.

DIGGING MOTHER WELL AND KAFKANI

One of the other accomplished actions, when the level of underground water decreases, is to make the well deeper and deeper. By digging the mother well, the level which water stops on it becomes lower and this makes the well deeper. Since the floor of well decreases so the floor of tunnels become higher than mother well, it is possible to dig the floor as far as the mother well decreases. This task will make maintain the slope of tunnel toward the appearance of subterranean canal and also flow the water and prevent from remaining the water in tunnels. When the water remains in the tunnel, the walls become damp and therefore collapse.

STORING THE WATER BEHIND THE SUBTERRANEAN CANAL

Continuous usage of underground aquifer especially subterranean canals reduced the amount of water gradually even if it didn't compensate the last water because of drought and it can entail to dry the subterranean canal up.

In order to prevent facing such problems it should be necessary to store running water during rainy seasons in pools which are upper the subterranean canal. This storage has bees used to store the water for the subterranean canal artificially. This water that stored in the pools directly is used for agricultural activities. For example it can be mentioned to "Azan" pool in "Meimeh". In this pool, not only running water resulting from rainfalls is stored but also additional water is stored in the upper subterranean canals and gradually penetrates in the soil of lower subterranean canals including "Zir asiab" and "Ziarat" storing the water in these pools usually begins day (December) until Esfand(March) (Figure 2&3).

INCREASING THE FLOW RATE IN SHORTAGE OF WATER

The shortage of water causes the amount of water as far as it will be impossible to irrigate the agricultural lands directly by subterranean canal or well. One of the feasible ways is to store the water of subterranean canal or the well in pools. For example in this manner for a farmer who should use the water of subterranean canal for ten hours, the gained water enters into the pool with flow rate $10_{L/S}$ and stores in it and then exits with flow rate 20 to $25_{L/S}$ so that it can be possible to irrigate with appropriate flow rate. In "Kashan" and "Aran & Bidgol" these pools were soiling and in the past they are called "Salakh". Usually they cultivated bamboo around the pool to make shadow and decrease the evaporation of water in the summer.

CONSTRUCTION OF CANAL ALONG WITH SUBTERRANEAN CANAL

In the areas wherever have the proper slope, the subterranean canals were constructed frequently. This work will make the springs of the upper subterranean canal feed the lower subterranean canal. In some areas which subterranean canals are frequently along with wells construct the canal. As an instance, it can be mentioned to the subterranean canal of "Golpayegan", "Khansar" and "Najafabad".

In this township, two large canals were digged at one or two sides of wells. these canals are called "La". These cause to store the water of upper subterranean canal in the lower subterranean canal and to feed the subterranean canal artificially. In addition, when it is raining, these canals obstruct the running water and prevent entering water accompany with sediment and other objects. During the time these sediment and objects cause the subterranean canal becomes full or stop the direction of water into the wells. In order to prohibit collapsing, usually the walls of tunnels will be covered with stone and the ceiling will be covered with planks.

DREDGING OF THE SUBTERRANEAN CANAL

Collapsing of the walls of wells and tunnels, sediments which enter into the subterranean canal will cause that the floor of tunnels become full of mud and slime. This problem not only reduces the speed of water but also it will make those walls of tunnels become damp. Therefore it is necessary to dredge the subterranean canals once a year. Not dreding the subterranean canals in recent years is one of the most important reasons for their extinction. One of the methods to dredge the subterranean canals in townships like "Khansar", Fereidan", "Fereidonshahr" is as follows: Because these townships are located in mountainous areas therefore the sediments are not very much. A person with a sweeper stirs the water. This task moves the mud and slime and prevents to become firm and little by little they will be exited by running water. Also the speed of water will increase and the subterranean canal will be needed to dredge lesser than before. The subterranean canals have regularly been investigated and if there was any problem, the necessary actions would be done.

KEEPING THE LIMITS OF SUBTERRANEAN CANAL

Commonly there is a limit for every subterranean canal and it should not be digged any other subterranean canal in its limit. Because the water of subterranean canal will reduce and even it is possible to dry it up. Furthermore around the limit of subterranean canal, other activities are forbidden such as arboriculture, agriculture, digging a stream, construction, road construction. Each of these activities will cause the subterranean canal collapse. Also it is necessary to prevent plants like "Khar shotor" and bamboo which growing by itself. Because their roots will destroy the walls of tunnels and wells therefore the subterranean canal becomes fall. According to the local regulations, this limit in Isfahan is 20 meters from two sides.

STORING THE WATER INTO THE SUBTERRANEAN CANAL

Having a permanent flow during the year is one of the flows of subterranean canal. This issue will cause to waste much amount of water when there is no agricultural activity and therefore the amount of underground water will reduce. Also it is not possible to dam inside or outside of the subterranean canal. Because by this task, the level of water will increase thus the walls of tunnels will become damp and will collapse but in some of these subterranean canals which has resistant wall, it is possible to dam inside of it and store the water there.

One of the popular examples for these dams is the dam of "Vazvan" subterranean canal in "Borkhar & Meimeh". This subterranean canal has 2 kilometers length. At the distance of 1500_m from the mother well, there is a dam. The height of tunnel is around 6_m. There are five holes in the dam. In the early Azar(December) they will be closed by mortar and until Farvardin(April) the water will be stored behind the dam. In farvardin, the highest hole will open the lower the level of water, the more holes will open. The water that stored behind of dam, not only cause to become full the tunnels but also will full all apertures and the level of water will considerably increase in surroundings wells. This amount of water is sufficient for 4 to 5 mounts from beginning of usage then the water of subterranean canal will be naturally used. The water had been exited from the holes with much pressure and without any control. In 1366(1988) Meimeh Jihad organization closed all of these holes and by plumbing and installing a 6 inch gave valve prevented to waste much amount of water.

KEI OR AN OPEN SUBTERRANEAN CANAL

In areas near "Zayanderood" river like "Ghohab" and "Baran" or "Zarinshahr" to use the surface run off, "Kei" has been used. The author of the book "Nesfejahan fi Tarife el Isfahan" in page 105 writes: Kei is not frequent everywhere. It is possible in a land that its water is near to earth's surface and there is not need to dig a well. for making a Kei , it should began to work in a lower land toward higher and dug a creek and went ahead. This method is opposite of subterranean canal. By going further, it becomes deeper and the water will increase. In deep depth the water seeps out and flows a creek. In some cases it becomes greater than subterranean canal. They can be large or small, long or short. This action is called Kei and is frequent in "Ghohab" (Hosseini Abari,1379/2001, 152).

Kei is used in land which its aquifers are located in upper layers of land and in swampy lands. Where the land was impenetrable and had a little slope, the level of water of river has been rose. Kei has been dug from where the water flew on the ground and like an open canal or creak was led to its source, the further it moves forward, The deeper it becomes. Gained water will transfer ti the lower lands by canals and farmers use it to agriculture. Additional water was absorbed by the land and was fed lower Keis.

Both subterranean canal and Kei have an equal characteristic that is an underground source, but in spite of subterranean canal, the canal of Kei is on earth's surface. This is the reason why Kei is also called open subterranean canal. Kei is operating like drainage and collects the seepage from surroundings lands and get ready these lands for agricultural activities. In recent years many wells were dug in these areas. The unmethodical use of pumps to extract the underground waters and recent droughts were caused to decrease the level of aquifer therefore there is not Kei any more like past. Many of them are destroyed or are turned into a dump. Growing moss and bamboo were common difficults which they had. Turning into a march caused that the water became smelly.

STORING THE WATER BY A POOL

Using pools in order to store the water for agriculture and animal husbandry is a method that developed in recent years. The water of these pools will provide from different ways. Using the running waters in rainy seasons is one of them. In central areas of Isfahan drain the pastures and lead the gained water into the pools by canals and then consume it. Some farm lands have s steep surface and there is a pool in the lowest point of farm land. In rainy seasons, the running waters which hasn't been absorbed by the land, stored in this pool and then are used for agriculture. Running water lead into the pools by small creeks which are made in the surface of farm land. In some areas of Isfahan like "Baran" and "Varzaneh" which irrigate the farm lands by well because of drought, the number of these wells decreased. The farmers store the water of several wells into a pool. This water has much pressure and is more appropriate for agriculture. The more and the faster water Transfers to the farm land, the more it is prevented to waste water.

STORING THE WATER TO CONSUME LIVESTOCK

In desert areas, people dug a pit to store the water in order to use in the summer for their livestocks. These pits are called water reservoir. The stages of these methods are as follows: At first they make a pit in the ground and then cover its walls with a plaster made of clay and straw. For this purpose selected a soil which the percentage of its clay is high and its permanent is very low. The floor of this water reservoir is covered with mortar. In some areas, the walls of these pits cover with mortar. The running water stores in these water reservoirs. These water reservoirs have ceiling in order to prevent to evaporate the water. In addition the water of these reservoirs is used by stockbreeders.

In recent years, agricultural organization helped to feed the water reservoir. In mountainous parts of desert areas, there are springs which approximately eight months of year have water but their water was little and they attracted less attention. Especially during the summer which noon didn't travel to the desert, they completely wasted. In recent years, the water of springs leads to water reservoir by polyetilin pipes which are very long even at the distance of 12_{KM} and then uses. In some areas, these water reservoirs will full by tankers.

In mountainous areas of desert townships and in some parts of mountain, there are water reservoirs. Since the land of these areas is stony, the water can be stored and there is usable during the year. Filling the holes increases the capacity of storage. Nomads of "Semirom" county dig pits to feed their live stocks. These pits will be full with rainfall. Usually in early year or in the time of childbirth, the herd transfers to the top of the mountain and make use of theses wells. When they finish, the herd transfer to the down of the mountain and drink water of springs and rivers.

CONSTRUCTION OF DAM IN PASTURE TO PROVIDE WATER FOR LIVE STOCKS

In pastures with steep lands, because of low permeable, the water flows. The owner of pasture moves the soil by spade and makes crescent- shaped walls which have 15_{cm} height in direction of water flow. In first and second years, these walls can not keep the water but by passing time, they will be coated with sediments resulting from rainfall. These walls don't let flow the rainfall. The owner of pasture feeds their live stocks for 2 to 3 months with the use of this water. There is no need to provide water from wells. This task will help to preserve the plants of pasture.

IRRIGATING IN NIGHT

Horticulturists irrigate their gardens during the night to prevent evaporating of water.

JUG IRRIGATION

Jug irrigation is one of the methods which has been used in the past in desert areas of isfahan but now it is forgotten. Jug irrigating has been mostly used in truck forming (like water melon and melon) and in arboriculture. This method has a main influence on preventing from evaporating. In this method when a tree has been cultivated, several jugs which are full of water put in the next of it. The gradual leak of water from these jugs will cause to grow the roots of tree. These jugs were shoddy and didn't keep the water cold. Because they were used jugs for a long time, they were full of moss therefore the water of these jugs has been smelly. In some areas, the half-cooked jugs have been used. Usually the farmers were investigated the jugs occasionally. By make use of this simple method economized water consumption.

In recent years, some farmers used this method in other forms in truck farming and arboriculture. For example one of "Borkhar" township farmers made a ting hole in a large soft drink bottle and put it next of a melon bush. After 4 to 5 days, he fulls the bottles the water of these bottles was absorbed by the soil and is used by the bush. In "Ardestan" township, an owner of pasture cultivated almond tree and used dry-farming method. He put a 4 kilos can to irrigate them gradually.

ARRANGING THE UNDER AGRICULTURAL LAND WITH WATER RESOURCES

In the past, that groups of farmers who had a limited water resource like a subterranean canal or a well, in raining seasons cultivated a land which has no need to irrigation (these land were far from the subterranean canal). In the summer they would cultivate a land which is near the subterranean canal so that the direction of water decreases .In this manner, they arrange the cultivation and irrigation of land and minimized the washing of water and made the outmost use of their water.

DAM CONSTRUCTION IN DIRECTION OF WATER

One of the oldest methods has been to make use of dam on permanent or seasonal rivers. The water which is stored behind these dams not only is directly used for agricultural activities but also causes to feed the land artificially(Figure 4&5).

INTEGRATIVE CULTIVATION OR CULTIVATION WITH AN AWNING

The farmers who live in central and desert areas of Isfahan, Cultivate two or three crops altogether to apply the utmost use of their water resources for example, the farmers of central parts cultivate corn, Cantaloupe and tomato altogether. At first they harvest cantaloupe and then tomato and in the end the corn. The farmers of desert areas plant watermelon or melon with cotton. Of course this kind of cultivation is possible in small farm lands and none mechanized. There is not possibility to use this method in large mechanized farms and at all is not economized. In "Khor and Biabanak", there are many palms. Sunflower, beef, turnip, wheat and barley were cultivated together with palms. Every one of them shades on the other one. This action causes to prevent evaporating.

THE CULTIVATION OF GRASS

One of the methods which is current among farmers "kashan" and "Aran and Bidgol" township is cultivation of grass in their gardens. Thus they use two purposes irrigation for both trees and grass. Nothing the grass makes a shadow and prevents evaporating but also it can be uses to graze the livestock.

USING ANIMAL FERTILIZER

In this method, some crops like onion, the seed is cultivated with much amount of animal fertilizer. The number of irrigations can be reduced by the water which stores in this kind of fertilizer. This fertilizer causes to increase the output of crop. This method will be used in the cultivation of trees. In this manner that the surface of land will be covered with this fertilizer so that to prevent evaporating. this fertilizer also helps the trees to grow better. In another method, large pieces of animal fertilizer will be thrown in the irrigational water. These pieces prevent evaporating of water entirely.

USING STRAW AROUND THE TREES

When the water was not sufficient, the horticulturists covered the surface of the land with straw. This caused to keep the humidity of soil.

KEEP THE WEEDS OF GARDEN

During drought periods, the horticulturists don't weed. These weeds prevent to evaporate.

CULTIVATION IN SEDIMENT RESULTING OF TORRENT

In the area of "Khor and Biabanak", when the torrents settled in fields, pits or in front of dams and the land is still humid, the peasants will cultivate water melon in this land. When the weather was getting warmer and the watermelons grew, they cover them with grass. This keeps the bushes from drying. However these gained watermelons are small, they are very sweat and delicious.

THE CULTIVATION OF TREES ON STEP LANDS

In mountainous areas of "Semirom","Chadegan" and "Fereidan" which it is impossible to agriculture in steep lands, the villagers dig creeks. These are vertical toward the land. In basin part of these creeks, they plant fruitful trees like peanut, walnut, sumac and vine by dry farming. In this method, they dig a canal with one-meter depth. They put a side the surface soil, this soil is appropriate for cultivation. The under soil is white and will be used beneath of slope. Then they cover the floor of pit with high-quality soil and cultivate the tree seeds in it. However this method has been common in the past but in present time, the agricultural organization helped to develop it more scientific and mechanized (Figure 6&7).

CULTIVATION IN A PIT

In north and east-northen parts of "Kashan" and "Aran & Bidgol" there is an area which is well-known to "Bandrig". This area has a range of sandy hills. "Bandrig" has about 120_{Km} length and about 20_{Km} width. It begins around "Qom" and along "Aran & Bidgol", "Kashan" and "Ardestan" stretches near the "Yazd". Because these hills are sandy, so they don't absorb the rain water. The rainfalls gather in surroundings lands. This water is not joined to aquifer. So the level of underground waters is high in this area. In the following there is a method which based on it the peasants would cultivate watermelon by dry farming technique.

There is a pit downward of hill with on area of 100 to 500 square meters(Figure 8&9). This pit is dug to 2 meters depth and its grit is kept around the pit. Of course The floor of pit made up of grit. The sandy walls are operated as a windbreak. These prevent the running sand to pour in the pit. Dry bushes one put around the pit or desert plants are cultivated to prevent the sand to pour in pit more. Newly the screen is used to prevent entering animals that may injure the watermelons. These pits have deed and even they are mentioned as marriage portion in bride's matrimonial deed.

On the floor of pits, some holes were dug with 120_{cm} depth and 40_{cm} radius as for as to reach to the water(Figure 10). Until 20 to 30_{cm} before the surface of land. This pit was full with a mixture of dry grit and bird fertilizer or chemical fertilizer. Usually each pit was full with 3 kilos bird fertilizer and 1 kilo chemical fertilizer. The method of mixing is as follow:

A 30_{cm} layer of grit and then a layer of fertilizer were poured. Rest of the pit was full with the mud. The watermelon seeds were cultivated in this muddy layer. 7 to 8 seeds were cultivated but after they sprouted and in the first stage 3 to 4 saplings were cut and in the second stage, when the saplings were grow and the possibility of their destruction is very low, just one sapling was left and the others will be cut.

The cultivated seeds of watermelon grow by the humidity of mud and their roots move downward in the soil so that to reach the aquifer. For this reason, the roots of watermelon may penetrate until 2 to $2/5_{m}$ depth. This was made possible by sandy land of this area. Dry bushes of "suf" (a kind of plant) are put among the bushes to keep the soil. The branches of water melon bushes wear in these plants. this causes to reserve the bushes against sever desert winds. These winds can't dry or eradicate them.

The watermelons are cultivated in early spring and will be harvested in middle of summer. The period between cultivation and harvest, the farmers don't have any work to do except they should weed a few times. Since it's too hot in desert, they begin to harvest from down until sun appears. These watermelons are large, sweat and juicy. When the harvest finished, after a while these pits will be filled will running sands. In order to recultivate, it is necessary to evacuate the pit.

TO MUDDY THE WATER OF CREEKS

One of the actions that farmers do to decrease the permeable of the ground is mudding the water of creeks. When the under cultivation lands of grain increase, the water should pass a cross a longer direction. This method is used in areas which its soil is sandy and as locals say this soil is "light". Therefore this soil has a high permeable. Some persons pour the soil in to the water and muddy the water. The mud settles as a layer and covers the floor and the wall of creek. The soil is called "Laye khak" (layer soil). This kind of soil has high percentage of day and it was gathered near the dams of rivers. The other use of this method is that live stocks don't drink this water any more.

DIGGING A WELL TO PROVIDE THE WATER FOR LIVE STOCKS

The Nomands of "Semirom" use spring water for their live stocks when the springs dry up, they dig a well there and provide the needed water of their live stocks.

MOVING LIVE STOCK OR DECREASING THEIR NUMBERS

When stockbreeders who live in desert areas of Isfahan can not provide the needed water for their live stocks. They will transfer them to the pastures. If this was impossible, they would sell some of them.

CONCLUSION

Iranian farmers and especially Isfahan succeeded to create appropriate techniques for irrigation. They could make use of water resources (surface and underground) and also reared many kinds of plants. These methods which were used by farmers from a part of our indigenous knowledge in agricultural realm. They formed during the time and evolved and transferred from one generation to another one.

According to the gained results, in dry areas like Isfahan one of the techniques which are used to provide drinking water and agricultural water has been digging a subterranean canal. In this method without any mechanical power and just by using gravitational force, the underground waters transfer to earth's surface. This technique makes it possible to gather a considerable amount of underground waters and flow them on the ground like natural spring during the year. There are different way to maximize the amount of water and productivity of subterranean canal. They are including "Pishkarzadan", digging a mother well, storing the water behind the subterranean canal, increasing flow rate in dry periods, construction of canals a long with subterranean canal, dredging the subterranean canal, keeping the limit of subterranean canal, storing the water into the subterranean canal.

In addition of subterranean canal, Kei or open subterranean canal has been one of creative methods by Isfahan farmers. They also constructed pool, water reservoir and dams on rivers and in the pastures. To prevent evaporating of the water, they cultivate the grass, use animal fertilizer, keep the weeds and use straw the trees.

The farmers used creeks and jug for irrigating. They irrigated the land during the night. Integrative cultivation, cultivation sediments resulting from torrents, cultivation of trees in steep lands, these are various kinds of cultivation which can be mentioned.

Figure1: Subterranean canal appearance

Figure 2: Azan pool

Figure 3: Azan pool

Figure 4: Sohe dam

Figure 5: Sohe dam

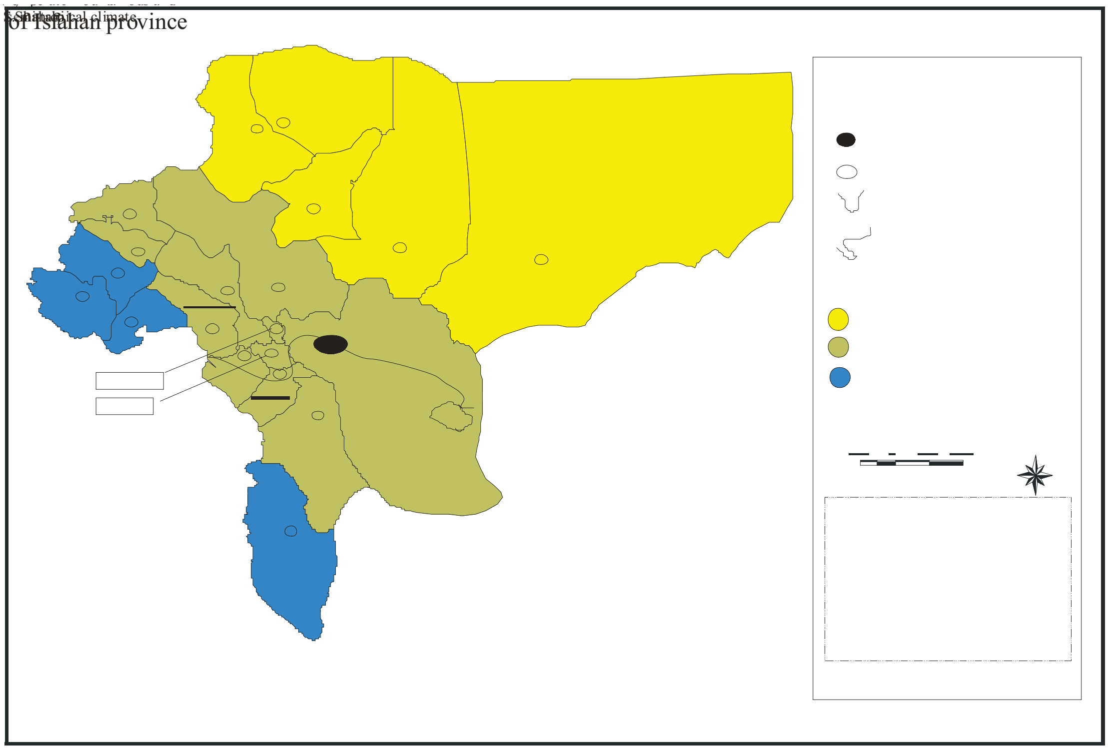
Figure 6: The cultivation of trees on step lands

Figure 7: The cultivation of trees on step lands

Figure 8: The cultivation in a pit in Band rig

Figure 9: The cultivation in a pit in Band rig

Figure 10: Digged pit for cultivation in a pit



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IRRIGATION SYSTEMS IN VIJAYNAGAR EMPIRE TIMES AND IRRIGATION STRUCTURES IN THE OLD MYSORE STATE

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ABSTRACT

India and Iran have common bondage from times immemorial as irrigation systems in both the countries are age old. The Persian wheel to lift water is a technique that came to India from Iran during Mogul times. Like wise the Ghanat system of tapping water from the hill slope by underground tunnels is also a technique from Iran used in many places in India during the Mogul time. Both are in existence in various parts of India. The irrigation systems during Vijaynagar Empire in the 14th century in the form of tank systems as well as simple diversion structures across large rivers like Tungabhadra are working efficiently even today although their maintenance is being done poorly. The gauging devices to measure tank storage and apportioning for various purposes speak of the high degree of understanding of Hydraulics and Hydrology of the then engineers specializing in water management and who were named as Jalatantris. There are even today in existence treatises on water management in some of the old archives in the country. Like wise the Wadeyars who ruled the princely state of Mysore during the 15th century onwards built number of irrigation diversion works across Cauvery River in the South India and many structures are in existence even today working well. The Bangara Doddi Kaluve Aqueduct carrying a distributary across the river Cauvery is more than 4 centuries old in good working condition and probably the oldest aqueduct in service in the world. The paper describes the design and construction features of the irrigation systems of the Vijaynagar Empire as well as those of the Princely Mysore State with some detail along with lessons that could be learnt from these historical and physical evidences in the field of water resources engineering with illustrations. Along with these two instances from the history of irrigation development in India are two cases that taught the engineers of the world about the need for providing a surplusing arrangements during flood periods and the understanding of flood hydrology and also the instance of a dam built in the beginning of the 20th century that made the water resource engineers aware of the fact of uplift pressure in the base of solid gravity dams, leading to such new interventions as the inspection and drainage gallery to relive the uplift pressure which is a common feature in all the modern masonry and concrete dams in the world. This led to a more safer technique in the design of gravity structures on

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rock foundations and is now a standard in all text books of dam engineering taught in the field of civil engineering.

Note: numerals in brackets ( ) in the text refer to the serial number of the illustration in the list of illustrations given at the end of the text as annexure. The text should be read with the corresponding illustration

1. INTRODUCTION

1.1. Historically, there has been a close bond between India and Iran from times immemorial in various fields such as culture, tradition, religion, and philosophy and even in the irrigation development. The Persian wheel to lift water from wells is a technique that came to India from Iran when the Moguls set foot in search of wealth centuries ago. This device was an improvement over the indigenous contraption of using a number of earthen pots strung on a rope chain attached to a rotating wheel over a well and actuated by a pair of bullocks moving in a circle on the adjoining ground with a central pivot and a crude gear mechanism to turn the rotating wheel over the well to lift the water (2). The Persian wheel became popular all over the Gangetic plains and the technique also moved to South India. Likewise the Ghanat system of collecting water from the hillsides through horizontal boring is also one other technique that was adopted in India.

1.2. Harnessing water from rivers is a technique developed in India thousands of years ago as is witnessed by the Grand Anicut (3) in South India across the river Cauvery that is highly exploited for irrigation purposes. Such and other techniques have also been taken in by Iran and other countries. Thus historically there has been a cross fertilization of ideas and techniques for the mutual benefit of the two countries.

1.3. This paper deals briefly some of the important irrigation developments in India and in particular elaborates the irrigation systems of the Vijaynagar Empire that flourished in the 14th and 16th centuries with a high degree of water management both for domestic and irrigational purposes. Although the domestic supply of water as done in that period is not in existence except the ruins of the water channels, (4,5,6&7) the irrigation supply for agriculture is continuing to function albeit with modification from time to time even now. The paper also covers some of the irrigation systems developed in the erstwhile Mysore state now merged in the larger Karnataka state during the 17th and 18th centuries by the past rulers for the benefit of their subjects harnessing the Cauvery River which flows through Karnataka. Two historical features in the country are also included as a tail piece.

2. IRRIGATION DEVELOPMENT UNDER THE VIJAYNAGAR EMPIRE

2.1. Before the advance of the Muslims under the mogul rule in the country towards South, there existed a powerful empire ruling most of the South India conquering a number of smaller kingdoms. This empire is famously known with its capital at Hampi earlier known as Vijaynagara (8) on the banks of the river Tungabhadra. It was at its peak under the rule of Krishna Devaraya the most powerful and popular king of the dynasty, which controlled South India for nearly two centuries spanning between the

14th and 16th centuries. Under the rule of Krishna Devaraya, several diversion works across the river Tungabhadra were constructed with a number of irrigation channels for extensive irrigation for agriculture and also for domestic water supply to the capital with its number of dwellings and the palaces of the kings. The domestic supply was mostly for the royal centre of the palace consisting of various bath structures and temple tanks. (9) of the palace. These are now in ruins following the end of the Empire that was conquered by the Muslim rulers of the Bahamani kingdom of Bijapur after the defeat of the later Vijaynagar kings in the battle of Talikote in the year 1565.

2.2. However the irrigation systems were not so much damaged by the Muslim conquerors and continue to supply water to agriculture fields even to this day, with some changes from time to time. The important channels that are functioning are the Raya and the Basavanna canals supplying water for irrigation in the agricultural zone between Hospet and Kamlapuram close to the Tungabhadra River (10). The canals were constructed during the medieval period. They have been subjected to a number of major changes during the 19th and 20th centuries. Currently the modern Tungabhadra dam at Mamalapuram supplies the canals as the original diversion structures are submerged by the Tungabhadra reservoir (11). The low level canal of the Tungabhadra dam incorporates the old Raya canal. The Basavanna canal (12) had originally irrigated a large tract of agricultural land between Vallabhi puram and Amaravtai.

2.3. The Tungabhadra dam has drowned most of the old canals, which were later extended to irrigate the land between Hospet and Kamlapuram while a portion of the canal is remodeled to carry the Tungabhadra waters. The Raya and Basavanna canals are presently combined into a single supply channel called the R&B canal which takes off from (11) the dam between the Tungabhadra right bank canal and the Tungabhadra high level canal. Before Tungabhadra dam, the canals were fed by the diversion weirs located at Koragallu, Vallabhi puram, Ramanagadda and Kuruvagadda. (13) The Koragallu and Vallabhi puram weirs acted as a pair in series connecting a rocky island in the centre of the river to either bank. The whole width of the river was spanned. The Ramanagadda and Kuruvagadda worked in parallel taking advantage of the river bifurcation at Anaveri. The Ramanagadda weir was located at the point where the river flow divided around the island and Kuruvagadda. It forced water between the island and the right bank of the river. The Kurvagadda anicut located down stream of the Ramanagadda weir had completely dammed the right bank of the river.

2.4. The weir at Vallabhi Puram supplied by the Basavanna canal. The anicut was 300 m long and straight in plan and was constructed of loose stones. The Koragallu weir fed a series of canals and the anicut was of loose stone construction done during the reign of Krishna Devaraya. A new one in year 1848 replaced the Vallabhi Puram anicut by Madras Irrigation Company and was further raised between 1927 and 1928. The Ramanagadda and Kuruvagadda anicuts supplied the Raya canal. The Ramanagadda anicut took the form of a low deflecting wall of loose masonry held together by stone clamps and pegs. The weir took advantage of the uneven nature of the riverbed integrating rocks and boulders which lay in the stream (8).

2.5. The Kuruvagadda anicut 4.8 km downstream joined the right bank of the river to the Kuruvagadda Island near village Hoskote (13). It was 22 m long and concave towards the flow in plan and constructed in rough stone masonry without martar. The

Gowripuram Vanka, a local stream, collected the surface run off from the south west side of the Sandur hills and discharged into the river, part of the flow was fed into the Raya and Basavanna canals (13). The Raya canal has remained essentially to its original form and it has three functions (13).

1. To irrigate a large portion of the land between Hospet and Kamlapuram village
2. Supply Kamalapuram tank with perennial supply. 13(A, B, C, D)
3. And also supply Kalaghatta canals

The Basavanna canal has been subjected to a number of changes after originally constructed in the year 1521. During the 19th century a number of modifications were done to improve its efficiency. As mentioned earlier the Raya canal was built during the reign of Krishna Devaraya (1509-1530). There is also evidence that this canal was originally built during the reign of Bukka II (1399-1406). The British engineers between 1856 and 1873 to improve the efficiency modified both the Raya and Basavanna canals. They were again further modified during the construction of TB dam.

2.6. The Hiriya canal irrigates an extensive area of land from Hampi to Bukka Sagara near Kampli (14). The Canal is fed by an arrangement of six weirs known as Hiriya and Turtha anicuts which block the flow of Tungabhadra between a low fertile island and the river's right bank. The supply of the Hiriya canal is boosted at two points firstly by the Kalaghatta canal, which passes the water from Raya Kaluve into the Hiriya canal. (15) Secondly the outlets and waste weirs of the Kamala puram tank discharge water into a single canal that connects the Hiriya canal. The Hiriya anicuts, which were originally constructed in the medieval period, have all been rebuilt in the modern times. Five small and one large diversion weirs divert water from the river into a single channel at about 2.5 km from Hampi. The weirs joining together out crops and shoals block the whole width of the river channel (16). In the post monsoon period the entire flow of the river is diverted making the river almost dry (17). The Anegundi Anicut and canal (14, 15) 19kms long commanding a large area and ends in another canal which takes off from the river at Suryanagundi.

2.7. These weirs may be divided into two groups, a series of five and the other larger single one. (17) The five are relatively small and are irregular in plan connecting with convenient obstructions protruding from the bed of the river. The sixth and the southern most is much larger and regular in plan (18). The five small anciuts take the form of low walls constructed from neatly dressed blocks of granite laid in regular courses and bonded with cement. Predominantly the weirs are provided with vertical faces on the upstream and downstream. However isolated sections have vertical upstream face and a gently curved down stream face. The remains of the original weirs are close to the new dam just downstream. These consist of rectangular slabs laid in regular courses with their short faces against the flow. Small holes are drilled at irregular intervals on top surface of each slab. (19) It is conceivable that iron clamps set in lead were used to bond them together instead of cement. The sixth and the southern most anciut is separated from the rest five by a rocky island.

2.8. The design of the canal uses the terrain with natural features, in particular, the out crops and boulders act as elements of the design, reducing constructional costs. The canal is not so much imposed on the landscape as determined by it using geographical peculiarities to their best advantage. The canal winds gently around and between natural boulders using them to impede flow or cause turbulence when a conversion of potential to kinetic energy is required. The design of the canal may be considered organic and functional utilizing natural resources with a minimum of superfluous labor and expense. The longevity of the irrigation systems is remarkable. The achievement of its builders is creating a durable and effective means of irrigating extensive agricultural tanks away from the river is measured by its continued use up to the present day. There are evidences that surface tanks with stone revetting existed during the first millennium BC in the pre Vijaynagar period

3. IRRIGATION DEVELOPMENT IN OLD MYSORE STATE

3.1. Agricultural production depends to a great extent on the development of irrigation. The tanks are the oldest in the irrigational system. In ancient days the cultivators constructed small tanks across streams to impound sufficient water for tier forming needs. They were any number of tanks of this description. The Moti Talab in Mandya district was one of the big tanks supplying water for wet cultivation. Major sankey one of the earliest engineers who worked in the mysore state addressed himself to the task of repairing tanks. In memorable words he has said "to such an extent as the principle of storage been followed, that t would now require some ingenuity to discover a site for a new tank. While restorations are, of course, feasible any new work of this description would within the area be almost certainly found to cut off the supply of another, lower down and to interfere in fact with vested interests". Though there are many isolated tanks in various regions the vast majority oft hem are on a connected system of streams and their feeders which are abundant in the tale lands of old Mysore.

3.2. There are many epigraphical records that indicate that irrigation had been practiced from Historical times in the erstwhile Mysore state, which is now merged in Karnataka. The inscriptions of the Ganga, Cholas, Hoysalas and the Vijayanagara and Mysore rulers not only speak of tanks, canals, sluices and other means helpful to facilitate irrigation but also mention about the steps taken for the conservation of such means of irrigation like repair of embankment , or desiliting of tanks etc.. The tradition of setting some piece of land in every village as *bittuvatta* also appears to be very old. Persons enjoying such land were charged with the responsibility of the upkeep of the village's irrigation facility. Copper plate inscriptions of the sixth century AD described Punnadu (present Heggaddevana kote region) as resplendent with Cauvery and Kabini river waters irrigating fertile fields with crops indicating a flourishing state of agriculture.

3.3. Irrigation was properly taken care of right from the Ganga Dynastic rulers' times in the 9th century along with the bittuvatta system for their proper upkeep. Excavation of tanks in Ganga times is referred in many records. The Gattavadi record mentions that there was a tank called Gallakkere prior to 904 A.D. excavated by a queen, and Shivayya a Brahmin scholar who caused the construction of the tank which was huge comparable to an ocean. At a place called Puttagoudanahalli, a local woman constructed a tank for irrigation and gave some land for bittuvatta. In about the 9th century, a Ganga officer provided a new sluice. Likewise there are numerous references to construction of tanks and canals from age old times. A type of Persian wheel called *Araghatta* was in use in the 13th century

3.4. Extension of irrigation facility by royal efforts continued not only in the days of Vijayanagara, but also under the Mysore rulers as well. Madhava Manthri, a Vijayanagara officer at Talakad, raised the famous Madhava Manthri Katte (20 & 21) (Weir) between the places Hemmige and Muduktore across the Cauvery in about the year 1341 and a record of the year 1638 speaks of it as (*Madarasa Vodeyara Katte Kaluve*). There is an old anicut at Dhanagere across Cauvery in Kollegal taluk and another at Ganiganur across Suvarnavathi River. The Mysore rulers also continued to take proper care of irrigation. The creation of canal by directing the flow of the river Lakshmanathirtha a tributary of Cauvery is mentioned in a record of the year 1669 and the tank is named Kantheerav Samudra. Tipu Sultan the famous Muslim ruler of Mysore State in those times raised a bund of 70 feet high in Anandur in Mysore taluk. In the days of Dewan Purniah a Popular Minister during the rule of Krishnaraja Wadeyar III, the sagarkatte dam was raised across Lakshmanathirtha. At Devanur, construction of a tank, Devarakatte is spoken of during 19th century. Chunchankatte has an old dam ascribed to one Chuncha. The Mysore rulers of those times, Kanthirava and Chikkadeva Raja had undertaken a number of irrigation works.

3.5. During the regency of Dewan Purnaiya, a generous sum \was spent on irrigation works. This expenditure was, to a certain extent incurred on the repairs of old tanks and canals, the majority of which had fallen into disuse during the reigns of Hyder-Ali and Tipu Sultan. During the period when the British commission was in power in Mysore, a large amount was spent on irrigation works. Most of the tanks were improved and many reconstructed from the disuse condition into which they had fallen. After the formation of the public works departments in 1856 the expenditure of the irrigation went up. Special attention was directed to irrigation between the years 1872 and 1878 because separate irrigation branch of the public works department was constituted.

4. TANK POLICY

4.1. The restoration of disused tanks had come to a definite state of advancement by the time the sate was handed back to the Mysore Maharaja in 1881. In 1856 the government of Mysore decided to hand over all the minor tanks yielding a revenue not exceeding Rs 300 to the cultivators for doing earth work themselves and the government only paying for masonry works where needed. All the other tanks were called major tanks. The restoration of these major tanks was the direct responsibility of the government and the cultivators contributed a moiety for their betterment. This scheme was tentatively introduced in one tank of each district and after a trial, was extended to all the other areas. A tank inspector was appointed in each taluk to assist the Amildar the revenue official in charge of the taluk and a trained sub-overseer was posted in each district to help the tank inspectors in technical matters. Under the rules issued in 1904, the cultivators were required to contribute 1/3rd of the total cost of restoration including earthwork, the other 2/3rd met out of public funds. In selecting tanks for restoration, preference was given to those tanks where the cultivators came forward with their contribution.

4.2. With a view to making the minor tanks restoration scheme a success, it was decided that larger and more liberal Government grants be made available for the improvement of such tanks. In regard to the maintenance, the cultivators were responsible for doing the earthwork to keep the bunds in strong healthy conditions. The repair to stone revetment and masonry were done by the government. In order to provide for the obligation of cultivators in regard to maintenance of major tanks and restoration, the government of Mysore in 1911 passed a regulation called the tank Panchayat regulations. The panchayats constituted under this regulation had absolute control over the tanks as also the power to administer the funds earmarked for the restoration, repair and maintenance. 1916 the minor tanks restoration regulation XIII of 1916 was passed, providing for the recovery of the cultivators share of cost of restoration compulsorily. Later measures fixed the cultivators contribution at 1/4th of the actual cost of the restoration among the many tanks the Thonnur tank called also the Moti Talab is an old tank with historical association functioning effectively even to this day. The bund of this tank is said to have been constructed in the 12th century by Saint Shri Ramanuja charya who named it as Tirumla sagar. Later Nasir Jung son of the Subedar of the Deccan gave it the name of the Moti Talab

5. RIVER DIVERSION WORKS FOR IRRIGATION

5.1. The Mandya district of this state is blessed by nature with perennial rivers, the waters of which are used for raising wet crops. Even in the old days anicuts were constructed across these rivers and the canal waters were let into the fields for growing paddy, sugarcanes and other water fed crops. The rivers in the districts, which have been put to irrigation use, are the Cauvery, Hemavathi, Shimsha and other small rivers and streams.

5.2. There are six old anicuts named Mandagere, Hemagiri and Thaggally anicuts and the later are the Bolenehalli, Uyyanahalli and Dummasandara anicuts. The Mandagere old anicut is 666 ft in length with two channels 37 miles long on the right side and 21 miles long on the left side. The Hemagiri anicut is also an old one across Hemavathi constructed is size stone masonry in surki mortar and is 1,360 feet in length. The left bank canal is 23 miles long. The Thaggally anicut across Shimsha River is 825 feet in length having a right bank canal of 12 miles and the left bank canal of 23 miles. The Bolenehalli anicut across Lokpavani River is 132 feet long is meant to feed the Madarahalli tank. The Uyyanahalli anicut is 370 feet long with a channel of 3 miles length. The Dummasandara aicut is 400 feet long with a right bank canal of 4 miles.

6. ANICUTS ACROSS CAUVERY RIVER

6.1. Several anciuts have been constructed across the Cauvery and its main tributaries for supplying water for irrigated lands. These anicuts and canals are very old and are functioning even to this day. A table showing the various anicuts across the Cauvery and the Hemavathi rivers along with the area irrigated is given below

6.2. The lower channels in the Cauvery valley given in the table below

Slno	Name of the anicut		Area irrigated in acres
1	Chikkadevarayasagar		14,245
2	Devaraya		2,022
3	Virajanadi		7,420
4	Bangaradoddi		762
5	MaddurAnicut		1,493
6	Kemmanu		958
7	Vaidyanathpur		249
8	Bairan		280
9	Chamanahalli		607
10	Mandagere		3,043
11	Hemagiri		1,381
12	Akkihebbal		380
13	Kalhalli	Since submerged in	1,216
14	Kannamabdi	Krishnarajasagar reservoir	1,156

Slno	Channel	Length	Extent of irrigation in acres
1	Virajanadi channel	42 miles	10,094 acres
2	Devaraya channel	23 miles	2,409 acres
3	Chikkadevaraya channel	72 miles	Not available
4	Bangaradoddi channel	5 miles	920 acres
5	Right bank low-level channel	19 ½ miles	3,420 acres
6	Left bank low-level channel	13 miles	1,430 acres

6.3. Even prior to the construction of Krishna Raja Sagara dam these channels were existing and were supplying water for irrigation. Close to the village Sitapur in Sri Rang Patna, taluk is the Madad katte dam, a low straggling structure of rough stone 2328 feet in length and averaging 45 feet in width. From this small dam the Chikkadevaraya channel is led off. This channel runs to a total length of 72 miles in both Mandya and Mysore districts. In its course the channels crosses the Anchehalla and Mosalehalla streams and also the Lokapavni River. Both the dam and the channel were constructed at the time of Shri Chikka Devaraya Wodeyar celebrated ruler of Mysore. The Balamuri anicut on the Cauvery river is situated one mile from Belagola giving rise to the Virajanadi channel on its right bank. The channel runs to a length of 38 miles in the Mysore district. The Bangaradoddi anicut is constructed across the Paschimavahini branch of the Cauvery River. The channel drawn form this anicut after crossing the little

Paschimavahini Island is led over to the Sri Rangapattana Island by means of an aqueduct (22, 23 & 24). It then divides itself into three branches, one entering the Sri Rangapattana fort by means of an under ground duct, the second terminating at the Darya Daulat garden and the third after traversing the islands ends near the Gumbaz.

6.4. Irrigation as practiced within Mysore state at that time was either from tanks a vast number of which existed all over the area or from channels from the rivers which were in the Cauvery valley. The tanks played an important part in producing rice and garden crops but the irrigation from this source was not always dependable. In 1876-77 a year of extreme drought the country suffered much for want of food and about $1/5^{th}$ of the population of the old Mysore state is said to have died from the effects of the disastrous famine. The irrigation from the old Cauvery channel was more secure, but its command area was small. Water from these channels was usually available only for the first crop and the irrigation of the perennial crops suffered from serious disabilities. Water supply in summer was precarious and crops like sugarcane and mulberry could not be extensively cultivated. It was therefore proposed to provide water for irrigation through out the year for perennial crops. In pursuance of this proposal it was thought best and feasible to impound the waters of the Cauvery on a large scale by recourse to modern aspects of hydraulic engineering. This led ultimately to the construction of the Krishna Raja Sagar dam in the year 1911-1930 under the guidance of Sir M. Vishveshwaraya the world famous engineer of yester years. As a precursor to this large dam is the construction of the Marikanive Dam across Vedavathi River in the drought prone Chitraduraga District.

7. IMPORTANT HISTORICAL STRUCTURES IN THE COUNTRY

7.1. In Madhya Pradesh, near Gwalior city there is a dam named Tigra Dam (25) which was constructed in the early part of the last century. This dam is presently serving the water supply needs of the city although primarily it was constructed for irrigation purposes. The transformation was due to the fact that the population of the city increased in the last one hundred years that the storage had to provide for drinking water supply needs of the growing city. Gradually the irrigation had to be cut down to a negligible extent. Drinking supply need has always an overriding priority over irrigation. The importance of this dam lies in the fact that for the first time (perhaps in the world) it was recognized that there is such a phenomenon as uplift force that needs to be taken into account in the design of the modern dams for stability.

7.2. The then Gwalior state which is now merged in Madhya Pradesh constructed the masonry dam during the years 1913-1917 over what appeared to be sound rocky foundation across the river Sank about 18kms from the Gwalior city. The dam was hundred feet high over the deepest river bed. However in the very first year of completion in the year 1917 when the dam was full, all of a sudden it breached for a length of 800 feet in the deeper river portion emptying the dam almost with a burst. The bursting force of the water was so much that entire sections of the dam in blocks along with the foundation strata was carried down stream and large blocks of masonry moved kilometers downstream. (26) Fortunately as the breach occurred during day time there were minimum loss of lives and property although some villages downstream were washed down.

7.3. The engineers at that time were at a loss to know the reason why the dam breached although the quality of construction in masonry was very good and the foundations were in massive rock. Advice was sought by the Gwalior state from outside abroad both from US and UK experts. It was only after 12 years of investigation that it was realized that the foundation strata was of sand stone formations with horizontal seams and crevices between massive layers of sand stone formation at considerable depths in the deepest portions. With the storage full of nearly 100 feet deep the hydrostatic pressure found way in these seams and crevices acting vertically upwards below the foundations of the dam reducing the gravity force of the dam holding down to the foundations. The dams were designed in those days as gravity structures which stood well on rock foundations like granite, basalt and other igneous formations which do not have the horizontal stratifications. Perhaps for the first time a masonry dam of that height was founded on stratified sand stone formation with seams and the uplift pressure in these seams at Tigra Dam caused the failure and ultimate bursting of the dam. This was realized by the expert engineers who had to make modifications in the design and construction to reduce this uplift pressure.

7.4. In the deeper portion of the valley upstream of the breach portion a deep trench was excavated and filled with impervious clay and a clay blanket was laid for a thickness of 3 feet tying the trench for a distance of nearly 2kms upstream. A clay blanket and the trench filled with clay was covered with a layer of quarried stones for protection. Later the breach portion of the dam was reconstructed with the same section on the rocky foundation for the entire length of 800 feet. The clay blanket and the trench reduced the uplift pressure drastically providing stability to the new dam sections. The dam is now standing since 1929 when it was reconstructed and serving the needs of the city even to this day.

7.5. Since this experience in the dam design technology the uplift force has been taken into account and modern dams are designed accordingly to provide stability. To reduce the uplift force the modern dams are now provided with foundation drainage galleries in which curtain grouting is done with cement to seal of joints seams and cervices after washing the drilled holes to sufficient depth removing any clay and soft materials. Usually the curtain grouting is done to a depth of half the head of the water in the upstream and is accomplished with a line of drilled holes at close intervals. As a further precaution in the drainage gallery, drainage holes are drilled at the downstream face of the gallery to release uplift pressures further. Usually the curtain grouting and drainage holes re drilled after a part height of the dam is constructed. This has become a modern practice after learning a lesson from the failure of the Tigra dam and hence its importance.

7.6. Close to Bhopal the capital of Madhya Pradesh, is a place called Bhojpur on the banks of the Betwa River in its head reaches. During the reign of Raja Bhoj the then ruler of a small kingdom which is now merged in Madhya Pradesh, a crude earth rock filled dam was constructed across the Betwa river in the 12^{th} century. The dam abuts a rocky hillock where a cut was made to provide for the flow of excess floods of the river without damaging the rock fill dam in the gorge of the river. Perhaps it was here for the first time that the engineers of those days had understood flood hydrology and accordingly provided for the surplusing arrangement to provide for the safety of the dam when the river is in floods. This could have been a lesson for the engineers later to understand flood hydrology and accordingly provide for such surplusing works as waste weirs, spill ways etc. At present at Bhojpur only the breach portion of the dam is standing as a witness even to this day. It is reported that the breach was not due to any natural cause or flooding but was done intentionally by a subsequent Nawab Ruler to make use of the silted lake bed to grow wheat in a large scale to ward off a severe famine affecting his subjects.

8. CONCLUSION.

8.1. The historical account in brief picking out some significant aspects in history of irrigation development in country is made out in this paper with a view that some important lessons can be drawn from this account. The traditional and age old techniques of the past could be integrated with the modern technology so that a more effective technology could be developed and at the same time comprehensible enough for adoption retaining some of the good aspects of the traditional practices. In this paper it has not been possible to incorporate all the geographical location with descriptions for getting a back ground of the many irrigational structures. However the intention was to give a feel of the engineering techniques that were used in the past. An important feature of the tank system is the interconnection of a group of tanks in the same valley as chain system of tanks the surplus of one is the upper seeding, the lower to conserve as much water as possible for irrigation and domestic supply. A second feature is the construction of a cistern downstream of the bund at the head of the sluice so that washing and bathing is done outside the water body of the main tank to prevent pollution as illustrated in the pictures of Kamala Puram tank (13 A, B, C, and D). To the extent some illustrations were easily available have been incorporated to make a sense of what has been described in that paper.

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LIST OF ILLUSTRATIONS

DAMS OF THE ANCIENT CITY OF ISTAKHR

Mohammad Jafar Malekzadeh[1]

ABSTRACT

Istakhr, from 500 B.C. to 1000 A.D. was a large metropolitan city of the ancient world. From the Achaemenid era to the early Islamic centuries, Istakhr was either the capital of the Persian Empire or the center of Istakhr province, a part of which is now called Fars Province. A major reason for the growth of Istakhr and its sustaining for 1500 years, besides other considerations, was the presence of Sivand River (Pulvar River in history). To use water for domestic and irrigation purposes, many storage and diversion dams were constructed on the 150-kilometer long Sivand River. Other hydraulic structures such as water mills, tunnels, canals, aqueducts, bridges and water control systems were also built around this river. Most of the diversion dams and the hydraulic structures are of stone masonry work with sarooj mortar. The stonework is coursed on the face and uncoursed inside the structure. Stones are of high quality broken limestone and brought from nearby quarries. In this paper, we introduce some of the remainders of the diversion dams that still are surviving on the Sivand River for more than 2500 years.

KEYWORDS: Ancient Dams, Istakhr, Sivand River, Sarooj.

INTRODUCTION

ISTAKHR CITY

The large mound of the Achaemenian city of Istakhr lies six kilometers northeast of Persepolis and north of the plain of Marvdasht. The actual domain of Istakhr was much wider than its present mound. In fact, Istakhr was the name of several interrelated districts of a long metropolitan city throughout its 1500-year history from Achaemenids era to the early Islamic centuries (Fig. 1). Different parts of the city were located in four different fertile plains. Namely, from south to north, Khafrak-e Paein (a part of Marvdasht plain), Khafrak-e Bala, Kamin and Pasargadae. The Achaemenid royal tombs of Naqsh-i Rustam and Persepolis palaces are located in Marvdasht plain and the fascinating tomb of Cyrus the Great and the ruins of the Toll-i Takht citadel is situated in the plain of Pasargadae. Many other monuments from Sassanid dynasty are identified in these plains. After the invasion of Arabs to Persia in the 7th century and the fall of

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Sassanid dynasty, Istakhr suffered extensive damage and lost its importance. Many people of Istakhr were killed or migrated to other places and the city started to disintegrate until finally only a name was left from it in history and geography books (Tabari, 9th century). Nevertheless, the ruins of many palaces, buildings, tombs, temples, roads and the relics of several hydraulic structures are remained that points to the extension and the glory of one of the greatest city of the ancient world. The hydraulic structures are mostly diversion dams, water mills, canals, tunnels, water control structures and bridges.

SIVAND RIVER

The strategic features of the land of Istakhr was perhaps the first factor for the Achaemenians to consider and select Pasargadae as their first capital. The plain of Pasargadae was far enough from borders of the Empire and more difficult for enemies to reach it. It was also surrounded by mountains that made the defense of the city easier. The fertile plains of Pasargadae, Kamin, Khafrak and Marvdasht and the pleasant climate of the region were of course other factors for the growth of the capital. However, the presence of Sivand River (Pulvar River or Parvab River in history) that flows from north to south through these four plains was a major advantage for the development and sustaining of the city of Istakhr (Figs. 2 and 3). Water from Sivand River was used for irrigation and domestic purposes. Many diversion and storage dams were constructed on the river. Water was flowing throughout the city and gardens in canals and ditches.

DIVERSION DAMS OF ISTAKHR

FIELD INVESTIGATION

During a one-week field survey, several remainders of dams and other related hydraulic structures were detected. The time for survey was chose in such a way that the river has its minimum water flowing, that is, in October. For each structure the geographical coordinates were recorded, at least one picture was taken and the type of material used in construction of the dam was identified. In the following sections we concisely discuss the characteristics of each structure. However, before that, we have to open an introduction to the materials that have been used in almost all of these dams body.

MATERIALS PROPERTIES

Sarooj. Sarooj is a Persian term for a mortar that may be called Iranian Cement. The word sarooj is derived from the middle Persian word “Charook” that means something compounded of four different materials. According to the old Iranian masons, these four compounds are lime, ash, water and cattail flower. The flower of cattail is added to sarooj mortar only if sarooj is supposed to be applied on the surface of walls for plastering. It acts as a reinforcement for distributing the shrinkage of the plaster and prevent it from cracking. There are of course other types of sarooj for special jobs. Like the one with egg white added to lime for sealing cracks. When for the first time Portland cement appeared in Iran as a new construction material, people called it “sarooj-e farangi" meaning "European sarooj". Sarooj has been widely used as mortar in almost all of the ancient hydraulic structures of Iran to bind bricks or pieces of stones together. Sarooj has been also used to plaster the surface of walls. There are different types of sarooj (Malekzadeh, 2002).

Air-setting sarooj. For ordinary buildings, sarooj is made from a mixture of quick lime, ash and water. This stiff paste is mixed and compacted vigorously for 12 hours and then applied to the work.

Hydraulic-setting sarooj. For hydraulic structures, burnt clay is also added to make a hydraulic sarooj. Burnt clay powder mixed with ash is derived from the so-called *nanak* (bread shape). To make nanak, water is added to manure and clay to make a paste. Using this paste, disks of nanak 4 cm thick and 30 cm in diameter are made. After drying the nanaks under the sun, they are set on each other to make a hollow truncated cone with dry manure in between. Finally, the whole cone is covered and filled with dry manure, leaves and bushes and set fire to it. After 12 hours burning, the furnace is let to cool. At last all the produced materials are pulverized to get nanak powder.

THE REMAINDERS OF THE DAMS AND BRIDGES OF ISTAKHR

Starting from the jointing point of Sivand and Kor River and going upstream, we located the remainders of the dams and bridges as follows.

Structure No. 1. This is Madabad Dam with its spillway at the middle of the dam. The spillway is gated with eight sliding gates. The spillway downstream surface is of the so-called ogee-shape ending in a widening stilling basin. Two separate water mills are incorporated inside the two left and right non-overflow parts of the dam. Madabad Dam was rehabilitated many times during its long life. The last time rehabilitated was 100 years ago.

Up to 30 years ago, the dam was functioning properly. From that time, the irrigation water for the plain of Marvdasht was supplied from the one billion-cubic meter reservoir of Dariush the Great Dam. Consequently, Madabad dam was left idle with no protection or repair. Madabad Dam is a gravity stone masonry dam constructed with broken limestone and sarooj mortar. The ceilings of the water mills are arched with bricks and gypsum mortar and covered with stone and sarooj mortar (Figs. 4 and 5).

Structure No. 2. Nothing is remained of this dam except a part of the stone masonry body inside the right bank of the river, and probably the foundation that is under water and not visible.

Structure No. 3. The lower part of this dam is still surviving. This dam is a good sample to be investigated for detailed information regarding the foundation and stilling basin of such typical dams (Fig. 6).

Structure No. 4. From this oblique dam, only the foundation is remained. The designer of this dam decided to choose the dam axis not at right angle to the direction of water flow in order to have a longer spillway crest and a thinner water layer on the spillway during flood seasons. The upstream face of the dam is plastered with sarooj mortar to prevent water from seeping through the dam (Fig. 7).

Structure No. 5. Before excavation, we are not sure whether this is the remainder of a dam or a bridge or both (Fig. 8).

Structure No. 6. This structure is a few footings of a relatively large bridge. The stones used to make the piers of the bridge shows that the original bridge was constructed during the Achaemenid period (Fig. 9). The collapsing of the arches of the bridge has caused the river to change its direction locally to the left. This may be the bridge called Khorasan bridge in histort.

Structure No. 7. This is the remainder of a control gate and a bridge on it. Other parts of this structure that have been made of wood, iron and bricks are completely destroyed. Only stone parts of the structure are remained. This structure has been a part of a water supply system for conveying water from Sivand River to Persepolis palaces and probably to some parts of Marvdasht plain. This structure is known as Takht-i Tavoos (Fig. 10).

Structure No. 8. This is a channel dug in the rock to convey water to persepolis. It starts from the aforementioned Takht-i Tavoos gate structure and after six kilometers, reaches Persepolis (Fig. 11).

Structure No. 9. 120 km. far from the confluence of the Kor and Sivand rivers, on a tertiary branch of the Sivand river in the north of Pasargadae plain, we located the remainings of an embankment dam and named it Didegan Dam, because of the Didegan village in its neighbourhood. Didegan Dam is built at the entrance of a small gorge which after one kilometer joins another gorge in which a secondary branch of the Sivand river is flowing towards the Pasargadae plain. Fortunately, some parts of Didegan dam body is remained, enough that we can guess its original dimensions and the materials that have been used to construct it. Figure 12 shows the left abutment of the dam. Figures 13 to 17 show different remainings of the Didegan storage dam system.

CONCLUSION

Our preliminary survey reveals that the Sivand river, throughout a long history of 3000 years, has been considered a major source of water supply for the purposes of irrigation and urban development. The durability of stone masonry diversion dams shows that:

- **a.** the builders of these hydraulic structures were able to select quarries to supply the most suitable crushed stones and had enough experience to produce the best cementicious mortar such as the Iranian cement of Sarooj,
- **b.** the dam engineers knew how to take into consideration various engineering parameters for the site selection of diversion dams, and
- **c.** in the case of limited locations for a reliable dam site, the foundation engineers were able to treat the foundation successfully.

The Didegan storage dam is a good example of large dams in the engineering history of Iran. Various features of this dam and its location show that the Achaemenian engineers:

a. knew how to control the floods of the Sivand river,

b. had enough soil mechanics knowledge to design earth fill dams,

c. could use construction equipments to compact soil.

The Didegan dam case seems to be very astonishing and hence more investigation on different engineering aspects of this and other hydraulic structures of the Sivand river is highly recommended.

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Figure 1. Istakhr, Pasargadae, Persepolis and the Persian Empire.

Figure 2. Map of Pars Province and the city of Istakhr (drawn 1000 years ago).

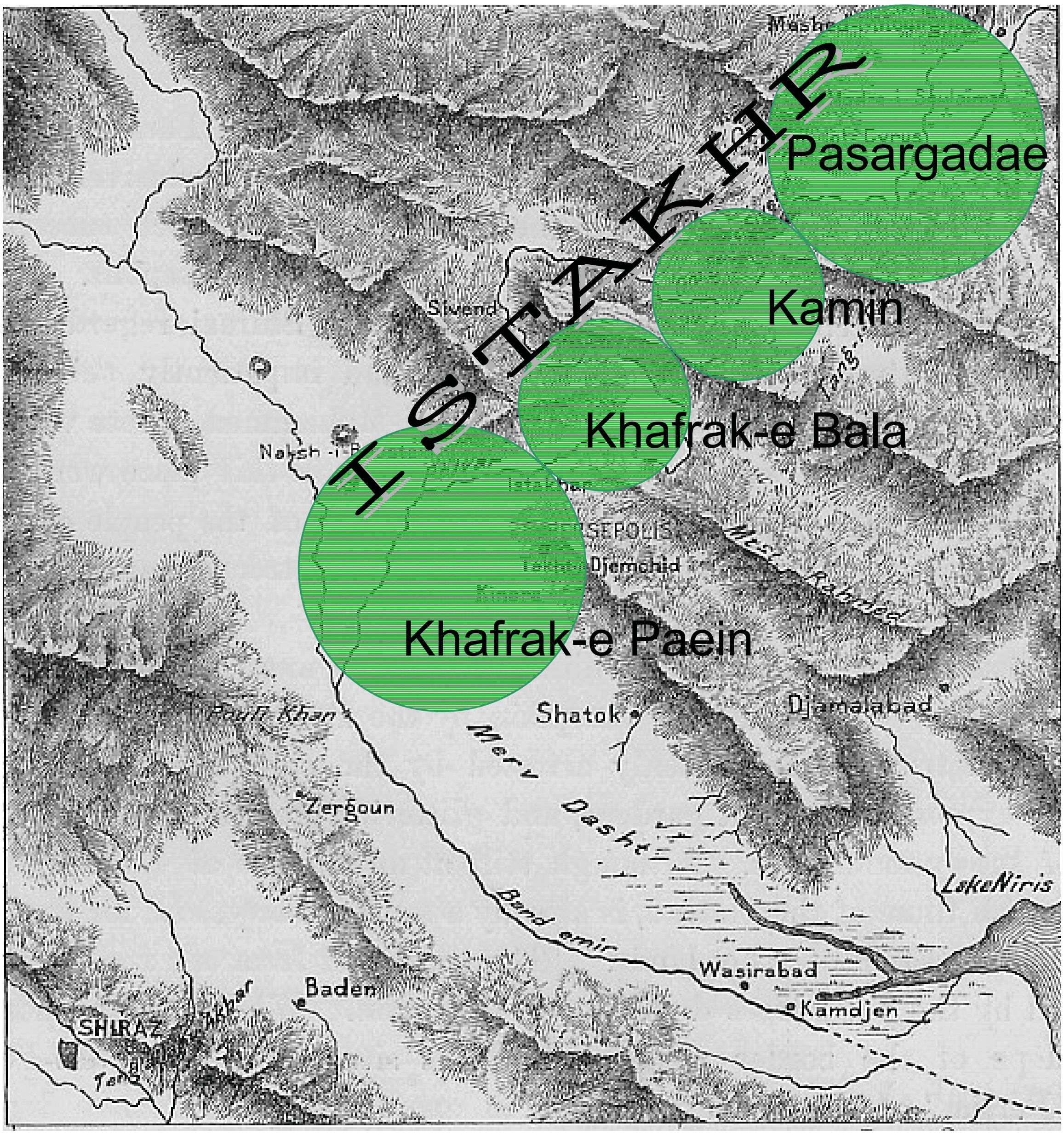

Figure 3. Different parts of the city of Istakhr spreading in four fertile plains of Khafrak-e Paein, Khafrak-e Bala, Kamin and Pasargadae along the sivand river**.**

Figure 4. Madabad Diversion Dam on the Sivand River (downstream face).

Figure 5. Madabad Diversion Dam on the Sivand River (upstream face).

Figure 6. A typical stone masonry diversion dam of the city of Istakhr.

Figure 7. An oblique diversion dam with sarooj plaster on the upstream face.

Figure 8. The remaining of a bridge or a diversion dam or both.

Figure 9. One of the footings of an Achaemenid bridge (probably Khorasan bridge).

Figure 10. The remainder of Takht-i Tavoos control gate.

Figure 11. The remainder of conveyance canal to Persepolis.

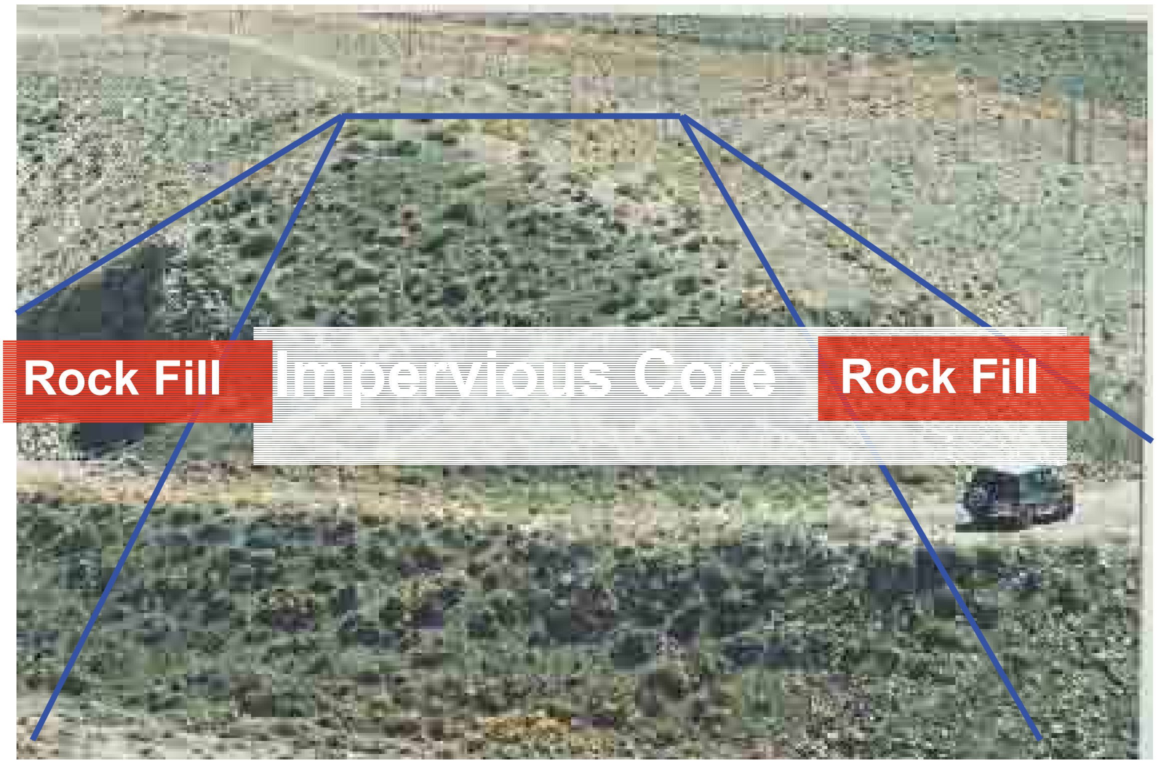

Figure 12. The remainig of Didegan embankment dam on the left abutment.

Figure 13. The texture of rock fill parts of Didegan dam.

Figure 14. The remaining of a stone retaining wall close to Didegan dam.

Figure 15. The remaining of stone pavement downstream of Didegan dam. Probably for scour protection.

Figure 16. Pieces of U-shape stones making a water conveying small canal downstream of Didegan dam.

Figure 17. Bottom of a piece of UU-shape stone with slots for fixing wooden slide gates in them. This has been an element of a water coveying system downstream of Didegan storage dam.

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TRADITIONAL IRRIGATION TANKS IN NANDED DISTRICT (INDIA)

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ABSTRACT

India has a long tradition of construction of chain of tanks as rainwater harvesting structures for agriculture, fishing, domestic needs and groundwater recharge. The undulating topography of Deccan plateau provided a good base for these innovative but simple structures, which the early settlers developed with their indigenous skill and technical advice from local craftsmen. Tanks are eco-friendly, ensure groundwater recharge, and provide protective and efficient irrigation. During the medieval period village communities owned and managed the tank system, collected taxes without interference from the state. During British period the tank systems were transferred to the state. Even after independence in 1947, the role of tank as a source of irrigation is getting eroded continuously. Poor status of tanks is attributed to centralized administration resulting in breakdown of community institution and system failure due to meager resource allocation. Urbanization is a phenomenon affecting the tank ecosystem on the fringes of the cities and upcoming towns. The expansion of human settlements poses a big threat to the common properties like tanks which are owned by the state, are taken over by the various departments for the construction of government offices, housing colonies, bus stands and other utilities. It has been established beyond doubt that the cities like Chennai have faced major groundwater drought due to total elimination of water bodies, which existed in the middle of urban settlements. The Dharmabad block in Maharashtra has 46 tanks constructed in 18th century, out of which six tanks were around the town of Dharmabad. These tanks have lost the purpose for the reasons mentioned above. The paper presents the success story of people's initiatives in modernizing the tanks by improving storage capacity and efficient management of water through beneficiary participation. The Dharmabad local self-government body has prepared a beautification plan of the tank costing Rs6.5 million which consists of improving storage, garden around the tank, garden statues, bird houses etc. The statue of Lord Shiva (14m high) will be installed in the tank for which expenditure will be met from the people's contribution. 50% work has been completed. The temple of Lord Shiva in the premises will attract thousands of pilgrims, which will ensure sustainability of the project.

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INTRODUCTION

India has a long tradition of using small storages (manmade and natural) and diversion works for irrigating crops. These works, found throughout the country, are among the most important and widespread traditional devices of water harvesting. Most tanks in India are of ancient origin, with several dating back to the 4^{th} and 5^{th} centuries A.D. Though they are found in all parts of India, they are concentrated in the Southern states of Andhra Pradesh, Tamil Nadu, and Karnataka. In Tamil Nadu, for instance, under *mirasi* system of land tenure, maintenance of tanks was one of the community activities for which a part of the produce of the village was earmarked. There were functionaries specifically assigned the task of handling tank-related matters. In Karnataka, the village community entrusted the responsibility to a person or group of persons who were granted a certain amount of land or tax benefit for carrying out the function. Similar arrangements evidently existed in Andhra Pradesh as well.

Until the advent of large reservoir based systems, most of the irrigation consisted of small storages, local diversion canals drawn from streams and rivers and shallow wells. While the area under large canal system increased substantially, the traditional local surface works were the main sources at the time of independence. Tanks are one of the oldest and important sources of irrigation and were maintained and managed by local communities. The community had their traditional organization and staff to ensure fair distribution of water among users. There are epigraphs dating 600AD to show how management of irrigation was looked after through farmers' committees.

INDIGENOUS TANK SYSTEMS

As one of the oldest man-made ecosystems, the tank system consists of (i) a bund or a dam which is generally of earth, but is also sometimes partly or fully masonry, (ii) anicut and feeder channels to divert water from adjoining catchments, (iii) a waste weir to dispose of surplus flood water, (iv) sluice or sluices to let out water for irrigation, and (v) conveyance and distribution system.

From various perspectives, the tank system is referred as;

- A management system as it is capable of becoming administratively and financially a self-reliant structure.
- A social system as the tank serves and benefits various sections of the village community such as farmers, fisher folk, animal rearers etc. The indigenous systems of tank irrigation are one of the surviving largest pool resources because:
- They are eco-friendly, i.e., a proper management of the system would itself ensure protection and preservation of the environment. They serve both as flood moderators in tines of heavy rainfall and as drought mitigations in times of long dry spell.
- Of being widely dispersed, if revived to their original capacity, they would ensure ground recharge and direct irrigation in rain fed areas.
- Of being numerous, small in size and spread over thousands of villages, they lend themselves to decentralized management which would better ensure their care and upkeep than any government department can ever provide.

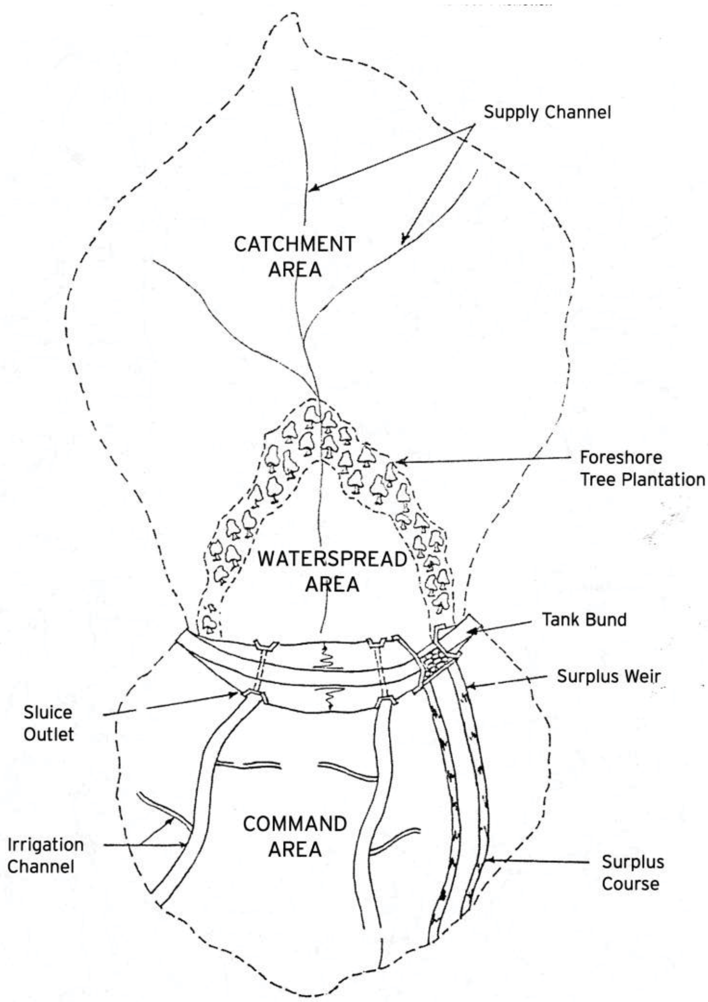

Figure 1. Schematic diagram of tank system

REASONS FOR DECLINE OF TANKS

There are numerous reasons for this decline each of which can be broadly characterized as representing economic, technical or social aspects of tank irrigation. Some of them are listed below.

i) Unreliable water availability

ii) Lack of profitability

iii) Poor tank conditions

a) Heavy siltation in tank beds and supply channels
b) Encroachment into places as tank foreshores, water spread areas and supply channels
c) Deforestation in catchment area
d) Defective tank structures such as leaky sluices and weak bunds

Since 1960-61due to the rapid expansion in well irrigation and the poor maintenance of tanks have combined to drop tank irrigation's share of the irrigated area to only 11.6 percent. After knowing Government investment in Minor Irrigation (having irrigation potential from 101 ha to 2000 ha) and importance of tank irrigation, there is urgent need to conserve the tanks to bring back the lost potential. In Maharashtra, the tanks (with irrigation potential less than 40 ha) have been known for their traditional irrigation system. If these are made functional, livelihood of marginal farmers dependent on these tanks can be ensured.

CHARACTERISTICS OF TANKS OF DHARMABAD

The rain fed irrigation tanks known as "Malguzari" tanks are found in the one-time Nizam (one of the emperors) state, i.e. parts of Andhra Pradesh, Karnataka and Maharashtra. Those were built about 200-300 years back by the kings and the landlords. As these tanks were source of revenue to the Nizam government, they were known as Malguzari tanks ('Malguzari' means revenue).

Malguzari tanks found predominantly in Nagpur, Chandrapur, Bhandara, and Nanded districts of Maharashtra are traditional irrigation tanks. The *koli* community built these tanks with their traditional knowledge and wisdom. They took into consideration various factors like catchment area, slope and soil type. Amazingly, they built tanks in series in such a way that the excess water (runoff) from the up stream tank feeds the tank at lower side. They constructed two types of tanks; bigger ones known as *Talav* which could irrigate more than 100 ha land and smaller ones, called *kunta* having command areas less than 100 ha. *Kunta*s were not much useful for irrigation and fishery where as the *Talav* held water even in summer, which was used as drinking water for livestock, washing cloths and other domestic purpose. There are 106 Malguzari tanks in Nanded district out of which Dharmabad block has a concentration of 46 tanks. Following figure shows the tanks in 14 villages of Dharmabad block.

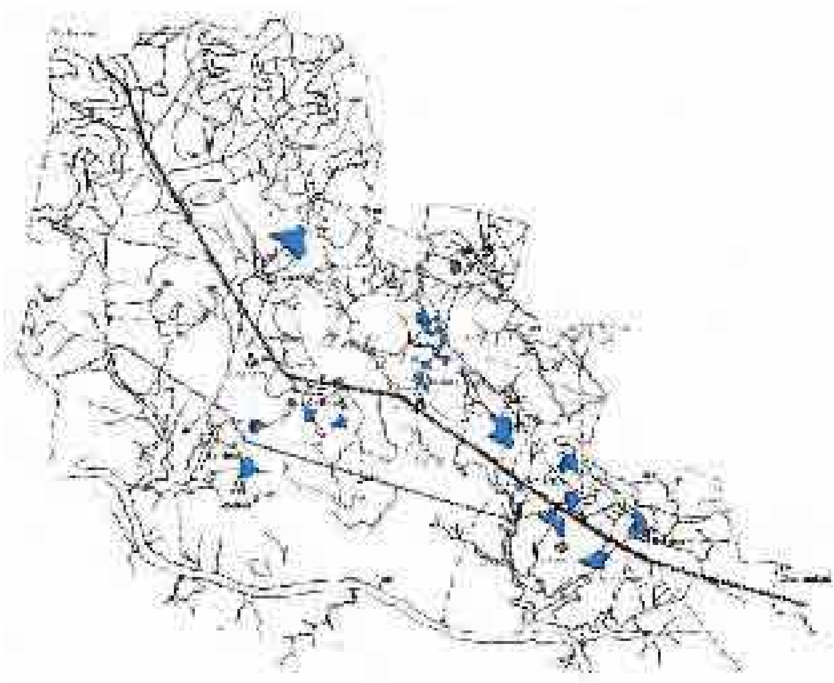

Figure 2. Location of Malguzari tanks in Dharmabad block of Nanded district

The Government of India has the responsibility for developing water resources but little control over water distribution. The present system of water distribution is vested with the local village people; in few cases village committees. It is supposed that the major maintenance works on tanks under control of Zilla Parishad (Z.P.) such as tank repairing bunds, tank sluices and breaches above the main canal outlet. Maintenance works below the canal outlet is primarily the responsibility of the farmers and the Panchayat union. Normally the water is released from the tank by a waterman called *Nirdee* who is paid by the villagers in kind. The appointment of Nirdee is made by local committees and is hereditary but he can be replaced if his service is found to be inadequate. Nirdee has also the responsibility of equitable and efficient water use at farm level but their main job is to open and close the tank sluice as directed by the farmers

Regulation of tank water by Nirdee

Spindle and rod mechanism of the outlet

Figure 3 Water regulating mechanism through sluice outlet (Tumbh)

A tank cascade is a chain of tanks located one above another within a sub-watershed. In tank cascades, drainage from one tank forms the major inflow to the next lower tank this cascade system had been functional but over time period it is disturbed which needs repair of linking of tank system. Such cascades are seen in all the 14 villages of Dharmabad block.

Because of the hydrological interconnections, development of one tank can affect other tanks and other water users. Although tank hydrology has a strong influence on groundwater in the form of increased water level, increasing capacities of tanks located in the upper sections of the cascade may reduce the inflows to the lower tanks. These linkages imply that water resources development plans should focus on tank cascades rather than on individual tanks.

FARMERS' INVOLVEMENT

The tank farmers belonging to Dharmabad tanks are marginal farmers and their land holding size varies between 0.1 ha to 1 ha. The farmers being the largest stakeholders in the tank system, their livelihood is dependent on performance of the tanks. It is observed that whenever tanks get injured, the marginal farmers take initiation to make tanks functional by availing local resources. They are found to have tried maintaining tank system so that at least one season crop could be cultivated. Some of the non-stakeholders are also supporting to manage tanks through *grampanchayat* (local administrative body) or through voluntary work.

Most of the efforts were contributed towards augmenting tank storage through desilting feeder channel and tank bed. A large scale weed removal, and delsilting of feeder channel and tank bed was undertaken by the Government of Maharashtra in 2005. The works / activities were aimed to involve peoples' participation in the form of labor and /or cash at the cost of diesel required for running machinery provided for desilting. The program '*Mahatma Phule Jal and Bhoomi Sanvardhan Abhiyan*' was launched to execute these activities by district level administration in Dharmabad. The villagers of Balapur were involved in executing these activities.

Though the tanks have been taken over by the government, the village communities still play a crucial role in the maintenance of tanks. Farmers contribute both physical labor and money for various tank management works. For mobilizing the required labor/money generally an informal meeting of farmers (not all the villagers) at the beginning of the season is arranged in order to decide what kind of maintenance work should be taken up and how to mobilize funds/labor. In some cases, the exact contributions are decided on the basis of the nature and urgency of the work to be taken up and the physical condition of different tank structures. Activities that are taken up very frequently are the cleaning up of supply channels and diverting water from the upstream, and minor repairs to sluices, surplus weirs and tank bunds. Labor-intensive activities such as cleaning supply channels are done by the farmers themselves, which is equally shared among all farmers irrespective of the extent of land owned under the tank command. Minor activities such as repairs to sluices, surplus weirs and bunds, which do not require labor from all farmers, are done by hired labor and the expenditure towards such works is met from the funds mobilized for the purpose.

Some of the tanks have been successful in raising amount of revenue through auction of fishes for running tanks. These fishes after getting matured are sold through auction. The rights of auctioning are vested with Zilla Parishad(District Council). In few villages fishing community has established society.. The local villagers and their collective bodies are not allowed to raise such revenues from the tanks.

The Maharashtra Water Resources Regulatory Authority Act 2005 which allows the farmers to take over water bodies for management, which covers all water bodies including malguzari tanks. Under "National Project for restoration, repair and renovation of water bodies directly linked to agriculture", an attempt was done by local sector (Z.P.) to divert funds from central government for renovation of tanks.

CASE STUDY OF DHARMABAD

An organization named ‘Prakriti Foundation’ took initiative to survey the conditions of the tanks in Dharmabad taluka with a view to restore the glory of the ancient system. Prakriti Foundation organized two meetings of the villagers of Balapur in March and April 2002. The plan of action for renovation of the Balapur tank was discussed and decided to repair the feeder channel and desilting by performing *shramadan* (contributing labour). The work began on 15th April 2002 with the participation of 40 people working two hours daily for a month. It resulted into the repairs of 1 km channel. This had positive impact on the neighboring village (Rameshwar village) and they started visiting the site. Meanwhile the Government of Maharashtra accelerated the renovation of the tank by launching “Mahatma Phule Jal Bhoomi Abhiyan’, which brought in earth moving machinery at the cost of fuel only. 45Mton of silt was removed from the tank in May 2002. Municipal Council of Dharmabad paid the cost of fuel for the machinery, since the tank was in the municipal limits. Second feeder channel was also repaired. This had increased storage capacity of the tank and strengthened the bund. Similar work of disilting by using Government machinery was approved consequent upon the request of the villagers of Rameshwar. Similar awareness has been experienced in village Samarala this year due to the training camp organized for the ‘youth for rural development’

Desilting of Balapur tank was done again in 2003 summer by employing the Government machinery for which the cost of fuel was shared by one local industry and two local administrative bodies. Farmers of the adjoining area had taken advantage of the silt by applying it to their fields. Municipal Council had prepared a road of 20m width and of length 500m around the tank by using the silt extracted during desilting. The success of this programme has laid the foundation for the innovative project launched by the Municipal Council. The project consist of a) road around the tank b) garden and garden statue for children c) electrification d) seating arrangement round the tank e) shops f) pitching and pointing of tank g) statue of Lord Shiva h) transplantation of big old coconut trees form elsewhere. The proposal for these works was submitted to Government of Maharashtra state, which has in turn sanctioned INR 3 million. The roads, garden and tree plantation work is in progress. RCC platform for Lord Shiva will be obtained by donation from potential donor. The appeal has been sent to prospective donors. With a view to attract tourists to Dharmabad and to improve the economy of the township, it was thought of putting it on the map of tourism. The pilgrimage centre Basar, very famous for the Goddess Saraswati temple, is just 7 km away from Dharmabad. The vicinity of Basar has enhanced the possibility of developing Dharmabad as tourism centre. Ambitious plan of INR 20 million was submitted to the Government of India under Integrated Development of Small and Medium Towns which included; a) Construction of shortest road from Dharmabad to Basar passing over Balapur tank (7 km length) b) Administrative building of Municipal Corporation and commercial complex c) Krantiteerth- a museum to install the statues of freedom fighters of freedom movement of India presenting life sketch of each martyr d) Meditation hall and exhibition in the Krantiteerth. The height (15cm) of statue of Lord Shiva in Balapur tank is planned in such a way that the same will be visible from the train so as to attract the tourists going to Basar. The amount of INR 20 million has been sanctioned by the Government of India and construction activity of road and building has been started.

Figure 4 Beautification Plan of Tank

PEOPLE'S INITIATIVE FOR ENVIRONMENT PROTECTION

The people of Dharmabad who were moved by the damaged condition of Balapur tank initiated modernization of tank. There were various social organizations that have participated in the endeavor by contributing labor and money. The people also supported beautification campaign launched by the Municipal Council. 20 tricycles were employed to collect solid waste daily from the houses and waste is being safely disposed off (which is not usually seen in similar towns). Hutatma Smarak; a memorial for the freedom fighters of India, had been converted into a live memorial place. It was again a people's initiative in 1995, which had developed a botanical garden, a library and reading room with seating arrangements. It is now a picnic spot for the people as the Hutatma Smarak is situated on a hill. With an objective of involving people in the tree plantation programme, the Municipal Council has presented saplings to the married women on the religious occasion. They were requested to plant and grow the trees around their houses. This scheme was successful and yielded good results.

MODERNIZATION MEASURES FOR TANK SYSTEM

In order to meet the growing human and environmental water needs and restore the tank ecosystem, a new strategy is required. This strategy should provide for appropriate instruments for the tank dependent agriculture while keeping the multiple utilization of tanks intact, to ensure a sustainable livelihood to the people. This means, establishing comprehensive tank system development programmes at watershed and river basin levels. An alliance of all the stakeholders concerned ranging from government, philanthropy, village communities, Panchayats and general public should be organized. The development strategies should have both short term and long-term technical solutions. The short-term opportunities include on-farm development works through modernization of existing irrigation facilities/structures and conjunctive use of surface and ground water resources. The long term challenges consist of establishing water grids connecting these modernized tanks in a chain to mitigate drought and flood at local level as well as encouraging the farmers' participation in planning and management of these irrigation facilities for sustaining the agriculture of this area.

To attain maximum field productivity, water must be supplied and regulated in such a way that maximum production could be obtained from the available tank water. Another avenue for safe-guarding the poor is to promote policies that encourage diversification of cropping patterns away from rice. Crop diversification may increase incomes and reduce the demand for water, which may enable poor farmers to purchase water from the emerging competitive water markets. To complement the above options, tank structures should be repaired for effective water control. Instead of continuous water withdrawal from tanks, tank management strategies such as sluice rotation (opening and closing of sluices on alternate weeks) will help save the tank water.

INSTITUTIONAL MECHANISM

The tank systems, which have survived over several centuries, were known for their institutional mechanisms related to tanks governing the issues like i) Administration ii) Management iii) Revenue generation iv) Conflict resolution and v) Water management.

For any system to sustain needs some kind of mechanism. Similarly the system can not run on its own but requires some kind of institution. The institution is formed by bringing the group of people together to perform some functions. One of such water institution is Water Users Association (WUA). With reference to the study conducted in Dharmabad block and traditional wisdom of managing the tank systems available with the people following proposals are worked out for modernizing the irrigated agriculture.

- Tanks must be desilted periodically so as to restore their original capacity. This would be possible by enforcing all the stakeholders to participate in cleaning the feeder channel and tank bed. This could be achieved by allowing the farmers work voluntarily or by employing laborers, or by giving labor wages as a substitute to both above. There should be checks and controls over increasing population settlement in the route of inflow, and encroachment of foreshore area through cultivation. All this may be necessary but not sufficient condition. To bring the efforts fruitful, the institution should be empowered with strong legislative rights to take action against the encroachments, excessive digging of land to procure material for development works etc.

- The youngsters should be tried to restart the cultural activities (related with the tank system) which have been discontinued due to some reasons, or they should be promoted to create the activities. This way somehow they would be associated with the system.

- There was no coordination found amongst different tank farmers in a village. This can be achieved by both the upstream and downstream farmers at Tank Federation (TFA) level. This would enable negotiation between upstream and downstream tank farmers to get water in their tank during times of scarcity and would help in understanding problems and difficulties associated with tank system.

- The institution should seek the tank system to develop as a tourism center around which urbanization has started developing or likely to be developed in future.
- Revenue generation can be mobilized through auction of usufructs, levying local cess and tax on tank water utilization, levying tax on well water utilization. The common property resources rights over tank assets should be given to the local village tank associations on a sharing basis with the local Panchayat. Such a measure would strengthen the local village tank associations in building their own funds for maintenance of tanks apart from using a common property for a useful purpose.
- The specific category of weed that grows and appears to be trouble in tank storage, could be used for producing biogas and bio fertilizer.
- The cooperation and coordination between pisiculture federation and the Tank Federation (TFA) should be developed and should be tried for further strengthening. The relationship with Forestry Department should be established and further strengthened in order to enhance financial viability of the institution through plantation and horticulture crops on catchment areas.
- The PRIs (Panchayat Raj Institutions) and WUAs should be as distinct as possible. Otherwise the local PRIs' interests will appear more in terms of acquiring political clout than to demand more powers to strengthen the institution itself.

CONCLUSIONS

In spite of the fact that it is difficult to protect, conserve and modernize the historical tank system against impact of urbanization, it can be done by reviving the cultural values around water bodies and through participatory management. People's participation is an essential component for handling small tank systems which has been accepted and encouraged by the Government of Maharashtra. These tanks as a result of people's initiative will be handed over to the WUAs in near future.

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TRADITIONAL WATER MANAGEMENT IN THE SEMI-ARID AREAS OF CENTRAL HIMALAYA

Maheshwar P. Joshi[1]

ABSTRACT

In the semi-arid areas of Central Himalaya, India, people have worked out an efficient water management system. Present paper focuses on some interesting technical and ideological aspects of this system.

The technical aspect reveals Central Himalayan peoples' intimate knowledge of different watering sources that were articulated in some thirty-five local names on the basis of topographical setting and available quantity of water. Furthermore, it describes how using locally available material the people developed various sustainable and highly efficient hydraulic contrivances to tap and store water from different sources; that based on simple technology most of these devices were executed and maintained by community efforts, hence free from financial burden.

The ideological aspect shows that in Central Himalaya ideology lent sanctity to water, accordingly several important rites and ceremonies were developed around it. Furthermore, images of different divinities were installed in the watering places to sanctify them. Consequently, in semi-arid parts ideology motivated people to participate in the construction, repairs, and hygienic maintenance of the watering places, and helped society in resolving water related conflicts, and agreeable distribution of water.

Combined testimony of the archaeological record, folklores, and ethnography unfolds that in Central Himalaya these two aspects existed from very early times. Naturally therefore the efficiency of traditional water management is time-honoured.

Sadly to-day due to State control in water management the people of Central Himalaya are distancing themselves from the traditional water management system that needs to be arrested, because its efficieny is beyond doubt. Indeed in the context of ever growing global water crisis, and technical, environmental, institutional, and social issues thereof, the traditional water management in the semi-arid areas of Central Himalaya is worth examining.

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TECHNICAL ASPECT:

The people of Central Himalaya have a long tradition of utilization of different water resources based on intimate knowledge of the "science of the concrete". It is evident not only from their classification of watering places but also in the use of simple technology to tap water in the semi-arid pockets.

Classification of watering places: The uncertain climatic conditions in Central Himalaya have made a deep impact on the lifestyle of its inhabitants. The great volume, force, and velocity of the snow fed rivers of Central Himalaya cannot be controlled by simple technology; therefore traditionally people use smaller streams originating from the forest-clad mountains having low volume and velocity. However, 80 per cent of the annual flows of these rivers occur between June and September, and during the remaining months water is always short in supply. Hence, the people of Central Himalaya explored other sources of water. Accordingly, each watering spot was given a specific technical term based on the quantity of water therein. So far the author has recorded some thirty-five odd terms referring to some or the other category of watering places. This helps considerably in water management as also unfolding the history of water.

It is interesting to note that each of the thirty-five odd terms of water under reference cannot be rendered into Sanskrit, Hindi, Hindustani (Urdu), or English precisely because of the deficiency of vocabulary of these languages concerning classified watering places. No doubt, these concepts are indicative of deep knowledge of hydrology, and bespeak a long scientific tradition.

Hydraulic devices: The Central Himalayan people have been practicing certain interesting, multipurpose hydraulic contrivances, which are very effective on account of simple and cheap technology. These are as follows:

***Khal*:** The *khal* (storage tank) used to be an extremely useful time honoured device to harvest water in the areas of water scarcity, where it has been the only source of irrigation.

The *khal*-system in some places is called "*kul jhuvamda*" (executing conduit). There are different types of *khal*-s, depending on topography and volume of the available water. The most elaborate one (example, Baugad stream, village Adigram Phuloriya, District Almora) consists of two *jamgi*-s (weirs to forming large pond) situated at two different points, the one upstream, and the other downstream from where *gul/ban* (diversion channel) takes off. The longer the distance between the weirs the larger the volume of harvested water, therefore it could stretch over a kilometre. The upstream weir, relatively more spacious, stores maximum amount of run off water of the stream at a higher elevation. In between these two weirs a series of *khal*-s (tanks) and *chupadal*-s (subsidiary tanks) are so constructed that surplus water exceeding the capacity of each tank is channelled to another, thus the entire series of *khal*-s and *chupadal*-s is filled with water. Each weir and tank is provided with an outlet at the base of its wall towards the direction of downstream, through which flow of the outgoing water is regulated. Whereas the outlets of the smaller tanks are blocked by a stone slab each that of the weirs and larger tanks have a *muni* (a stone slab with a hole). When water is released through the hole of *muni* it rushes out with great force to its destination through *gul/ban* and *kul*-s (irrigation channels). The height of a weir is about 1.5 meters or more, that of a *khal* is about a meter, and of a *chupadal* about 80 centimeters. The capacity of the tanks (both larger and smaller) varies according to availability of water and may range from roughly 500 litres to about a few thousands.

The *jamgi, khal, and chupadal* are simple walled structures to store flowing water. The ingenuity lies in making them almost leak proof. For this pieces of *digada/jhupuk* (turf/sod) are collected from the banks of stream. A layer of these pieces is placed on the foundation of the masonry wall above which is laid the first course of boulders and pebbles, followed by another layer of turf. Thus by laying alternate courses of turf and stone the weirs and tanks are raised to required height. Sod is also placed in the gaps between the boulders and pebbles. It checks leakage and binds stone masonry firmly.

Gul and ***kul*****:** *Gul* (diversion channel) and *kul* (distributing water ditch), the time honoured irrigation devices, are constructed with great ingenuity along streams and have withstood the test of time for generations. Following points are taken into consideration for their construction:

a. An appropriate site for constructing a *ban* (weir).

b. The weir should have appropriate height to facilitate construction of network of *gul* and *kul*-s to irrigate surrounding fields. The *gul* is also used to run water-mills, hence easy and forceful flow of water is the main consideration.

c. The weir should harness maximum water throughout the year.

Ethnographic evidence suggests that construction of a *ban* (weir), *gul* and *kul* is a community affair. These used to be designed, constructed, maintained, and regulated with the approval of concerned community. As a custom each and every household using water from the *gul* and *kul* must help in the construction and repairs of the *ban*, *gul* and *kul.* Whereas able-bodied male members offered physical labour, others substituted it for cash or kind, which was used towards payment of wages to labourers employed in the construction work. Distribution of water in some deficient areas was done on the basis of *hara* system in which the farmers collectively entered into contract with one of the natives competent enough to undertake repairs of the distributing channels as well as regulate and distribute water properly. In return, at the time of each harvest he received a certain portion of the grain produced by each farmer (cf. Pande 1997).

Construction of a *ban* (weir) is done in two ways. A simple construction involves piling in row huge boulders, pebbles, and gravel, brought down by the river during heavy rains. Where necessary, it is further reinforced by loose irregular framework of wooden logs, stakes, brushwood, etc. The row is constructed across the river somewhat obliquely with a slight curve towards the direction of the flow, as a result of which the forceful flow of the stream does not easily wash it away. It is interesting to note that on the advice of a native engineer the same geometrical knowledge was applied by the British in the early 20th century to successfully raise a dam at Bhimtal (District Nainital) after repeated failures in damming the Bhimtal Lake.

Another type of weir, called *ghori bund*, is relatively advanced in technology. Its base is constructed with crates filled with boulders above which is fixed a framework of a series of tripods made of newly cut wooden logs measuring about two and a half metres. The tripods, called *ghori* (literally mare), are so fixed that they slant towards downstream; their front two legs face upstream, while the third leg towards downstream acts as a pivot. These tripods are tied with one another through front legs slightly above their base with wooden logs. The framework of these tripods is filled with boulders and pebbles together with an irregular mesh-like formation of twigs and branches of trees on the top, which in turn is packed with gravel, sand, and silt. At a certain strategic point of the weir a few tripods are left separated so that in case of heavy floods the weir is breached to allow floodwater gush, sparing the remaining part (Pande 1995: 48-50).

The *kul*-s (distributing channels) are usually dug in the surface soil. These channels are lined with stone only at those points where turns are provided, and their remaining part remains unlined. In these channels local variety of such grass as withstands the flow of water is allowed to grow which checks soil erosion very effectively. Sometimes, when the water is carried to longer distances through precipitous rocks or ravines aqueducts of deodar or pine, supported by huge columns of wood with masonry base or rough stone masonry pillars erected on the ravines, are used. The height of these columns is often more than 12 metres (Pant 1935: chapter XIII). Likewise, traditionally, the Rajis, a hunter-gatherer band confined to mainly Didihat *tehsil* (District Pithoragarh), used to convey water to fairly long distances using banana leaf-sheaths.

The advantage of *khal, gul* and *kul* systems is that the material required in its construction is locally available in abundance, and free of cost. They are very cheap light constructions; their design and technology are simple, and can be executed by untrained labour force under the supervision of a few experienced persons. These simple weirs are very effective and sustainable because they have negligible impact of silting, for the annual floods wash away the rough walls together with silt at the vulnerable points. This obviates silting of the weir, which is the unavoidable problem of the heavy, permanent dams constructed at high cost with cement, concrete, steel, etc. When the flood season is over these weirs are again repaired by the community labour. On account of these qualities the *khal, gul* and *kul* used to be very popular in the water deficient areas. Sadly, these days water is being drawn from distant places by diesel pumps during lean season, consequently *khal*-s are being given up.

Irrigation works are necessary for successful agricultural operations. Inscriptions reveal existence of irrigated land and water channels (*gul* and *kul*) in Central Himalaya from at least *circa* seventh century AD, as is evident from the Taleshwar Copper plate of King Vishnuvarman of Central Himalaya which mentions grant of *kedara* (line 21, Gupte 1915-16: 119), meaning ‘irrigated land’ (Monier-Williams 1986: 309), and *sa=kulyam* (line 20, Gupte 1915-16: 119), meaning ‘together with = channels or canals’ (Monier-Williams 1986: 296).

Water sealing devices: To make water channels and weirs almost leak proof plaster of *chupad/lesu-mat* (sticky fine clay), or *dhyudathamauka-mata* (clay of the anthill), preferably the latter, sometimes mixed with cow dung and natural fibres, is used. Interestingly, in many places cow dung dissolved in water is flown through the channels, consequently particles of cow dung settle in the cracks and pores of the channel, which minimize water leakage considerably.

Naul: Variously known as *nauva, nauli, naulo,* the *naul* (covered/open reservoir below ground level) is a tank in which water oozing from the ground of the earth is collected. There are two types of *naul*-s, namely, the one having a superstructure that covers the tank, and the other without a superstructure. The size and plan of these *nauls* may vary, according to the topography. The spill over water of the *naul* is used in irrigation.

A *naul* is constructed in those places where water oozes in very small amount from different spots from the earth so that it cannot be collected directly. Therefore, a spot is selected where a pit is dug to ascertain whether sufficient water oozes for collection. Having found such a place the pit is dug according to the available volume of water as well as the requirements and means of the people constructing it. It is then lined with chiselled stone slabs, thus forming a water reservoir. Its storing capacity may vary from some one thousand to five thousand litres or even more. The tank, a rectangular structure, is raised up with two parallel walls on each side which rise slightly above the ground level to prevent rainwater, mud, soil, grass, twigs, etc., falling into it. The inner walls forming tank are stepped, and the outer walls almost vertical. Stones employed in the outer walls are roughly dressed and bonded in 'English bond' style with alternate courses of headers (*thada*) and stretchers (*mudhi*). Fine clay mortar is used in bonding. The vertical walls serve as foundation to the superstructure of dressed stone masonry with a pointed sloping roof of stone slabs supported by stone beams laid in lantern pattern. The gap between the stepped and vertical walls of the tank is packed with extremely fine clay locally called *chupaud mata*. According to the masons the clay filling not only seals the water completely but also binds the entire structure remarkably. Dhaulavira (Gujrat) evidence suggests that compact clay filling was also used by the Harappans to seal water in a stone masonry tank as early as third millennium BC.

The stone employed in lining the tank is fine-grained, impervious, and can be chiselled smoothly without using much force. The hammer used in chiselling the stone has a pointed end on one side and the other side has a flat end. Sometimes when the chisel is not used the pointed end of hammer is employed in dressing the stone. Whereas the exposed parts of the stone slabs are finely hewn, the covered ones used in bonding are so chiselled that they bear fine chisel marks forming intricate widthwise rows of grooves (directionally from the side of walls towards the centre of the tank). According to the masons, the stone slabs are so laid one above another in the masonry that the grooves could serve the purpose of tenon and mortise, and that the fine stone powder produced in the course of chiselling is spread all over the grooves to fill in the gaps as a result of which the water gets sealed in the tank. However, in some examples where water trickles into the tank from the side-walls (usually opposite outlet) the stone powder is not used; in that case the grooves provide a smooth passage to the flow of trickling water. Significantly, the bottom of the tank in some examples is provided with a *pati* (stone slab) bearing a hole from where water oozes from the ground. Obviously, this hole as well as the base of the stepped tank reveals that the masons are aware of the potentials of hydraulic pressure. Nevertheless, it may also be noted that the design of the tank may vary according to the flow of water. Thus where water trickles from rocky surface the inner walls of tank are provided with steep steps, or walls, in the latter steps are provided only at the entrance of the *naul,* which also being the outlet for the overflowing water.

Uncovered *naul* is a simple structure, and may consist of a single course of lining to four or more, the depth ranging from about 50 to 70 centimetres. In most cases it is made with stone slabs. To construct such a *naul,* a 60 to 80 centimetre deep and 100 to 150 centimetre square pit is dug. Having a stone slab floor it is lined with finely chiselled stone slabs of equal size so as to look like a cistern. The ends of all of these stone slabs are proportionately perforated at equal points; subsequently copper wires are passed through the perforations for bonding the stone slabs with one another securely.

The *naul* is indeed a marvel of hydraulic technology, and has survived the vagaries of nature for centuries. Significantly, the storing part of the *naul*, constructed below the ground level, has never been found in ruinous condition, nor anyone has ever heard of its restoration, even though it has dried out or else its superstructure has fallen. The only maintenance required by some of these *naul*-s is that of cleaning, that too sparingly. Before the introduction of the iron and steel pipes *naul* was the main source of potable water supply in Central Himalaya. So far, the epigraphic evidence indicates existence of a *paniya samgraha* (water reservoir, *naul*?) in Uttarakhand Himalaya from *circa* sixth century AD (Gai 1971). However, there are a few extant *naul*-s (water reservoirs) in Kumaon, still in use, containing inscriptions in Nagari characters bearing dates between Samvatsara 1329 and Saka 1391 (AD 1272 and 1477). One can still see extant *naul*-s in almost every old settlement which continued to be built up to the first half of the 20th century AD.

Ceramic pipes: An interesting early device of conveying water to distant waterless locations without seepage was the use of ceramic pipes which have been unearthed at several places in Central Himalaya, notably, Silor Mahadev, Champawat, Lohaghat, Chandpurgarhi, etc. These pipes are about 40 centimetres long with an inner diametre of 8 to 10 centimetres. The top end (inlet) of the pipe is wider and the bottom end (outlet) narrower so that the latter of one pipe is inserted into the top of another, thus forming a line. Using gravitational pull water through these pipes used to be carried to its destination through uneven terrain that was otherwise impossible before the introduction of steel pipes.

IDEOLOGICAL ASPECT:

Combined testimony of the archaeological, archival, and ethnographic sources clearly shows that in Central Himalaya people held water as a sacred element. Therefore, watering places used to be adorned with images of some or the other deities. The most frequently represented image found in the old watering places is that of Seshasayi-Vishnu, because traditionally it is believed that water becomes scarce only in those places with which god Vishnu is unhappy. The other deities whose images are installed in the watering places in different parts of Uttarakhand Himalaya are Siva, Uma-Mahesvara, Ganesa, the river goddess Ganga, etc. Among these, Ganesa is the most popular deity next to Seshasayi-Vishnu. All these deities belong to the great tradition of Hinduism. However, local deities representing little tradition associated with waters are also not wanting. Thus, in the northern fringe of Uttarakhand bordering western Tibet (China) Pancha-Naga, Gabla, Bhumiya, Dharmua and Hardyul are associated with water.

Watering places in Central Himalaya form an important part of several rites, which are performed at certain exclusive spots having perennial water. Thus, one of the concluding parts of several ceremonies is *naul seuna* (laying paraphernalia at the watering place), performed exclusively by women. For example, in a marriage ceremony, the women of husband's household lead his bride to the *naul* (watering place) to which place she carries an anointed pitcher containing water and several other auspicious items, including a wisp of *kusa* (Panicum Dactylon) grass. She empties (*seuna*) these items at a fixed spot of the watering place where she also performs certain rituals. Finally, she fills water in the same pitcher and carries it back to her husband's house. Another interesting ceremony is the *jala-yatra* (water journey). It is performed in several places in Garhwal by women, who, forming a row, carry on their heads pitchers filled with water from a watering place to its destination. A long sheet of white cloth is thrown over the pitchers as if forming a stream. Initially it seems to have symbolised bringing water to the needy place, but now it is also associated with the descent of the Ganges from heaven.

Interestingly, the Uttarakhand Himalayan customs recognize twelve forms of marriages, one of which is termed '*Panidhara* marriage'. It takes place 'when the husband is unavoidably absent, or astrological considerations render his actual marriage with the person of the bride undesirable... the bride is taken to some sacred place on a river, occasionally even to an ordinary spring, she is publicly "married", and declared to be the wife of the bridegroom. Absentee soldiers are often married in this way' (Lall 193: 7). Significantly, rites concerning death are also performed exclusively in the watering place of the concerned settlement. Naturally therefore, these rites and ceremonies lent sanctity to the watering places and inhabitants of every settlement collectively maintained them (Joshi 2005).

Ideology not only played vital role in managing watering places in Central Himalaya, but it also inspired people to generously participate in their construction and maintenance to earn spiritual merit. So much so that inspired by ideology Madho Simha Bhandari, the legendary General of King Prithvipati Saha (AD 1631-1667) of Garhwal, is said to have sacrificed his son Gaje Singh to seek divine favour to cause water flow through "a nearly 100 meter long tunnel about 350 meters from the diversion head" (Pande 1995: 57), which event is still remembered by holding an annual fair by the villagers.

Thus, ideology lent sanctity to the watering places, and in semi-arid parts it helped considerably in resolving water related conflicts in society. Water was not held as an item of contention, rather being offered water entailed obligation for the recipient to remain indebted to the giver. Hence the popular saying "*anjal*" (*anna* = grain, i.e., food, and *jala* = water) is used as destiny of a person.

CONCLUSION:

In Central Himalaya during the pre-British times the State encouraged community/private involvement in the control and management of water. People held water as a divine element, and traditionally all watering places were considered as the abode of some or the other deities, particularly Vishnu in the form of Narayana (he who reclines in the water). Therefore, construction and maintenance of watering places were considered pious acts and socio-religious obligations. People, by and large, willingly involved themselves in such activities. The driving force behind these activities was that if the concerned spot remained pure, sanctified, God Vishnu would be pleased to have it as his abode; hence it would remain full of water by his presence, for he reclines in water.

The deep-rootedness of the sanctity of water in Central Himalaya can be assessed from the fact that whenever and wherever scarcity of water was felt tradition-bound people used to say “God Vishnu is angry”. They did not blame the government authorities who supervised and controlled water resources. This ideology is dying out sooner than later, because nowadays water is controlled by the government agencies (see, Water Rules of 1975). It is purchased as a commodity. Therefore, water is losing its sanctity, and traditional hydraulic technology is fast disappearing.

In recent years considerable data have been collected from different parts of India showing the ingenuity and effectiveness of the traditional water harvesting and management system (see, Agarwal and Narain 1999). For a sustainable water managemnt the Third World will have to revert to traditional knowledge system.

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IRRIGATION AND DAM HISTORY IN SISTAN

Iraj Afshar (Sistani)[1]

Sistan in the eastern part of Iran is located beside Iran border and Afghanistan and because long- standing geographical particular position, continental specific conditions, contiguity with fruitful Hirmand and Hamoun (includes as the largest lake of freshwater in the world with international point which is known such as huge capacity of "biosphere"), also by political typical situation has had special validity to the point of strategic and is considered as passage of auriferous India and Far East too.

Sistan, the national mythology of land, has been bloomed like cultural cradle from the old days as its great and brilliant antiquities are seen nowadays and admired by the world. It has been recognized as the capital association of monumental cultures in Vara-roudan (Mavaraonnahr), Mesopotamia, Send, India, China because of its cultural Characteristic.

Sistan is one of the most fertile lands in Iran with its alluvial soil and plentiful water which has been one of the prosperous states in Iran in the past. The Iranian and foreign notable experts who have evaluated Sistan's questions perfectly called it as "Auriferous Land" and "The Storage of Wheat of Iran and Asia".[1]

The continental diversity, topography and geographical conditions, disharmonious distribution and crossing and inconstant of current flow beside water needs and changes during the year reckon hydrologic characteristics of the vast part of Iran, especially Sistan. So, the principals of irrigation engineering has been noticed by Iranian from the ancient times, who are named this "Irrigation Art".[2]

Iranian were telling water, purity symbol and immortality element and were revealing this opinion with sacred believes like Anahita, the guard angel of water, which was showed water's value.[3]

Precipitation and lack of water resources in Sistan has motivated Iranian to find new solutions for provide, storage and exploitation of water and Iranian engineers create intellectual and competent management methods to find, increase efficiency and water distribution. Monuments, buildings and many structure with variety in Iran water culture, among Sistan, in spite of centuries, events and natural variations have firmed show the intellect, facility and incomparable management of this region's engineers.[4]

In the ancient times Sistan has had real regular artificial irrigation by making extended net of dams, rivulet and streams separated from Hirmand river and Achaemenian kings

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have been enjoyed of dams in order to military aims.[5] In the Sassanide Era, the irrigation method trascend not only in the western parts of that government domain but also in the eastern parts of it, that means in Khorasan in Morghabdistrict and Sistan in the Hirmand realm. Irrigation installation of Morghab had influenced on Arabs which they named "Morghab" one of the dug river in the eight century (AD). Also the engineers and hydrologists who had been taken by Arabs victors from Sistan to Mecca in 7 A.D, treated irrigation affairs and management around the Mecca with the whole Sistani slaves who had done water provision and irrigation have had released.[6]

One proverb in Sistan says: Sistan's prosperity conditions depends on three dams: water dam, gravel dam and corruptors dam. The Sistani historian has written this proverb with suit words in thousand years ago:

"Sistan's prosperity conditions has depended on daming on: water, gravel and corruptors. If these dams have been closed, there wouldn't be any pleasant place except Sistan in the world, if they do, it is possible and if it has done, consistency will be bring for Sistan through the times."

From ancient times Sistanian have known that if they want to exploit of Hirmand river they had to hold it and dam. Sistan had been an instance which wants stone and mount, standing dams of Sistan were made by brick, lime and mortar.[8] Monument relicts from some dams are so surprising and honourable for engineers and water managers affairs of Sistan in that time. For instance, Ta'am river which was separated from Roudbar dam had 150 kms length which had needed huge volume works for construction and retention.

This essay reports about ancient dams of Sistan which turns in Roudbar superior or a point which large arch of Hirmand changes its direction from the south into the west:

In this paper it hasn't been mentioned to diversionary dams on khash- Roud, Farah-Roud, Harout and khousepas although particular sections of Sistan territory have been irrigated especially by Khash- Roud and Farah river in different times.

The first step for research and detection in old dams sites is evaluation and definition of Hirmand river crossing in its delta from the initial terms.

The oldest remainder crossing of Hirmand is "Dour" river or "Poudaei" or "Poudeni" doubtless is the same "Ourouda" river wich mentioned in Avesta. Another crossing had been before settlement in Sistan after "Dour" river period. Today this passage is called "Sena-Roud" which is differ from Sena-Roud or Siah-Roud in Islamic epoch in which was a grand separated canal from Hirmand river. The water was flowed in present passage of Hirmad to about Kamal – Khan port next alternatively has left to the north and the northern delta or has been passed through the west and the southern delta in current dry passage named Biaban river or Terakoun. Most of the main diversion dams on Hirmand in several times have been charged water from named dam into the deltaic lands which have been naturally dispossessed of Hirmand water flow. So these dams were been placed on superior where Hirmand water has choosen its passage in the northern or the southern deltas.

It has been resulted from researched 114 sites by archaeologists:

1) PRE- HISTORY PERIOD (4 MILLENNIUM TO 1500 B.C.):

The Hirmand's flow was toward the southern delta. It hasn't come any considerable effects of human occupancy in the northern delta in this period possibly Biaban river had been the main crossing for Hirmand.

2) POST – HISTORY PERIOD (1500- 600 B.C.):

In uncertain time, likely about 1500 B.C.

Accumulation of Hirmand sediments in Biaban river crossing has been caused channel flood which made river to choose another way along one of prior minor branches toward the north and has gone to the northern delta about current Nad- Ali, where has been one of settlement centers in the northern delta.

This changing in Hirmand passage from the southern delta into the northern delta is the essential factor in abolishing settlemental centers in the southern delta (such as burnt city).

3) THE ACHAEMENIDIAN ERA (600-200 B.C):

In this period, the southern delta wasn't inhabited and Hirmand water has been poured into the northern delta. The most obvious sites of this term have been Dahaneh-Gholaman cities, Zarin or Darangiana and Sorkhdak of Nad- Ali fortifications.[9]

4) THE ASHKANID ERA (200 B.C TO 200 A.D):

In this ages has controlled the east part of Sistan by Sakas. But the Ashkanids could achieve Hamoun region, south delta and Saroutar gradually. Sakas has to leave Sistan for Helmand but named their name "Sistan " (Sakestan) on it forever. Segmentation of Sistan between Sakas reign as "Arakouzia" and Ashkanids as "Derangiana" is about the same current division of Sistan between Iran and Afghanistan. The famous centers of residence have been Kakha or Kak-ha city in Kooh- Khajeh, some places in Saroutar, province and temple of Dahaneh- Gholaman (slaves gate).[10]

5) THE SASSANID ERA (200-700 A.D.):

The Hirmand river has been nearly flowed into the northern delta and water has been arrived to the southern delta with diversionary dams. The occupancy centers in the Ashkanid era have grown in the Sassanid era and extended around the Hamoun lake, Saroutar in the east of Hirmand and the west of Margou plain to the next Chokhansour.

6) THE FIRST PERIODS OF ISLAMIC EPOCH (700-1400 A.D.):

The most evident of characteristics of this time is the quantitative and qualitative growth of cities and major habitational centers like Zahedan and Pishavaran and celebrated city, Zaranj has been reckoned as Sistan's capital.

7) THE LAST PERIODS OF ISLAMIC EPOCH (1400-1700 A.D.)

It was begun with Taymuriyan reign which Hirmand river has flowed into the south delta and Biaban river passage. But the northern delta had been received its water needs by diversionary dam and seven ample canals. Taymur Gurkan beside destruction of a strategic and large city, Zahedan and Tagh fort (Saroutar) and the other fortresses, ruined Rostam dam in 1383 (A.D)/ 785 (A.H.). Later his son Shahrokh ruined the substitud dam, "Havanak" again in 1408 A.D./ 811 A.H. Following devastation of this dam and the others, people of the northern delta moved around the lands near the Biaban river and settled there.[11] Afterward Malak. Ghotb-ed-Din could escape from his captivity place in Samarghand to Sistan. After domination for supporting water needs of the northern delta made Fath castle and two diversionary dams. This situation has been continued till again return of Hirmand water against the northern delta in 1692 A.D./ 1104 A.H.

8) NEW AGES (1700 A.D. TO PRESENT TIME):

This age has been originated from the first 18 century (A.D.) with regression Hirmand water toward the northern delta style. Upon this reaction, the Biaban river passed into a canal with limited volume and Malak- Bahram – Khan canal dried along this river and finally the southern delta, after Sistan political division between Iran and Afghanistan supposed to be dehydrated forever. The transition of the Hirmand passage into the northern delta during 1692 to 1722 (A.D.) in Malak Fath- Ali Khan reign conincided with a wide torrent which swept Boulba- Khan dam and the whole bulwarks and embankments.[12]

It is mentioned to some well – Known dams of Hirmand which had been built on vein and next to some noses as followed:

1. Kooshk, Gholaman

This dam has been located on 6.5 kms superior of Khabgah village and 3 kms superior of Kooshk ruins against Gavak castle. The building was accredited to Pishdadiyan dynasty and some sites of the Pre- History have had in it which Gireshman has written its inveteracy till 3 thousand years before the nativity and had been coeval with Burnt City period.[13] But after turning the main flow of the Hirmand to the northern delta and fallen lands belong to Burnt City and Biaban river delta, occupancy and farmlands near Nad-Ali have developed and has been built a more permanent irrigation system. In north desolations of Haftarkand persists 4 old channel effects with one stream which is extended to the west called Gholaman river and the dam "Gholaman dam". "Key" city (instead of Nad- Ali), the capital of Sistan was survivor in Achaemenidian Era but according to Golshan Zarnegar the capital transfered to Zarin and to Dahaneh-Gholaman according to Ketzias.

After Dahaneh- Gholaman the capital transfered into Ram- Shahrestan or Abar-Shahriyar and again Nad- Ali or key construction as "Zaranj" became the capital of Sistan.

2. Anoushiravan, Yakab

This dam has been built on Hirmand and entrance Sistan against Miski nose on a vein of alluvium next to the ruins of ancient cemetery and hilly which located a little castle named Dak- Deileh (Deileh castle) that protects spillover or dam.

This place rests on 19 Kms far from the north of Kamal- Khan port.[14] Fath castle, the last capital of Sistan's kings before ceased domination is at 13 kms of the north of Dak-Deileh. Zarkan and Zourkan channels which were made in the Sassanid era have been separated like a individual channel from the right corner of this dam.[15] They had drained a stream from the west part of this dam which should be the same large river of Sabouri-Shah city or the east Shilleh of the next Zahedan. The passage of current river Niatak in the underneath of connected to Maleki river is the proceeding passage of the east Shilleh.

In ancient writings among Ehya-ol-Molouk has been mentioned Yakab dam supposed the same Noushiravan dam.[16] This dam has been provided Fath castle water and the east regions.[17]

Notwithstanding the Anoushiravan dam (later Yakab dam) had standed till the last 11 century (A.D) that the Hirmand river changed the passage into the southern delta and the dam became worthless. After that the irrigated dams to the northern delta have been transfered into Kamal- Khan port superior.

3. Rostam (Targhou dam) Havanak

The Rostam dam is the famous dam on the Hirmand river on the upper of Noushiravan dam where depends on the southern delta water flow (Biaban river) and the northern delta.

Most of the Iranian and Arabs geography writers scince Estakhri and some European geographers and archaeologists in 19,20 centuries (A.D.) have called each old dam as Rostam dam which is not correct while the Rostam dam or Targhou has been a special dam in a particular place. The Rostam dam has been built or reconstructed by one of the Kiyanid kings after the Hirmand direction change and flowing into the Biaban river passage. It was located at 6.5 to 8 kms superior of Kamal- Khan port against Rouding tower. The accumulated water behind the dam has been produced a lake where continued to the east part of the dam in Chahar- Borjak village. The water needs of the northern delta has been provided by this lake and flowed into the north in a crossing by an old channel.

A Kermanian engineer who has compiled the first map of Sistan of Iran in 1251 (solar calendar) has written:

"The dam sign is two Farsakh up to Kamal- Khan port which called Targhou. The stream which has been slaked by dam courses from north to the west just toward the north with 14 farsakh distance. All dams were made by bricks and lime.

If this dam is closed there wouldn't be any water in down."[18]

So, the Targhou dam is the same which Sir Persi Scicks mentions: Before Taymour Gourkan they had built a dam on the Hirmand river in the southwest of Roudbar. This dam hasn't any space to the current Kamal- Khan port. Taymour conquered Sistan for the second time in 785 (A.H.) and ruined the fame Rostam dam or Aghvan or Afghan.[19] The Rostam dam was made from baked bricks, lime and mortar. There were been placed great clayier pipes on the upper part which led flood into the west.

The Rostam dam has been repaired after demolition and called as "Havanak" means the dam which was made from stone and lime in Garshasb period and Sistan's survival depended on it. Shahrokh Taymouri destroyed Havanak, Yakab and Boulbaka dams in order to cut water flow into the northern delta.

4. Boulbaka

Also Boulbaka dam or Boulba- Khan has been built in Malak Ghotb-ed-Din times on the river spread in the beneath of Mashi nose.

This dam not only has been provided Fath castle water needs but also further regions to Nishak lands by separated channels.

In 3 kms the north of Fath castle, entrance Sistan there is a watershed where the water which was parted from the Hirmand river was distributed into the Boulba- Khan dam place. Thus a wide stream has circulated in the old passage of Zarkan which was ended to Ziarat- Omran or near it. The neighboring lands and surroundings regions were irrigated by this stream.

Kermani who had been traveled to Sistan in 1872 A.D. has written: "There are some traces of dam against Mashi nose and Madar- Shah citadel that have made with brick and lime where has been extended a stream from two sides of it."[20]

In 1021 (solar calendar), and Indian soldiers line who had advanced in the Helmand valley ruined the Boulbaka dam, Surrounded the Fath castle sometime and destroyed perimeter regions. So the water flow ceased from entrance or division part of Sistan into the northern delta and the whole river water streamed to the southern zones.[21]

5. Kazak

The Kazak dam had been made on Basht- Roud near Karkouyeh. The word "Kazak" is written by Estakhri[22] for the first time. From Estakhri explanation derives that Kazak channel has watered Karkouyeh region. This was the same channel where has Zaranj-Harat way with a long bridge between Karkouyeh and Basher means new Pishavaran. Moghaddasi has written: "Kazak dam was irrigating through karkouy of Zaranj".

Moghaddasi aim was one of the five gates of Sharestan of Zaranj which has been led to the north and Khorasan. In a house Zaranj of Ta'am river has been separated from Hirmand and was watering the whole villages to Nishak then another stream yclept Basht- Roud which was extended to Kazak has been flowed where they had built a dam in order to keeping water doesn't penetrate into lake.[23]

6. Roudbar (Saroutar)

This dam under Pelalak and Landi has been built by brick and lime reputed as Roudbar or Saroutar dam. Roudbar is a name of a region nowadays where had been concluded from two little towers with 800 ms distance. This dam is older than Boulbaka dam although haven't any distance and the separated left channels of them as" Garshasb Jouy" have joint passage from Mashi nose.[24] Frih says: After Dishou pass Helmand river near Roudbar village in labyrinthine survivor trees there was traces of a dam which its pier located inside water and had been made from bricks in a square yard.

Ravlinsoun has written: in the old- times a grand channel as Garshasb-Jouy has separated about Roudbar from Helmand superior. Accomplished works for river dam and turning this channel to the left had been so great and surprising according Mr. Frih reports.[25]

The vestige of brick walls dam has been found but the bricks dam have been used in residential buildings. Also Poulak- Bilo group hasn't seen any channel at the right side of the river in this section.[26] Albeit Kermani writes: There is a sign of a dam over Karbask tower which 22 Farsakh has been extended the river, this dam is called "Saroutar".[27]

7. Baba- Khan (Abol- Fath- Khan)

This dam has standed at 12 kms of Chahar- Borjak superior, against Hossein- Abad and Eshkinag. From the north of the river have been extended a stream which its traces remained and has been held about 60 kms. This stream has reached water into Fath castle and around lands.

Supposed Nouh- Kalan (1885 A.D) awful torrent overturned Fath castle where only the over part of the castle is out of water. Tomas Holdich has seen the torrent effects in fath castle region in 1885 A.D where on the plain coast and tower with 5 meters height.[28] Evidently Baba- Khan dam has been built coincident Fath castle choice for caliphate. The date of Fath castle and Baba- Khan dam constitution had been about 1397 A.D./800 A.H rather 1422 A.D.[29]

8. Kohak (Sistan dam)

Instead of current Kohak dam has been another one (not the same name) which has been separated Milli river or Mileh river. The Mileh river was irrigating a zone where contains about Ghasem- Abad mill, Bonjar to Kachian now.

The Kohak dam likely is known today, for the first time about the foremost yeas of 1820 A.D. decade erected on the northern passage (Nad- Ali channel). Warlord Taj-Mohammad- Khan Sar- Bandy made more firm this dam in order to origination Taj-Mohammad- Khan river is 1855 A.D/1234 (solar calendar). The Kohak dam structure has been firm again in 1250 solar calendar. But in 1839 A.D. the river moved its passage about khajeh- Ahmad to a new path toward Dak- Tir and Eshkin swamp which was named Alamdar river and the western Sistan dehydrated. After formation insuccessful dam, finally shaped a dam which was joining the new path of Hirmand into the previous passage while was going toward Sekouheh with a pond named "Madar-Ab".

With Madar- Ab, two branches of joint Parian and large canal (Sistan river) hold gradually where was separated from Kohak.

9. Gazi dams

The Gazi dam of Sistan (Kohak dam) was made on Hirmand beneath part of separation of the main Channel or Sistan river on the Hirmand. Later because of Sistan river water addition specially after the new track "Nohrab" birth, the Sistan river attraction multiplied thus people had to build two Gazi dams, one on the Hirmand river another one on Sistan river. Each of dams were building on the beneath of Kohak on two rivers. Annually they were building both the Gazi dams till 1317 solar calendar, thereafter hasn't made any dam for two years because the depth of the two rivers was suitable and naturally was dividing water between them. After 1319 solar calendar Sistan river became more deep as a little water was flowing into joint parian (borderline Hirmand). "…were building river (joint Parian channel) in it …".

Under this situation they had to dam only on the Sistan river in order to rising water surface and entered to the borderline Hirmand. So in 1320 solar calendar decade the Gazi dam was made just on the Sistan river lower than Kohak to lead water into joint Parian.[30] After 1326 solar calendar was used Gazi dam for watering new canal Azar[31] in order to irrigation Miankangi part because the inner parian[32] has been filled with sandstorms partly which water couldn't enter inner Parian from joint river except torrental time just strong torrents. Finally about 1331 solar calendar has made a concreted valvular[33] dam in the same place of provisional Gazi dams on Sistan river which is now famed to Kohak dam and in lower have build another one as "Zahak" dam.[34] While the Azar river was active (till 1340 solar calendar), this dam was called Miankangi because the water needs of Miankangi region was provided by Azar canal.

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A[VG1][VG2][H3] GLANCE AT HISTORICAL QANATS IN IRAN WITH AN EMPHASIS ON VAZVAN QANAT IN ISFAHAN

Ghorbani B[1].[H1]

ABSTRACT

Qanat is a way of conveyance of underground water to ground surface for irrigation and drinking. This is a technology born and developed in Iran and extended to other countries in the East and the West over the time. The total number of Iranian Qanats is 18000 and their total discharge is about 7.4 billions cubic meters. Among the Iranian Qanats some of them are specific from the point of view of mother well depth, length, rate of flow, oldness and attractiveness. Keikhosrow Qanat in Gonabad (Khorasan Province) has the deepest mother well, that is 400 meters. One of the Yazd Qanats has the largest tunnel that is 116 kilometers. The most flow rate Qanat is Payekam Qanat in Bam suburb which is 312 lit/s. From innovation and talent point of view, there are few historical Qanats in Isfahan such as Moon Qanat in Ardestan in which the tunnel has two parallel floors and Vazvan Qanat in which flowing water is collected beyond an underground dam for a period for irrigation purposes over the following year. There are a large number of benefits resulted from Qnanats, and few disadvantages as well, but the benefits are more. If the idle Qanats are repaired and renewed, then the rate of available water will be 1.7 billions lit/s, i.e. 4 times of Karroon River in Iran or ¾ of Nile River in Egypt. But from author's point of view, this is not possible, because of shortage of rainfall and falling water level tables which had been happened due to huge number of dug wells.

1. INTRODUCTION

"Qanat digging technique is an important ancient innovation in Iran. Recognition of its social, technical, operational, managerial and cultural dimensions is vital in understanding of the system" (Semsar et al, 2006). Qanat is a way of conveyance of underground water to ground surface for irrigation, drinking and other purposes in Persia since ancient time (Tolman, 1937). Qanat was a technology born and developed in Iran and its innovation backs to 800 years B.C. According to Goblot (1973), evolution of this art can be found just in Iranian culture and its most attractiveness could be found in Gonabad (Iran), not in elsewhere in the world. Later on, this human art had been extended to more than 34 countries in the East and the West over the time (Behnia,

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1988). Due to this great innovation many investigators and writers called Iranian civilization as a Qanat or a hydraulic civilization. The oldest Qanat which was discovered in the North of Iran had been excavated for 3000 years, i.e. as old as Aryans arrived in Persia (Behnia, 1988).

Qanat conveys water to ground surface without utilizing any electrical or mechanical power. According to Petroschifescy (1976), some times not far away there were 18400 lines of Qanat running in Iran. The sum of water rates from this huge number of Qanats was enough for irrigation of 1.5 millions hectares lands.

There are many different definitions about Qanat. For example, Goblot (1973) who refers to 534 references about Qanats in his book defines: "Qanat is a way of exploitation of underground water by using a drained corridor". One of the most general and complete one is as follows: A number of wells and one or more tunnel, with a slope less than ground surface slope that collect and convey underground water that is available in sub-surface layers of high level regions of lands, rivers, ponds and lakes, under gravity force without consuming additional electrical or mechanical energy to low level points, is called Qanat (Behnia, 1988). Indeed, Qanat is an underground drained gallery that collects drained water and conveys to ground surface for irrigation and drinking (Jahad Sazandgi, 1981 and Agricultural Committee of Jahad Sazandgi of Isfahan, 1982). There are more than 27 names in Persian, Arabic and other languages for this hydraulic structure, but the famous names are Qanat, Canat and Kariz. (Razavian, 1979).

2. ESPECIAL QANATS

There are different figures stand for the number, length and discharge of Qanats in literature. The total number of Iranian Qanats range from 4000 to 50000 and the total length recorded from 160 to 350 thousands kilometers and the total recorded discharges changes from 238000 to 1000000 lit/s. However, among these the most reliable and newest figures are the figures issued by Office of Water Resources Researches of Iran Ministry of Power. The figures of Qanat number and discharge are 18388 and 7.359 billions cubic meters respectively (Programming and Management Organization, 1981). But it is not clear that this number does or does not involve all commission and deserted Qanats. Among the Iranian Qanats some of them are specific from viewpoint of mother well, length, rate of flow, oldness and attractiveness. Among the working Qanats, the Keikhosrow Qanat in Gonabad (Khorasan Province) has the deepest mother well, that is 400 meters. This one backs to 13th century B.C (Goblot, 1973). One of the Yazd Qanats has the largest tunnel that is 116 kilometers. The most flow rate Qanat is Payekam Qanat in Bam suburb which is 312 lit/s (Kerman Regional Water Company, 1984). From innovation and talent point of view, there are few Qanats in Isfahan such as Moon Qanat in Ardestan in which the tunnel has two parallel floors, that is one is above the other. This one depicts the curiosity, talent and accuracy of Iranian hydrologist, master well diggers in the history (Figure 1).

Obviously, the length of Qanat depends on the climate conditions. This means the more rainfall of a region is, the length of Qanat will be less and the depth of mother well will be shallower and vise versa. The reason is the availability of water level at upper horizon in humid region.

The excavated Qanats in deserts have the deepest well and longest tunnel compare to humid and semi humid regions. In these regions the pervious layer are so thick and Impervious layers might be more than one hundred meters below the ground surface. Some times, the depth of Qanat well reaches to 400 m, especially in central, southern and southern east regions of country.

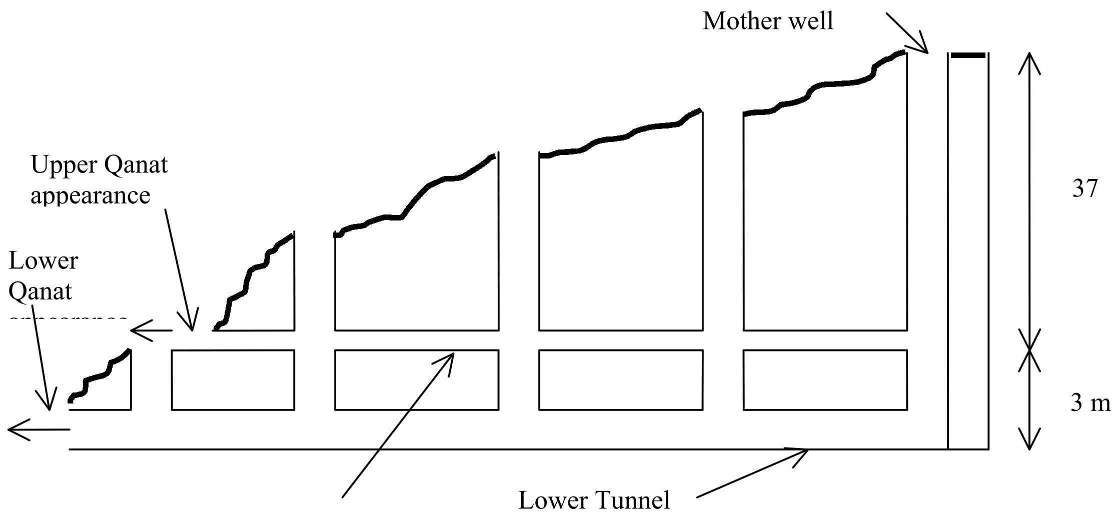

Figure1. Longitudinal section of Moon Qanat in Ardestan, Isfahan Province

Some times calcium and magnesium bicarbonates and / or calcium solphates deposit in Qanat bed. The materials that deposit in Qanat bed are called Zangabeh. The composition of Zangabeh is mostly bicarbonate which is solute in water. Of course, these materials deposit on Qanat bed where the tunnel converges to ground surface and water temperature rises. These materials, some times, block the water way that should be removed every year.

Compare to deep wells and electric pump, Qanat has several advantages such as:

1- Its beneficial life time is more
2- Its flow rate duration and yield is safer
3- It does not consume any electrical or fossil energy. It just runs by gravity force.
4- No need to access road for transportation,
5- It does guarantee the safety yield of ground water. In other words, wells spend capital, but the Qanats consume its obtained benefit.
6- No need for skilled workers and guard,
7- The cost of maintenance is low,
8- It is a good pattern of cooperation system and has a positive role in developing this system.

9- It is an effective drainage method locally and regionally and prevents rising underground water surface.

10- It is simple to be dug by domestic workers with simple tools,

11- It prepares job for people,

12- It does not necessary to spend dollars,

According to Goblot (1973), if the idle Qanats are repaired and renewed, then the rate of available water will be 1.7 billions lit/s, i.e. 4 times of Karroon River in Iran or ¾ of Nile River in Egypt. But from author's point of view, this is not possible, because of shortage of rainfall and falling water level tables which had been happened due to huge number of dug wells.

In spite of large number of benefits come from Qnanats, there are also few disadvantages as follows:

1- Technology of digging Qanat is not still modern. So, it will take a long time to excavate one with traditional tools,

2- Qanat excavation is a hard low income job. Unfortunately, no replacement had been performed for many practitioners and skilled diggers who have changed their jobs or died so far.

3- Rise of salaries for worker and high cost of construction materials disable the farmers to maintain and dreg the Qanat galleries,

4- It is not easy to save or control water flow during the non agricultural season, so a large amount of water is lost,

5- Natural disasters such as floods, earthquakes and enemy vandalisms are big problems for security of Qanats,

6- The eventuality of water contamination is high, especially when Qanat passes through cities or villages,

7- Penetration causes a large amount of water to be lost in dry section (this section is called Khoske Kar),

8- Risk of life for Qanat diggers who dig one, but it seams still to be less than for mines worker,

3. VAZVAN QANAT

Among the historical qanats in Iran, Vazvan Qanat is a great Iranian innovation and talent in the past. This is because of construction of underground dam to store water. Regarding the Qanat disadvantages written in previous section, few of the them have been solved and some had not been yet. For example, water saving had been carried out during the non agricultural season by constructing an underground dam in Vazvan Qanat in Isfahan suburb.. Some of the properties of this Qanat are depicted in Table 1.

Vazvan Qanat dated to 3000 years ago, as reported by people. In this Qanat flowing water is collected beyond an underground dam for the period of Nov 20th to Apr. 20th every year. This dam is a thick wall made in a well that is 600 meters far from the mother well. Diameter of this well is three meters longer than other wells. This well is located on the intersection of wet (Tar-e-kar) and dry (Khosk-e-kar) sections of Qanat. The height of dam is as tall as the well depth, its width is as long as the well diameter and its thickness is 1 m. Seven orifices with 30 cm diameter are located every one meter started from the ceiling of tunnel upward (see Figure 2). The Qanat tunnel passes through the lower end of dam and the seventh orifice is seven meters above the tunnel crest. Figures 3 and 4 are illustrative of this hydraulic structure.

The main path way and all orifices are blocked from Nov. 20th to Apr. 20th every year. It was observed that the water level raises beyond the dam some where above the highest orifice every year. Later on, in Apr. 20th, the first highest orifice is reopened and let the first part of stored water depleted for irrigation. Each orifice is reopened every ten days and eventually all stored water will be depleted Finally, the main tunnel orifice is reopened on Jun 20th. This date is very important from wheat growth point of view. because this date fells on the irrigated wheat crop blooming stage on which a full irrigation is needed.

Table 1. Some of properties of Vazvan Qanat

Factors	**Amounts**
Length (m)	1800
Number of wells	72
Distance of wells (m)	25
Location of underground dam	Well number 40 from appearance of Qanat
Irrigated area (hec)	300
Discharge (l/s)	300
Height of tunnel ceiling (m)	7
Height of mother well	12.5

(A) (B)

Figure 2. Illustrative of orifices on underground dam (A) and tunnel (B) of Vazvan Qanat

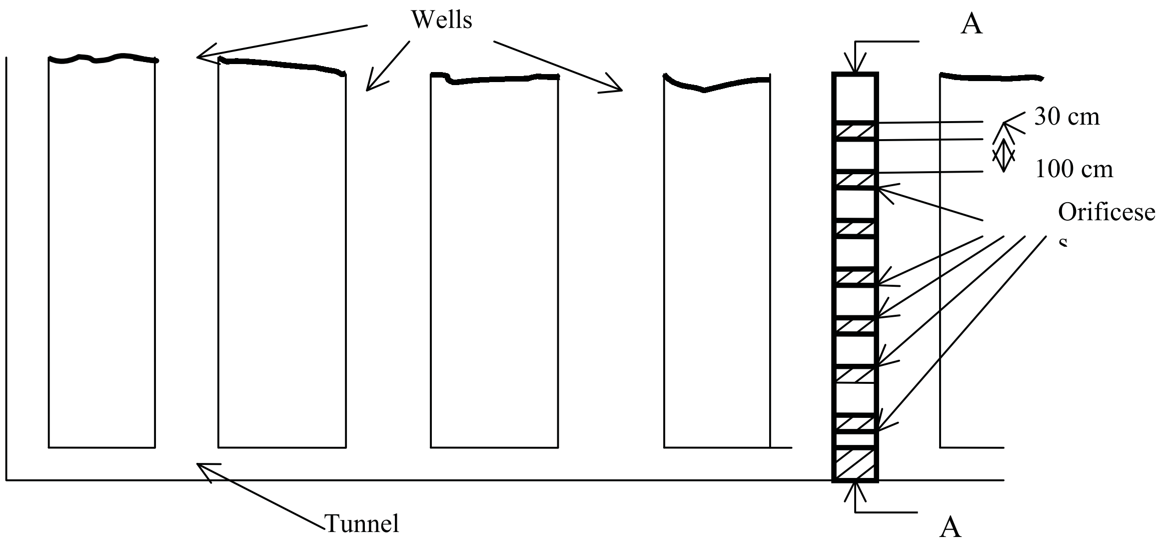

Figure 3. Structure of under ground dam built in Vazvan Qanat, Isfahan

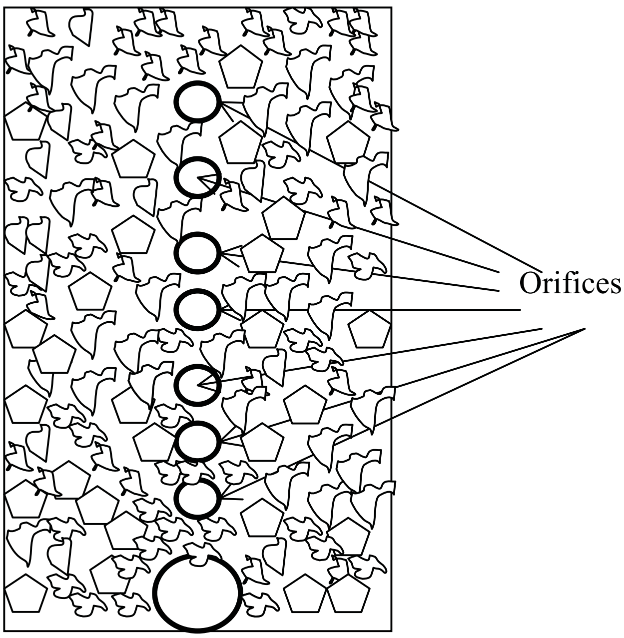

Figure 4. Section A-A as depicted in Figure 2

In this date the dam discharge is quite enough to supply this amount of water for wheat irrigation (Behnia, 1988).

Vazvan Qanat is still working, but, some parts have collapsed due to many reasons over time. These parts are repairing as shown in a video film report by Jahad-e-Keshavarzi of Borkhar and Mimeh, Isfahan (2006). They are constructing a second ceiling on the tunnel and put new covers on shafts to protect gallery from unpredicted risks (see Figure 5).

Figure 5 Second ceiling of Vazvan Qanat under construction

4. CONCLUSIONS

The following results are derived from this study:

1- The Qanat technology was invented and developed in Iran and extended to other countries in the East and the West passing of time.

2- There are still a large number of Qanats still working. Among these some are specific from point of view of mother well, length, rate of flow, oldness and attractiveness. Keikhosrow Qanat in Gonabad has the deepest mother well, one of the Yazd Qanats has the largest tunnel length and the most flow rate Qanat is Payekam Qanat in Bam. From innovation and talent point of view, Moon Qanat in Ardestan has a tunnel with two parallel floors and Vazvan Qanat has an underground dam to store water in non agricultural seasons.

3- Although the advantages of Qanat are numerous but renewing the idle Qanats for over seams to be a dream. This is due to sharply falling water level table takes place every year and every where due to rainfall scarcity and huge number of dug wells.

ACKNOWLEGEMENT

I would like to acknowledge Jahad-e-Keshavarzi of Borkhar and Mimeh, Isfahan that prepared a video film from Vazvan Qanat and also appreciate Mr. Samad Ghorbani who prepared the documents for this study.

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IRRIGATION TANKS AND THEIR TRADITIONAL LOCAL MANAGEMENT: A REMARKABLE ANCIENT HISTORY OF INDIA

Conjeevaram Ramalinga Shanmugham[1] and Arumugam Gurunathan[2]

ABSTRACT

India, a South Asian tropical country, has historical evidences of its human interventions in the management of water for agriculture from village water bodies. One such intervention is an irrigation tank. A tank is a simple rainwater harvesting structure designed by early settlers using indigenous wisdom and constructed with the generous support of native rulers and chieftains. There exist 500,000 irrigation tanks in the country, of which 150,000 tanks are located in the semi arid region of Deccan plateau. They are located in hydrologically favourable sites, some of them in sequential chains or cascades, effectively capturing the rainfall and serving multiple uses with irrigation having the major share. Tank irrigation systems are simple but fragile structures. They have to be constantly maintained, monitored and conserved. Even more difficult is sharing the scarce water amongst its consumers, particularly farmers. And yet, people across the country have devised a variety of mechanisms to share the water and maintain their tanks. One such mechanism is a community effort, locally known as "kudimaramath" by which the tank is periodically maintained. In a few tanks, the farmers have formed informal organizations on their own, and undertaken water distribution. But the tanks which are in multiuse are presently under the 'ownership' purview of State governments. Their management functions also come under the different line departments with neither integral approach nor common purpose. This has resulted in the steady decline of the performance efficiency and degradation of these precious small scale water bodies. DHAN Foundation has therefore chosen to intervene and restore these multipurpose tank systems to their designed standard and revive their local management by the users through community initiatives. This paper presents the efforts taken and the results obtained to benefit the poor whose very livelihood depends on these water bodies.

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INTRODUCTION

India, a South Asian democratic country, has many historical evidences on irrigation structures, systems and management, almost from 8th century A.D onwards. They captured India's long history of human interventions in the management of village water bodies for agriculture. One such intervention, is an irrigation tank. A tank is a simple earthen banked rainwater harvesting and storage structure, designed by the early settlers using their indigenous wisdom and constructed with the generous support of native rulers and chieftains

over the past several centuries. Surprisingly these earthen structures have withstood the test of time and survived over many centuries. They are simple technological innovations developed by those people to accommodate their primary needs and adapted to the distinctive Indian climate – intense monsoons followed by protracted droughts. A few of the quotes narrated below explain the importance of these precious village water bodies, namely, minor irrigation tanks.

Sir Arthur Cotton, a well known British Engineer who worked in India at the time of Colonial imperialism exclaimed on seeing the constructed tanks:

"The natives have constructed tens of thousands of tanks in almost every kind of soil with earthen bund without the puddle bank, which English Engineers fancied necessary".

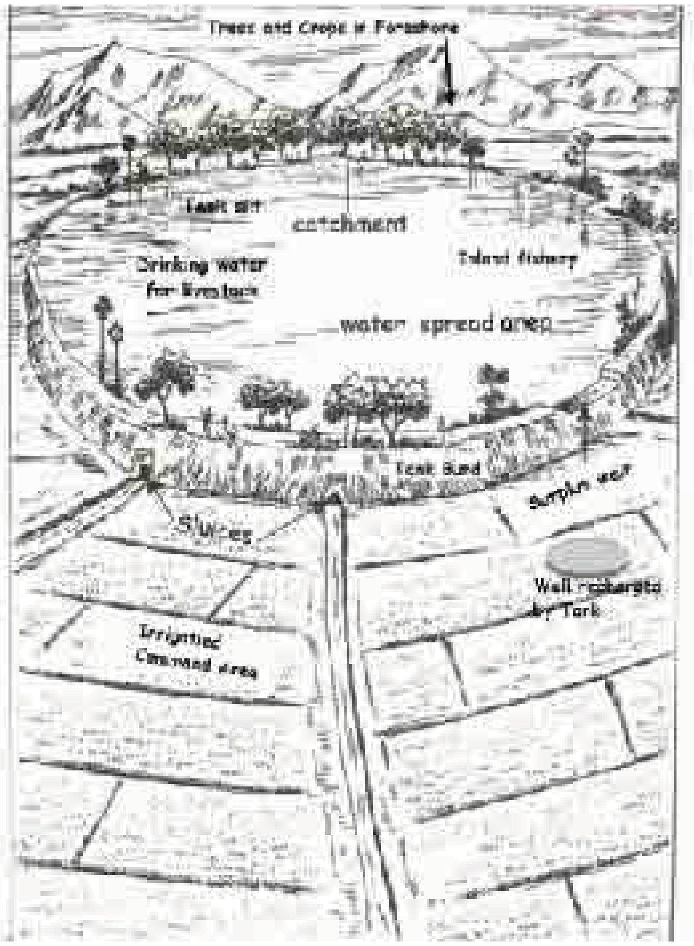
From one of the ancient verses from *Tamil Purananuru,* it could be inferred that the early settlers gave importance to form tanks in the lands wherever depressions were found, so that much of the rainwater could be harvested and stored. The topography of Deccan Plateau provided a good base for locating these innovative water bodies.

TANKS AND THEIR IMPORTANCE IN INDIAN IRRIGATION HISTORY

Village tanks have been one of the most important water resources on which the rural communities depend for their livelihood. A tank is a village water resource formed by constructing an earthen bund (a man made embankment) across a shallow valley to impound the rainwater runoff from its catchment area. The stored water is utilized by gravity flow to the lands situated below, primarily for irrigation purpose. As small scale irrigation systems, the tanks are easily adaptable to the system of decentralized village administration that prevailed during the mediaeval period and thereafter. The precise shape and size of each tank seem to have been determined by the terrain along with the native wisdom of local villagers. There are quite a few eminent quotes available in the literature praising the contribution of tanks in the development areas. One such quote is presented below:

John Ambler (1994) aptly describes the usefulness of tank systems as follows:

"Tanks need to be thought of in terms of a wide complex of natural resources, physical facilities, land use patterns and managerial institutions. The tank is not simply an irrigation system that starts from the reservoir down. It is also a collection point for run-off from the catchment area, pond for pisciculture, source of silt for fertilization and construction material, a recharge structure for local groundwater, a location for cultivation on common lands, a source of drinking water for livestock, and finally, an irrigation system for crops. To help keep in mind this multiplicity of uses which spans the administrative ambit of several government departments, it is useful to think of tank complexes rather than tanks, which too often connote only the direct surface irrigation aspects of these systems."



Even in the 21st century, the tanks, not only in Indian context, but also in South Asian context have very high relevance in practicing Integrated Water Resources Management (IWRM). As per minor irrigation census (1994), there exist 500,000 irrigation tanks in the Country; of which 150,000 tanks are located in the Deccan Plateau covered by South Indian States. These irrigation tanks are situated in sequential chains (cascades) with the slope mildly dipping towards the Southern coastal plains. As a result, the rainfall runoff flowing from a sub basin and / or watershed is effectively impounded and harnessed for multiple uses with irrigation being the major user.

TANKS AND THEIR FUNCTIONS:

The tank system has four different functions in irrigated agriculture: soil and water conservation, flood control, drought mitigation and protection of environment of surrounding area. Likewise, development of tank irrigation has to undergo the four phases, namely, water acquisition or harvesting, storage, disposal of surplus water, distribution and management of water in the command area by an institution. The tank complex comprises the catchment area, the feeder channel, tank bund, water spread area, sluice outlets, command area, field distributaries (water courses) and surplus weir.

While the South and East Indian tanks are known for their antiquity and are created essentially as a source for providing supplementary irrigation during monsoon season, innumerable small water holding structures called ponds have been in existence in many North Indian states and some were constructed even after Independence for multiple uses including irrigated agriculture. Although many of these ponds are primarily meant for inland fresh water aquaculture, they have also been used for multiple purposes like irrigated agriculture, livestock and other domestic uses. Tank irrigation has thus a rich heritage on account of long historical antecedents in various regions of India. Over centuries, tanks and ponds constituted an important supplementary source of water to the distressed poor.

TANKS AND SOCIETAL NEEDS:

Tank is a centre of socio economic activities of a village catering to the multifarious needs of the village community. The tank is not simply an irrigation system appended to big reservoirs. It has multiple uses and serves diverse needs of people, animals and plants. Apart from the above, the tanks contribute to the recharge of ground water, microclimate and the environment to keep the surrounding area green and cool. This environment attracts the migratory birds from far and near.

The advantage of tank irrigation is its proximity to the command area, so that the water requirement of the crop can be assessed and supplied from the tank, which is the core issue of water management. Most of the small tanks serve one single village and its hamlets, enabling the de-centralized management to be effective.

IRRIGATION RIGHTS FROM TANKS:

RECORDED *MAMULNAMA* IN VELLORE DISTRICT, TAMIL NADU

In the early years, irrigation rights in tanks were largely governed by custom and local practices. Yet they were not in a proper recorded form. It is quite interesting to observe the recorded irrigation rights of pattadars of 188 tanks of Vellore taluk in 1815 A.D. under the heading "Water *Mamulnamas*". These were printed by the British in the year 1907. The *Mamulnamas* have been written in Tamil and signed or attested with thumb impression by the "Karnam" (Accountant of Village land records) and important farmers of the village. (Source: An English version of the *Mamulnama* extracted from G.O.No.660 I; dated 8th February 1918 and cited by Sivasubramanian K., 1995). It is astonishing to note how meticulously the *Mamulnamas* have been written, recording the period in which the tanks got water supply, the quantity of water available in particular months, the area that could be irrigated, when the tanks got full supply and the distress period, the mode of irrigation, the permissible number of wells that could be sunk in the *ayacut*, (command area of tank) the crops that could be cultivated in the area etc.

Even though the irrigation rights and practices were not recorded in all the tanks, they were meticulously observed by the ryots and the community from time immemorial. However, some customary rights could be ascertained from the "A" register maintained by the revenue department and the old settlement records. These customary rights along with *Kudimaramath* systems (described below) were followed with high dedication and vigil by the ryots and villagers during the 15th century A.D. and even under East India company rule for some time. But after the introduction of Ryotwari settlements by the middle of 19th century, the effectiveness of the traditional system deteriorated progressively, with the result the tanks were not maintained properly in the country.

LOCAL MANAGEMENT OF TANKS IN PRE COLONIAL PERIOD:

The feeder channels to the tank and water distribution channels from the sluice outlets were desilted and restructured by community effort, locally known as "*kudimaramath".* In a few tanks, the farmers had formed informal organisations on their own, with specific roles and responsibilities allocated to each member through consensus, so that water distribution could be equitable and the tank maintenance be effective. Before the advent of British rule, ownership of water bodies and land was with the community and village assemblies. The powers and functions the village assemblies possessed over irrigation, especially from the tanks include:

- Ownership of water resources
- Construction, repairs and maintenance of water bodies
- Transactions related to irrigated lands
- Management of water distribution
- Dispute settlement
- Relationship with government agencies on certain matters

(Source: Annual report of Epigraphy 1934-35 and Pudukottai inscriptions)

The ancient donors did not stop their work after creating tanks. They also provided grants and tax remissions to those maintaining the tank to ensure their good repair. The striking feature is the care which they took to maintain all these structures for sustained irrigation. They had a very elaborate system of management including repairs, maintenance and improvements. The tanks, channels and sluices, especially those which were not wholly built of stones, bricks and mortar, required great care in order to maintain them in good condition. Frequent removal of silt was considered to be the most essential aspect of the maintenance of tank complexes. The breaches in tank bunds and supply channels due to excessive rainfall and floods had to be repaired promptly. But, the wanton damage done to irrigation works was certainly not known in those days. Many South Indian inscriptions contain description and references to the damages caused to irrigation works on account of heavy rains and floods, the action taken by *Urar* and *Sabas* for the upkeep of the tank complexes and also the endowment created for the maintenance and repair works by individuals. The village assemblies managed the water from the tanks systematically, ensuring equitable water distribution to all the needy villagers. They also maintained the physical structures of the tank in good condition.

WATER SHARING AND MANAGEMENT OF TANK SYSTEMS

Tank irrigation systems are simple but fragile structures. They have to be continuously maintained, promptly repaired and constantly monitored. Even more difficult is sharing the scarce water amongst its consumers, particularly the farmers. And yet, people across the country have devised a variety of property right mechanisms to share water and to maintain their tanks. To ensure equity in the distribution of tank water, villagers in some tank commands elect one among them or appoint a landless person as a water guide and/or water manager, locally known as *"Neerkatti"*. The *Neerkatti* ensures that each farmer receives tank water in proportion to the area of land he owns. Therefore conflicts over the use of water are rare. When the *Neerkatti* is elected from among the local farming households, the position of *Neerkatti* rotates among all households on a turn basis to ensure that no household monopolises this critical post. The broad functions carried out by the *Neerkatti* are:

- Watch and ward of tank assets and preventing wastage of water
- Water management functions (includes normal water supply and scarcity water management
- Mobilise village labour for periodical tank maintenance and at times of flood damage to tank structures

Neerkatti is paid remuneration as a share of the crop produced, with a fixed quantum of grains per land holder, and allocation of some common land for cultivation. His appointment and fixation of norms and functions are managed by informal village assemblies.

THE EAST INDIA COMPANY AND BRITISH RULE

When the British East India Company annexed Indian territories, the tank irrigation systems also became the company's property. But the British administration did little to rejuvenate the sustainable management of tanks. They spent little on tank rehabilitation and maintenance.

Presently in India, the tanks which are in multiuse and multiple user system come under the 'ownership' purview of 'State government departments'. Their management functions also come under the different line departments with neither integral approach nor common purpose, which led to the decline of such irrigation marvels.

TANK PROGRAMME OF DHAN FOUNDATION

Even though the tanks form the backbone for the survival of human beings and provide support for agriculture in several parts of peninsular India, it is appalling to note that there has not been much importance given by the formal disciplines and professions. DHAN Foundation has therefore chosen to intervene to restore these multipurpose tanks to their designed standard and performance efficiency, by mobilizing the users, organizing them into associations and undertaking the restoration work through them, thereby reviving the traditional local management.

The program has a number of components that are necessary to ensure that the interventions are sustainable in the long term. The measures that are proposed in rehabilitation of tanks comprise improvements not only to the physical works but also the software aspects like operation, maintenance and management of water resources. They comprise the following:

PRIORITIZATION OF TANKS FOR REHABILITATION

The tank irrigation systems taken up for rehabilitation are spread over the four states of Tamilnadu, Andhra Pradesh, Karnataka and Pondicherry. The tanks are selected based on the scope for working with the marginal communities in tankfed agriculture. The villages and tanks are identified in such a way that cascades of tanks are selected and all the tanks in each cascade are improved in a phased manner based on the following criteria:

- Willingness farmers to contribute a part of the project cost through labour and/ or cash; while the landless will contribute labour.
- Willingness of the community to execute the works themselves without involving contractors and maintain and manage the system thereafter.
- Participation of both women and men in planning and implementation of the program.

TANK INSTITUTIONS AND THEIR ROLES

DHAN Foundation facilitated a three tier system of community participation.

(i) Tank Farmers Associations (TFAs)

- Enrolling the farmers having land and the other interested groups in the village under the command area, as members.
- Planning and implementing development works like tank rehabilitation, community well construction and on-farm development.
- Undertaking activities such as pisciculture, tree planting and brick making as a measure of generating revenue for the tank associations.
- Maintenance of tank systems and their management including water distribution.
- Building up a corpus or endowment for the tanks for maintaining and managing the tanks through the revenue.

(ii) Tank Cascade Associations (TCAs)

- Formed with the Tank Farmers Associations as members across the cascade.
- Undertaking the development works such as cleaning and excavation of feeder channels and repairs to diversion weirs/ regulators on feeder channels.
- Resolving conflicts among the Tank Farmers' Associations in water sharing and maintenance.
- Mobilising funds across villages for the betterment of the tank irrigation systems.
- Providing improved services on agriculture and water management.

(iii) Tank Farmers Federations (TFFs)

- Formed with the Tank Farmers Associations as members.
- Organising the tank farmers federation in the administrative district or block level.
- Mobilising funds for the rehabilitation of tanks from various sources including the District, State and Central government administrations.
- Organising training programs on tank related aspects for the TFAs, TCAs.
- Monitoring the operation & maintenance of rehabilitated tank systems and the performance of TFAs and TCAs.

DHAN perceives that these arrangements empoweer the organisations to conserve and maintain tank irrigation systems during the years to come in a sustained manner.

TANK REHABILITATION

Tank rehabilitation includes not only restoring the physical structures to their originally designed standard, but more importantly, facilitating the proper maintenance, efficient water management and improved cropping practices in a sustained manner.

PRIORITISATION OF WORKS

The people's felt needs and priorities are given importance in formulating detailed work plans and cost estimates, as the planning itself is done with people's involvement. The works included in the tank rehabilitation follow an order of priority, which the users perceive as most important.

i. Acquisition of water
ii. System restoration
iii. Improvements to water use efficiency
iv. Tankfed agriculture development
v. Micro finance activities (MFAs)
vi. Endowment for TFAs

EXPERIENCE OF DHAN FOUNDATION

DHAN Foundation's tank program came into being from the analysis of rural situation in the chronically drought prone areas of Tamil Nadu. The tanks need to be saved from extinction. DHAN's efforts in working with the small and marginal landholders for the restoration of tank irrigation and regeneration of farmers' management have met with success. Water as the basic input for farming in dry tracts has brought tremendous benefits in the life of farming communities. The farmers are organised around the tanks with DHAN's efforts to conserve the tanks and improve their performance. The first phase of the project (1992-'95) was initiated with the objective of rehabilitating a few tanks. By this effort, their storage capacity could be increased and water supply to the crops could be made reliable. The experience gained from this phase provided the realization that the program should be multifaceted and that there was need to work with various other actors concerned with tank systems. So the project involved constant interaction with the local and state government agencies for funding, approving project proposals and changing their perspectives and policies for a better tank administration in the second phase (1996-99). Through the years, DHAN Foundation has undertaken more than 650 units of development works such as tank rehabilitation, community well construction, drinking water development works and watershed development works covering nearly 78,350 farmers and benefiting their small holdings in the dry areas of South India, through more than 1050 Tank Farmers' Associations (Vayalagams) and 11 Federal Associations.

DHANs' program is presently focussed towards the effective rehabilitation of tanks through management by the farmers and by building their stake. Also, in the last ten years, the project could take up many issues related to tank rehabilitation and agricultural development with people's participation, investment, and management transfer and ownership rights to many forums. The program has in recent times gained importance nationally and internationally for its sustained and innovative work towards this poverty alleviating natural resources management.

VAYALAGAM MOVEMENT

Vayalagam movement is conceived as an offshoot of advocacy efforts of tank farmers and their associations at various levels. The activities are mainly aimed at mobilising the participation of tank farmers from different states in the country. By getting together, they feel that they could be strengthened and better able to speak out on issues pertaining to the conservation of small scale water bodies like tanks, farm ponds and drinking water ponds.

Approximately 40,000 tank farmers spread over Tamil Nadu, Andhra Pradesh, Karnataka had gathered at Madurai, on September 28, 2005. Their demand for self-determination, empowerment, self governance and their desire to preserve and improve their capacity to manage the water resources further, fuelled their efforts to establish the movement. It was spear headed by a group of leaders drawn from the tank farmers' federations at district level. This event provided an opportunity for the tank farmers to be seen and heard at National and International levels.

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ANCIENT WISDOM IN DEVELOPMENT AND MANAGEMENT OF IRRIGATION TANKS

Palaniappan Gomathinayagam[1] And Mariappan Ratnavel[2]

ABSTRACT

Observations of Great Civilizations show that their development was directly related to the extent to which they could control and manage water resources. The hydrological characteristic of the Indian monsoon necessitated the creation of storage facilities to hold the rainwater of the monsoon and utilize the same at a later date. With extraordinary engineering, managerial and social skills, an extensive system of rainwater harvesting structures like tanks and ponds had been built and maintained by the people for centuries. The community had the complete control over water. The village organizations had well laid out rules and fixed responsibilities to manage water efficiently. Traditional system of water allocation and sharing was based on custom, belief, and the concept of equity, as they perceived. This ensured smooth sharing and minimized conflicts. The structures built with the technology then available also contributed the efficient management. Behind these existing indigenous systems of irrigation, there thousands of years of tradition. A closer examination of the technology behind these structures indicates that the design that the design principles developed thousands of years ago still hold good and applicable in future also. This paper documents some of the ancient technologies in building tanks and water management principles followed in ancient period. The methodology adopted is to collect information available in literatures, epigraphs, inscriptions, and interpretation of the features of the ancient structures still in use and discussions with villagers. The antiquities of the tanks were established by the archeological dating principles.

INTRODUCTION

The Tamilnadu state is in the southern part of India. Irrigation development in Tamilnadu dates back to several centuries BC. Archeological discoveries on the banks of the Thamiravaruni River in Tamilnadu indicate a civilized life in the area around 1000 BC. Iron tools are found in the sepulchral urns excavated in Adhichanallur on the banks of Thamiravaruni. The evidence in the form of epigraphs appear from 200 BC. An epigraph dating 200 BC mentions that *" the assembly of Vembiurar constructed a*

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large tank" (ARE B.265 / 1978-79, IAR 1978-79 p.83). The tank is still in use. There are evidences of well-developed irrigation systems in Sangam literatures, epigraphs and also remnants of structures. Some of the irrigation structures described in *Sangam* literatures are still functioning and they are the standing monuments of indigenous irrigation technology. Behind these existing indigenous systems of irrigation, there are thousands of years of tradition. The water management techniques had thus an opportunity to be perfected over time. This paper attempts to rediscover and study the techniques adopted by the ancient Tamils in building and managing irrigation systems with a special focus on Tank Irrigation.

IMPORTANCE OF TANKS

Though Irrigation works are found everywhere in the world, nowhere are those as important as in monsoon Asia, stretching from India to Japan. Its unique rainfall pattern distinguishes the monsoon Asia from the rest of the world. Hence the course of development of agriculture has been different in monsoon Asia and the rest of the world. To attenuate temporal variability of rainfall, these countries had followed from time immemorial, a policy of conserving rainwater for subsequent use through innumerable tanks and small storage structures like ponds, built owned and managed by the local people through community organizations. Tank systems developed ingeniously and maintained over the centuries, have provided insulation from recurring droughts and floods and vagaries of monsoon, and provided the much needed livelihood security to the poor living in the fragile semi-arid regions.

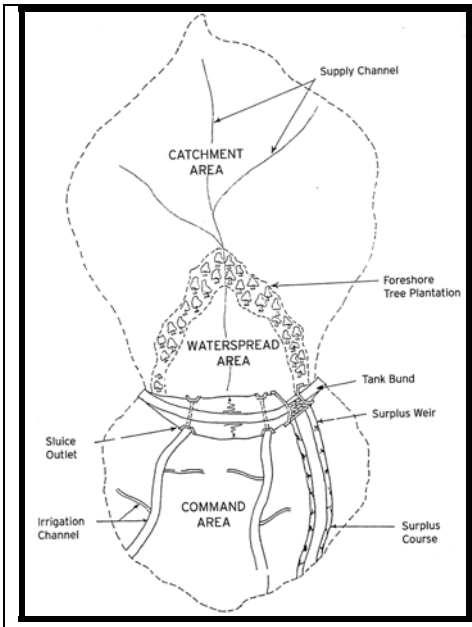


Figure 1 Components of Tank Irrigation System

COMPONENTS OF TANK IRRIGATION SYSTEM

The tank irrigation system has three major components as depicted in Figure 1. They are:

1. The source - Supply channels,
2. The tank proper with its surplus works and irrigation sluices
3. Irrigation channels

SOURCE

In Tamilnadu, there are about 39,000 tanks all over the State. These tanks are either system tanks that get supply from nearby rivers and may have their own catchment source or Non-system tanks that depend mainly on their own catchment. As the tanks are of shallow storages, formed across the existing contours and as the contours themselves fall gradually towards eastern plains, they lie one below the other. The lower one gets the benefit of the spills from the higher. These tanks are called a 'Chain of Tanks' and the last in the chain spills out to a drain. In system tanks the chains are linked to a supply channel excavated from a diversion weir on the nearby stream or river. This additional facility greatly enhances the stability and sustainability of the tank's source.

TANK PROPER

The Tank proper has three components, tank bund, surplus arrangements and irrigation sluices. The tank bund sizes and cross section vary depending up on need. But in each of them, suitable surplus arrangements exist. The surplus arrangements are designed to carry the maximum flood discharge. A unique feature in the surplus weir construction is that, invariably one or more vents are provided to release water to a lower down tank in the chain even before this tank gets filled up and spills. This also helps to lead the flood flows in the river through the supply channel to reach the tail end tank in a short time. The irrigation sluices are also provided at different elevations depending upon the contours.

IRRIGATION CHANNELS

The tanks serve their ayacut through a distribution system consisting of channels taking off from the sluices. They have, depending upon the size, branches, minors and watercourses. They supply tank water to the fields and they also act as a drainage channel when ever the water is surplus than the demand. This enable the applied water to reuse many time within the command area.

ANTIQUITY OF TANKS IN TAMIL NADU

The literatures belonging to the third *Sangam* (300 B.C. to 200 A.D.) are the earliest records of history of Tamilnadu. The Socio-economic conditions of Tamilnadu in first millennium B.C. are portrayed well in *Sangam* literatures. Another source is *"Periplus of the Erythrean Sea*" (AD 81-96) which informs about the trade between the Roman Empire and Tamil kingdoms. The most important development of this period is the spread of irrigated rice cultivation. Some of the irrigation structures described in *Sangam* literatures are still functioning and they are the standing monuments of indigenous irrigation technology.

A possible way to identify the antiquity of tanks could be from the artifacts and other remnants found during archaeological excavations. During the megalithic age, there was a practice of burying the dead in an urn near a watercourse, either in the banks of rivers or near a tank (either in the foreshore or out in the bund). If a Sepulchral urn is found near a tank, we can conclude that the tank probably belongs to the Sangam period (300 B.C to 200 AD). All the dead were not always put into urns in the above period; many were burnt also. Hence we have to be cautious in using this method to identify tanks of Sangam age. In addition, many tanks have been referred in the epigraphs and copper plate inscriptions found in different parts of Tamilnadu. However these epigraphs and inscriptions could not provide the clues to the exact date of formation of these tanks.

EVOLUTION OF SLUICES

A Sluice is the water drawing structure from the tank to the command area. The sill levels of various sluices in a tank could be same or different. The sill level is fixed based on the commandability of the ayacut lands (command area).

TYPES OF SLUICES

PULIKKAN MADAI

The *Pulikkan Madai* (Tiger's Eye Sluice) has three circular holes of roughly 2" diameter in a triangular shape on the masonry head wall of the sluice. The head wall will be of cut stone place on the tank side of the sluice. This arrangement of holes in this way resembles the eye of a Tiger and hence this name. During early period of cultivation when more water is required all the three holes will be opened. When the demand reduces the number of holes to be operated will be reduced. Water flow in the holes will be in relation to the depth in the tank. The discharge through an orifice (hole) will be equal to C_d x A x $\sqrt{2gh}$. When, the depth reduces, the bottom two holes will be opened to maintain the same discharge. This design indicates that the traditional knowledge of hydraulics compares well with present principles.

KARKUMILI

The off-take sluices of the tanks were located in the deepest portion. In the case of deep sluices, the sluice barrels got extended to the deepest bed of the water spread to ensure maximum drawl of storage. Even now one can observe that two vertical stone pillars protruding in the waters connected by two or more horizontal stone slabs with a central hole. They are referred as *"KARKUMILI"* in inscriptions. These are the "Plug and Socket" type sluices called *Kumili* in Tamil. A person has to swim to the pillars and operate the sluice. There will be two inlets for water. One on top is the socket in which plugs will be used to open or close the sluice. The top shaped plug provides an annular ring opening for partial lift and is capable of allowing varying discharges in accordance with the fluctuations in water level in the tank as well as for varying water demand. If the water level goes down the socket level, the second opening, usually closed with Clay or wooden piece, will be opened. This is called *Setthumadai.* The arrangement is shown in Figure 2. In this type of arrangement there will be minimum or no dead storage.

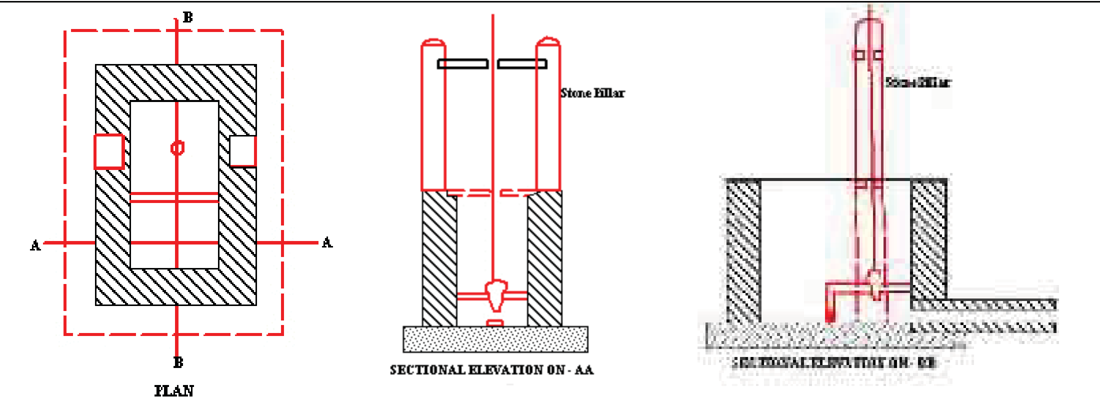


Figure 2 *Kumili* – Plug and Socket

REAR CISTERN

Figure 3 Rear cisterns with 7 distribution channels

A cistern is provided on the rear side of the sluice barrel. When the tank is at FTL (Full Tank Level), the velocity with which the water rushes through the barrel will be very high causing erosion and damage to the field channels in the command area. To reduce this force, the cisterns are provided that will store and release water dissipating all the energy. The cisterns are in different shapes – Square, Rectangle and Semi-circular. They divide the water into two, three and more, sometimes up to 7 parts and distribute to various areas of tank command through field channels. Photo 15 shows the rear cistern of Srivilliputhur tank where 7 vents are provided. The inscription found in the tank indicates that the tank was built by Raja Raja Chola in his 12th year of reign (997 AD). The inscription mentions as *Perumadai* (big sluice) and elaborates the arrangement, seven channels distributing water equally in seven different directions.

When the water rushes through the sluice, the velocity makes the water flow towards the vent directly in line with the flow. Hence a stone barrier acting as energy dissipater is placed just behind the vent as seen in the Figure 3. To see that no one disturbs or removes the stone, an image of God is carved on the stone. The figure of God Vinayaka is carved on this stone.

ARRANGEMENT FOR SURPLUS WATER DISPOSAL

SURPLUS WEIR OR *CALINGULA*

The *Calingu* or Surplus Weir is the most important component of a tank acting as the safety valve for the tank. They were constructed with care and its protection and maintenance received special attention of the villagers. The surplus weir is sometimes referred as *Kodu*. The people use the word *Kodi Paythal* indicating that the tank surpluses. The word *Kodu / Kodi* is used in Tamil to indicate 'one end'. Usually the escape was located on the extreme end of a tank. In a tank formed across a stream, the weir will be high if located on the stream and will also be costlier.

Providing dam stones in the surplus weir was a common practice followed for centuries till recently in Tamilnadu. These stones were generally of 6 inches. X 6 inches square and 2 to 3ft long. They are built into the crest of the *Calingu.* The top of the dam stones would be at Full Tank Level (FTL) of the Tank. The dam stones would be fixed at 2ft to 3ft interval. Figure 4 gives the Dam stone arrangements in a Calingu.

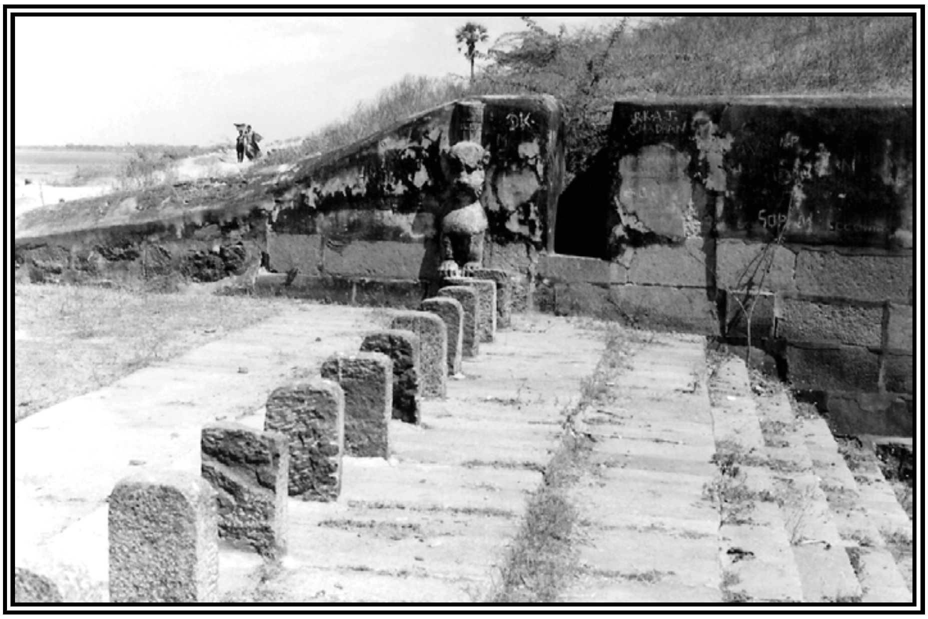


Figure 4 Dam stones in a *Calingula*

The spaces between the dam stones were blocked up with clay and turf so that water could be held up to FTL. In the normal time, when the first tank in the chain receives water, it will be allowed to fill up and start to surplus. This will be followed in all the tanks in chain. The last tank will not have dam stones but the crest of weir itself will be at FTL. When the last tank fills up to FTL, the farmers will start closing the dam stones and store water up to FTL in the upper tanks. Then, the immediate upper tank will be filled up to FTL and so on till the first tank stores up to FTL. Only after the first tank thus gets filled up, all the farmers in other tanks can start opening their sluices for irrigation. During flood time, when the water level rises and overtops the turf bund, it would be washed away rapidly and the surplus weir surpluses the flood water quickly.

ANICUTS

Construction of anicuts or weirs on the bed of a river/stream raises the water level sufficiently and ensures gravity flow in the channels to irrigate lands, which are at higher elevation and feeds tanks. The anicuts across Thamiravaruni River are the classic examples of technical ingenuity. They are built on the riverbed as elongated and at an inclined angle and irregular "Horse Shoe" shape. This shape was interpreted as that they have been aligned to suit the rock out crop. However there are two reasons. The First one is that, these alignments ensure the waters to flow into the channels even during low flows. The second important reason is that by increasing the length of anicut, the affluxes during floods are contained within the river. In Thamiravaruni system, the command area of each channels (Contour canals) lies between the channel and river and the excess water drains back to the River (A method of reuse). So if any increase in water level of the river will submerge the cropped land adjoining. Though at these anicut sites rock out crop is everywhere, they have followed this shape.

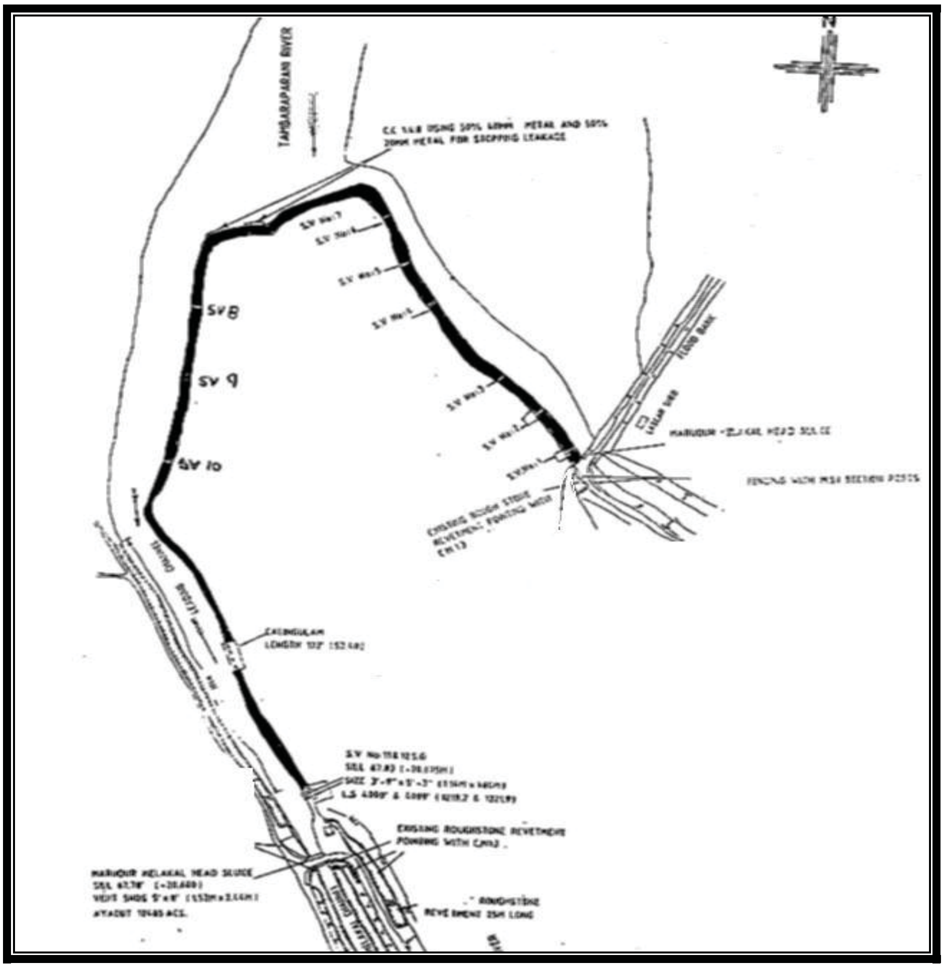


Figure 5. Plan of Marudur Anicut

The Marudur Anicut built by Maravarman Sundara Pandyan (1238-1258 AD), has almost a length more than three times the straight width of the river (Figure 5). When the British came, they built the first straight anicut across Thamiravaruni at Srivaikundam during 1858. The historical flood records show that the height of water over the Srivaikundam anicut was more than double that of Marudur anicut. This forced the British to build flood banks on both sides upstream of Srivaikundam anicut for 3 km. This not only increased the cost but also created water logging and drainage problem in the ayacut behind the tanks.

WATER MANAGEMENT

IRRIGATION INSTITUTIONS OF SANGAM AGE

The earliest form of peasant organization was the *Ur* a settlement of people who pursued agriculture. The *Ur* encompassed one or more villages. The agricultural settlements *Ur* also had their own assemblies to administer their settlement. The members of the assembly of *Ur* were the *Urar. Nadu* is a collection of *Ur*s and a bigger administrative unit. Historians agree that *Nadu* is the fundamental building block of rural organizations. The assembly of *Nadu* looked after the administration of *Nadu*. The members of the assembly of *Nadu* were called *Nattar.* Similarly *the* settlements of traders were the *Nagaram* and its assembly members were the *Nagarathars.*

"Karai" is the word used to denote the land unit along with right to the land. There are many epigraphs mentioning the *Karaiolai* or *Karaicheetu* used to the periodical redistribution of land by lot (Picking at random). Notable feature in the early Tamil kingdoms was that there was little or no (probably) private property in land. All land being held nominally under the authority of *Urar* with the "owners" holding merely the right of possession at the Urar's pleasure. The produce of all arable land was divided into two main parts Melvaram (Upper share) belong to the state and the Kilvaram (lower share) belonging to the local villagers. So there is a need to redistribute the lands each year among the cultivators. The names of all cultivators was written in separate palm leaves and put in a pot. One child would pick one leaf and corresponding land unit is allocated to him for cultivation during that year.

BRAHMADEYA AND *ERI VARIYAMS*

The settlements of Brahmins (Priests) were called *Brahmadeyas.* The *Pallava* period (600 AD to 900 AD) epigraphs extensively mention the *Sabha*, the village assemblies of Brahmadeya villages. Village Sabha consisted of all the male inhabitants of the area. They had complete control of the rural administration and acted on their own initiative independent of any directive from kings.The Brahmadeya villages had a local self-governing institution called **"Village Sabha".** For the purpose of administration, the Sabha created committees called *"Variyams".* The word *Varam* means Share and a committee of shareholder is the *Variyam.* The following committees for the various purposes are mentioned in inscriptions and copper plates.

Samvathsara Variyam	General Administration
Thotta Variyam	Garden Crops
Eri Variyam	Tanks and Irrigation
Calingula Variyam	Surplus weirs
Kazhani Variyam	Land development
Thadivazhi Variyam	Roads and paths leading to farms
Pancha Variyam	Tax collection

The Management of tanks was entrusted to a committee called "Eri Variyam" and its members were known as *Erivariyapperumakkal* (Honourable Members of tank committee). The members of the committee were elected every year, which enabled fresh members to get in and serve the committee. The electoral process was picking by lot. Similar to *Ur* But the Brahmadeya Sabha had excluded Non-Brahmins from contesting and stipulated conditions like land holding size, education, wealth etc for eligible candidates. The disqualifications have also been elaborated. Who had misappropriated the common funds, his family members and relatives cannot contest the elections. The sabha had the right to recall its elected representatives.

Kings, noblemen or the villagers for the purpose of maintenance of tanks made endowments in the form of gold or land. The income from these endowments was utlised for the maintenance of tanks. The *Erivariyam* took up the responsibility of regular maintenance, failing which the members of the assembly were liable for fine and punishment. The committee employed persons to operate sluices (*Madaiyaans*), distribution of water (Neerani, *Neerkatti or Kanduvetti*). There were village accountants, village watchmen (*Kaval*). All these persons and the village artisans were paid from the total produce of the village. The remaining was shared between state and villagers.

WATER MANAGEMENT

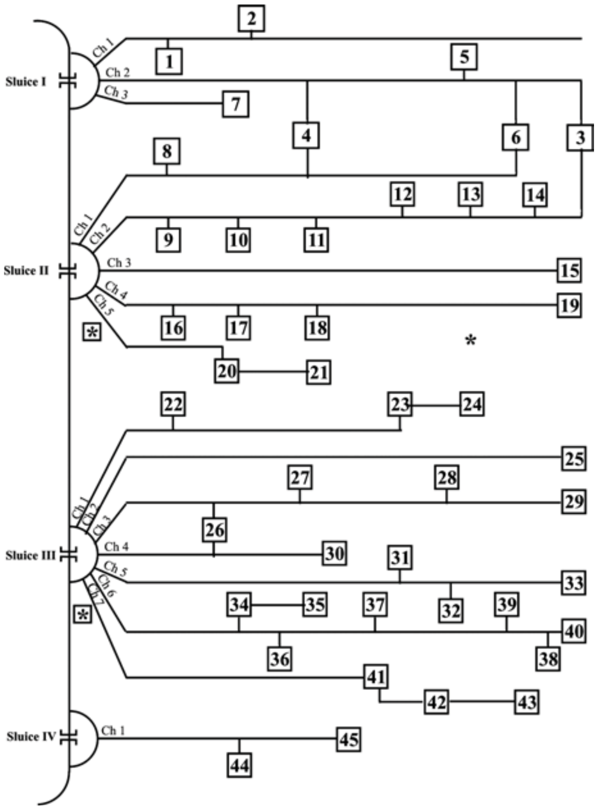
Inscriptions contain wealth of information on water sharing, distribution, water rights and responsibilities that are the elements of water management. The words *Nazhigai Vattam* (Time cycle) and *Nazhigai Kanankkan* (Time keeper) found in epigraphs and sangam literature point out that a turn system based on time and a persons who calculates the time allocations were in existence. There was a cycle of turns (Vattam) and an order in turns (Murai) adopted for irrigating the lands.

The Ur and Urar had the authority to allocate and distribute water from irrigation sources. Thus gradually the rights to water came to be attached to the land. The inscription of Maran Sendan in 770AD is the earliest describing the water right. The message is that the urar had sold land to one *Velsendil* along with water right specified for a time duration (S.I.I.No17) Similar messages are found in many inscriptions. One inscription giving this information was found in Pudukkottai district.

" When the Urar of Alattur sold in auction to a dancing girl of the temple 12 ma(1.6 ha) of land they also sold with the lands 16 naligais (6.4 hrs) of water out of 180 naligais(3 days) for which Perunkumili (Big sluice) was drawing water from tank."

- Pudukkottai Inscription No.666

The *Kasagudi* Copper plates mention that any tapping from or obstruction to the feeder channels was a punishable offence. The inscription found in *Kuruvithurai Peumal Temple* states that **"**When a channel is drawing water for irrigation from river, no channel should be excavated in the upstream". Such excavation will affect the flows in the old channel; this inscription protects their first right to water. The globally accepted concept of water rights "Prior Appropriation Right" and Riparian Right" have been in existence in the early Tamilnadu.



Case study of Muthunadu tank (Based on interview with farmers and Govt. record)

Muthunadu tank is unique in its construction and function. The tank is a balancing reservoir to 45 yendals (baby tanks) below it, through which only irrigation is made to its ayacut. The tank is not supplying directly to any ayacut (command area). Water supply to the 45 tanks is made through 4 sluices with an intelligent distribution from the rear cisterns of the sluices. 16 channels are taking off from the rear cisterns and 45 tanks are supplied. Vents are provided in the rear cistern to distribute water proportionally to the distribution channels.

The informal institution, which manages the tank system, is the UR constituting all farmers at *yendal* tanks. Before the commencement of the irrigation season, every year, all the farmers of each *yendal* tanks meet in any one of the villages where the farmers live, in a rotation. In this meeting they select the farmers who have to act as water distributors for each *yendal*. The selections are made randomly through lot. The names of the farmers are written in separate ballot paper, rolled and put into a pot or box. One child will be asked to take a few papers ranging from 1 to 5 for each tank according to its requirement. Such persons elected are called *Sethakkarar* If the farmers selected by lot as *Sethakkarar* are not residing in the villages, then they are permitted to employ others at their cost and responsibility. If they are not working to the satisfaction of other farmers the non-resident farmer is answerable for the misconduct. The appointments of the *Sethakkarar* are valid for only one year. When the selection processes are made for the successive years, the names of farmers worked in the previous years will be deleted. In this system only farmers or their representatives alone are employed, the distribution will be better as the name itself indicates as *Sethakkarar*. They are paid wages fixed by the urar.

The duty and responsibility of *Sethakkarar's* is to bring the water from Muthunadu tank to their *yendal* tank without loss and as per the time schedule according to the customary rights. And below the yendal they should distribute the water in such a way there is no loss of crop productivity. Even though they are selected before the crop season, they start distribution of water below the *yendal* only after transplantation or broad casting, which is predominant, is completed in the command area. Till then farmers themselves operate the sluices according to the requirement and convenience of individual farmer. There is no rigid scheduling below the tank.

Muthunadu tank has a customary operation plan indigenously developed many centuries. The channel flows are distributed to *yendal* tanks according to a fixed time schedule in units of *Velai* (a unit of time of 12 hours). Each yendal tank get the supply varying from 1 *Velai* to 6 *Velais* in each turn till all the tanks got filled. During the period of a turn, if there is no flow to Muthunadu tank, the rotation of supply to *yendal* tanks will be disrupted. But, if the flow resumes within 7 days then, the supply to *yendals* will be continued as per the schedule. If the disruption is more than 7 days, the supply has to be resumed from the first tank in the channel and a fresh turn / rotation has to be followed. When all the *yendals* are filled to their full storage capacity or when the flow to the Muthunadu tank is higher than the drawing capacity of all supply channels, the excess water will be stored in the Muthunadu tank. Adequate surplus arrangements are available to dispose surplus floodwater when the tank got filled in. The time allocation called *Velai* in distribution of irrigation supply in this tank system is still followed.

The time schedule may present an unequal distribution of supply when compared to the command area. The sluice sill levels are at different levels and when there are low flows, the channels in the elevated sluice may not draw any water. Further the slopes of the channel bed vary under sluices. But to rectify these anomalies, the widths of the channels are designed in such a way the supply to yendal are equal to their requirement. And the sill level of the vents in the rear cistern of sluice III are raised so that the flow in the channel starts uniformly with that of sluice II.Yet another inequality in supply occurs when the flow in the channel is varying as the flow is not controlled. However the flow pattern itself may minimize the variation. There may be low flows at the start of the rotation and higher flow at the end and vise-versa Further, preference is given to the first tank whenever there is a break in supply for more than a week. The lower down tanks are in an advantage position to receive return flows from the upper command area and surplus water from upper tanks. Even if there are variations in supply in some rotation, such variation will not affect the crop as the storage in the *yendal* will compensate the short supply. Thus the double storage system provides more flexibility in operation and ensures equity and equality in irrigation supply between the total supply to these tanks. During drought years, the farmers postpone the starting of cultivation till the end of Tamil month *Purattasi* (15^{th} October to 15^{th} November). The farmers meet and decide to what extent the area of cultivation could be done by each farmers, generally proportionate to the total land holding.

CONCLUSION

1. Tanks constructed / existed during the Third Sangam period (300 B.C to 200 A.D) are still functioning.
2. The earliest inscription dated to 200 B.C describes about the construction of a tank by the community itself.
3. The literature provides / contains valuable information about the components of tank complex, its preferred location and shape.
4. Inscriptional evidences throw light on formation of institutions and their functions.
5. Number of inscriptional evidences are available on water management, farmers' water rights and responsibilities.
6. Inscriptional evidences are available about the periodical maintenance works carried out and the ways of raising funds for such works.
7. The modern technology being undertaken in construction and management of tanks is nothing but the revival of our ancient wisdom.

ABBREVIATION

ARE - Annual Report on Indian Epigraph

IAR - Indian Archeology, Review

SII - South Indian Inscription

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WATER SUPPLYING MANAGEMENT IN SHIRAZ DURING THE 12TH CENTURY (A.H)

amirhosein hekmatnia[1]

ABSTRACT

This exploration contains of two main points .The former, introducing and analyzing of seven Karim- Khan-i reservoirs - instead of those four usually presented-along with regarding the causes of their construction and the latter, a brief description on water transferring from Rokn-Abad to Vakil quarter besides giving an explanation on its engineering. The latter part includes a try to identify the gutter pipes and ceramic barrel-drain as well as the other hydraulic constitutions and the fountains.

Finally, this article leads us to the admirable services provided for public by Karim-Khan his civil engineers.

Key words: Ceramic barrel-drains, fountain, reservoir, Karim khan Zand, Rokn Abad subterranean canal, siphon

In the process of urban water supply of Shiraz, the name of persons of distinction is imprinted in the eternal floor of history. From Dilamids and their famous king Azd al-Dawleh in fourth century A.H to Qajar in thirteenth century A.H wonderful monuments are remained that their study, scientific exploration and registration are necessary.

Aren't the song tingle of agitated nightingales among the flowers and the foliage of the trees and the tranquility under the shadow of evergreen cypresses among a city that doesn't have a permanent river, good reasons to respect those who brought water from out of the city's boundary inside in different ways to irrigate the ground and whoever lives on the ground?

Subterranean canal was the most important invention of Iranian for transferring water from the furthest spots to their desirable places. But it wasn't the only way of water transferring. Other methods such as reservoir, water distributors, mills and siphons were other man-made structures playing important rolls in their better lifestyle.

Rokn Abad subterranean canal is the most famous subterranean canal in Iran established by the order of Hassan Rokn al-Dawleh Deilami, the father of Azd al-Dawleh, in 338 A.H. Because of that Shirazi people call it Rokni water.

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"Shiraz o abe Rokni o an bade khosh nasim

Eibash makon ke khale rekhe haft keshvar ast."

Don't find fault with Shiraz. It is the mole of seven countries because of its nice breeze wind and Rokni water.

"Ze Rokn Abade ma sad lohash allah

Ke omre khezr mibekhshad zolalash"

We should admire the Rokni water. It is very fresh and wholesome and anybody who drinks it can live for more than one thousand years.

Rokn al-Dawleh by staying in Shiraz for nine months, guaranteed the regards of people for himself for nine centuries. He found the north valleys of Shiraz which were en route of Isfahan to Shiraz, called Akbar Abad today, the best alluvial source for irrigating the plain above Khoram Dareh River. Rokn Abad water was transferred to Shiraz from this spot. It renewed this city and dedicated a beautiful landscape to perimeter of Quran Gate.

"fargh ast ze abe khezr ke zolemat jaie oust Ta abe ma ke manbaash allah-o akbar ast"

Wherever Mostofi talks about Shiraz water, he introduces the Rokn Abad subterranean canal as the best one. Ibn-e Batoteh, in eight century, names Rokn Abad subterranean canal as one of the five running streams in Shiraz.

En route of Shiraz to Persepolis, Tomas Herbert who traveled to Shiraz in Safavid period while Emam Gholi Khan was the ruler of Fars encountered an aqueduct which was carrying water from one side of the valley to the other side in Allah-o Akbar strait. In this case he has written:

We traveled from Shiraz to Persepolis which is located 30 miles away from north east of Shiraz. First we passed from a famous flood-channel which was the same as Daloon strait. Pouring lips made firm on pedestals passed from mountains and reached Shiraz. Indians named this mountain "Akbar tangi" and Iranian named it "big strait" that both have the same meaning. Most of the beautiful groves which were full of flowers and fruits were irrigated by this water.

On the strength of Herbert we find out from those pouring lips that the writer supposed them to be the ceramic barrel-drains indeed specialized for transferring water, that transferring water to Shiraz by plumbing is started from safavid period.

Safavids were the founder of this process but they couldn't complete it unfortunately and Karim Khan Zand was proud of completing this great service.

THE VISAGE OF SHIRAZ DURING ZAND PERIOD

Overthrowing of safavid dynasty in 1135 A.H and Afghans' ruling over Iran on the one hand and suppression of autonomic Khans by Nader on the other hand changed Shiraz from that beauty and splendor into a ruined place that its dwellers had migrated or had been sick or mournful for their innocent killed youth. Shiraz never again had that grace and pleasantness of Shah Abbass time. After the death of Nader in 1169 A.H, Khans started their activities again. When Karim Khan assumed the reins of government, he selected Shiraz as the capital of Iran and turned the magnificence and honor back to it. He revived its visage by constructing the governmental, private and public structures and immortalized himself in the heart of Shirazi people by restoring and adding extra parts to other structures and other actions such as alleys and streets pediment, tax reduction, religious equality and paying attention to the artists. Transfering the Rokn Abad water to Shiraz was the privilege of Vakil al-Roaya's (the attorney of Iranian subjects) fame and honor in the splendor of city visage.

METHODS OF PROVIDING WATER AND WATER SUPPLY

The most important problem of Khan of Zand (and probably The Safavids') was that if they wanted to transfer uncovered water from the distance to the city, it might lose its wholesomeness and freshness and become muddy. But Karim Khan(Vakil al-roaya), by inviting the experts to design this great water construction, could transfer water for about three kilometers from its origin (Allah-o Akbar strait) to its destination (Karim Khan citadel) by creating the subterranean gutter.

This brook which is made firm at least two meters under the surface of the ground traverses across the Quran gate's street to Isfahan gate and turns to Bahman 22nd street (former Shahpour) and enters the Zand complex.

The foundation, enclosure and the arch of these subterranean gutters are made of brick and plaster of lime and sand mortar with the thickness of 45 centimeters. The width of these subterranean gutters on the foundation are70 centimeters and on the foot of the arch are 35 centimeters and their height are 80 centimeters.

In each meter of the length of this brook is used 1.6 cubic meters brick and mortar that about 30% of that is plaster of lime and sand mortar and 70% of that is brick.

Accordingly, 1440 cubic meters plaster of lime and sand mortar and 3360 cubic meters brick have been used on the whole along this three kilometers route. If we consider the depth of earthwork 2 meters and its width 2.5 meters in average, about 15000 cubic meters have been uncovered in this pass.

At least two siphons have been used in this gutter from Allah-o Akbar strait to the Zand complex that the first one has been used in the Khoram Dareh River (Shiraz Dry River) and beside the Ali Ibn-e Hamzeh Bridge and the other one in a ditch that Karim Khan had dug all around the city. The first one has 30 meters width and 3 meters depth and the second one has 20 meters width and 6.5 meters depth.

Karim Khani citadel was the first place receiving water from these gutters. Accordingly they started to create another siphon beside the southwest tower through which the water was transferred to the citadel and poured into the back yard's pond of the same angle and after that irrigated 6 other ponds.

The water of other structures was provided in the same way and by using the ceramic barrel-drains. Each barrel-drain (pouring lips) had 30 centimeters length and had been constructed with various diameters. Each one had one narrow head and one wide head acting as male and female to pair the pouring lips. Then their fissures were filled with the plaster of lime and sand mortar to prevent water seepage. The barrel-drains' mouth from small to big are 18 to 30 centimeters and their thickness are 0.8 to 2 centimeters. A thick enclosure of brick and plaster of lime and sand in various rectangular or horse shoe forms had been constructed all around of these subterranean canals (water courses) to make the pouring lips firm against all pressures. All the water transferring affairs were very expensive. As the historian of this dynasty Mirza Sadeq Nami has written:

Vindication of the cash payment that was allocated to this slight matter from the treasury is above the perception of the accountants' imagination and beyond the patience of state accountants.

FOUNTAIN

Another hydraulic structure of Zand period was the great number of fountains. Each fountain had 4 parts:

1. POURING LIPS:

The under pressure water in a pouring lip was leaded into the belly of a ceramic vat through a narrow pipe having an eight-centimeter diameter.

2. CERAMIC VAT:

This vat was the same as the jug of a wide and long mouth hookah.

3. STONE COLUMN:

It was a column inside which a narrow pore with 2 centimeters diameter had been cut. This column had been connected to the hookah's jug as a part of its body. In all fountains of this type, a small part of the column was placed under the ground and 80-90 centimeter of that above the ground.

4. BRICK ENCLOSURE:

To keep the water pressure away from the thin crust of pouring lips and jug, a firm enclosure with 60 centimeters length and 130 centimeters width was constructed around them.

The Reservoirs of Zand period (the Methods of urban water providing)

Most of the researchers, according to the written documents and of course without traverse and scientific exploration, believe that there isn't any vestige of other reservoir of that time except the reservoir named "Karim Khani" near the Divan structure on the north area of Karin Khan citadel. Furthermore they mention different numbers of reservoirs.

Some of them imitating Asef Al-Dawleh count the number of Zand reservoirs two.

He has written in his book:

"According to his order….two vital and very great reservoirs and numerous siphons were constructed to transfer water from an inferior land to a high land that high thick round hollow solid stones were installed on the mouth of all of them."

Most others believe that Karim Khan has constructed 3 reservoirs -Vakil bathroom, Divan structure and Hafezieh- during his ruling over Shiraz. Those who had explored minutely introduced 4 reservoirs: Vakil bathroom, Divan structure, Hafezieh and Haft Tan (seven bodies).

A worthy of hesitation point is that there weren't any special attention to the number of reservoirs during Zand period. Because Mirza Mohammad Kalantar has written in his book:

"Several reservoirs had been constructed and repaired in Shiraz that about one hundred thousand persons were drinking from them during the summer. They certainly drank four or five times a day and each time they asked for forgiveness."

We can correct and complete the number of reservoirs of Zand period as follow according to the book and forum surveys done about the management of providing urban water and Zand constructions water supply.

1. DIVAN RESERVOIR

The reservoir named "Karim Khani" today is on the north of citadel and on the right side of Divan structure. The point that distinguishes this reservoir from other reservoirs is the Naghare Khaneh structure (a place where the drums were beaten at fixed intervals) on top of it or in other words on the second floor of it which is demolished today. The only monuments of this reservoir are the brick arch, tank and steep staircase.

2. VAKIL BATHROOM RESERVOIR

On the west of Vakil mosque, the Vakil bathroom and reservoir were constructed with a lane between. This reservoir was established behind the bathroom to provide its required water, which is proper more or less but has lost its usage and is not in public show. A wind catcher shaped like a high tower was constructed on top of it for the ventilation.

3. HAFEZIEH RESERVOIR

As Khan of Zand was interested in serving those who were in his presence and respecting the eminent position of Hafez Shirazi, he constructed a garden on his tomb. He established a central hall with four solid stone columns to divide the space into two parts and provided a splendid grave stone to be put on the tomb of that great man of Literature and Gnosticism. Furthermore, he ordered one reservoir be constructed to provide the water needed for irrigating the garden and Pilgrim's consuming water. Because of constructing the new structures in the next years, there is just a little vestige of that today.

4. HAFT TAN (SEVEN BODIES) RESERVOIR

The value and respect of 7 Gnostics and mendicants buried on the foot of Mount Chehel Magham which had a lot of pilgrims and eager every week, made Karim Khan respect and value his people again. So he constructed a structure with brick enclosure and a veranda with two huge solid stone columns and created a garden with adumbrated trees for the pilgrims' tranquility. He took efforts to construct one reservoir to provide the water needed for irrigating the structure's tree and Pilgrim's consuming water that its vestige is still remained.

5. RESERVOIR ACROSS FROM THE KHAN SCHOOL

Across from the Khan school that its antiquity goes back to Safavid period, the remains of a structure buried under the ground is visible. We succeeded to investigate that through a hollow made in a part of that. Consequently, there was a reservoir buried under the ground. We believe it belongs to 12th century A.H as compared with the arches, shallow dome and thick piers of Zand period reservoir.

6. RESERVOIR OF JAHAN NAMA GARDEN

Jahan Nama garden that its antiquity goes back to 8th century A.H is on the Quran Street. During the splendid Zand period, an octagonal structure named pavilion was constructed in the center of this beautiful garden for Karim Khan's recreation. While we were investigating for the water distribution in this structure, we encountered a reservoir on the right corner of the garden. According to our criterion it belongs to the Zand period. This reservoir was constructed to irrigate the garden's trees and provide the pond's water.

Shiraz municipality has taken efforts to excavate it and the inside façade of its tank is visible now. As Jahan Nama is located on the pad of plumbing water transmission from Quran gate to Zand complex, we are going to be sure that this structure is created in Zand period. Because that's enough to create two parts in the barrel-drains or making a little reel in the barrel-drains by using a few bent spout consequently to lead water to the tank of this reservoir.

7. RESERVOIR OF ALI IBN-E HAMZEH

Formerly a reservoir was established by the order of Karim Khan Zand beside the Ali Ibn-e Hamzeh mausoleum. There is not remained any vestige of it today.

Asef Al-Dawleh has written:

"There have been constructed one caravan sari gate and one bathroom gate interconnected and one reservoir and one Tekiyeh with grace and pleasantness in the vicinity of the tomb of the offspring of the 7th imam, Shah Mir Hamzeh worthy of bow."

According to this valuable document which is one of the important studying sources of Zand period, we can find out that in order to serve his people Karim Khan took efforts to create this reservoir to provide the drinkable water and the consuming water of bathroom.

8. RESERVOIR OF QURAN GATE

During Zand period, beside all other reconstructive Karim Khan made in Shiraz, he made some improvements in Allah-o Akbar strait. He restored Quran gate which had been semi-ruined because of passing the time and earthquake and constructed two rooms at the sides for sentry post and toll-house, and a reservoir beside it which was filled with the Rokn Abad water and was used by the new comers. These structures were demolished because of the earthquake during the Qajar period and because of boulevard development during Pahlavi period.

CONCLUSION

We found out that the transmission of water to Shiraz by ceramic barrel-drains had been started from Safavid period but it couldn't be succeeded. During Zand period, this important matter was performed by the knowledge of the engineers of that time.

Using the ceramic barrel-drains, siphons, two-part conduits and fountains were the most important hydraulic structures of that time using to transfer the water with that very wholesomeness to Shiraz to incarnate the Persian Paradise.

By constructing the reservoirs, a valuable service was presented to the dwellers of this city. For the first time we perceived that the number of reservoirs in Zand period was eight and the reflection of their existence was the tranquility of people, the city cleanliness and the irrigation of the trees.

RESOURCES

1. KHOUB NAZAR, HASSAN, "SHIRAZ HISTORY", page 35.
2. MOSTOFI GHAZVINI, NEZHAT AL-GHOLOUB (enlivening of the heart), page 115.
3. MOROCCAN IBN-E BATOUTEH, who traveled to Shiraz twice, coincident with theruling of Sheikh Abu Eshagh Inju on 727 and 748 A.H. to visit a wise scientist, "SheikhGhazi Emam Majd al-Din Esmaeel". Ibn-e Batouteh's itinerary contains valuable informations about Shiraz visage, gardens and structures important characters of that time.
4. AFSAR, KERAMAT ALLAH," THE HISTORY OF THE OLD TEXTURE OF SHIRAZ", page 95.
5. TOMAS HERBERT came to Iran with ROBERT SHERLI and some of the English charge-d' affairs and were the guest of Emam Gholi Khan Beiglar Beigi about three months in Shiraz.
6. SEDAGHAT KISH, JAMSHID, "THE STRUCTURES AND REMAINS OF ALLAH VERDI KHAN", page 73.
7. AFSAR, KERAMAT ALLAH, "THE HISTORY OF THE OLD TEXTURE OF SHIRAZ", page 184.

8. JAVAN, MAHMOOD, and JAVAHERI, MOHSEM, "THE ENGINEERING AND TECHNICAL SPECIALITIES OF HYDRAULIC STRUCTURES USED IN THE SUBTERRANEAN CANALS OF SHIRAZ PLAIN", page 30.
9. In the construction of Shiraz ditch, 12 thousand workers from Iran's cities worked. That deep ditch behind the enclosure and circuit wall of the city show the chaotic and unstable situation of that time. The ditch created around the circuit wall and the small ditch surrounded the citadel were two example of the Karim Khan's problem in transferring of water to Shiraz, but the master of that affairs succeeded to solve these problems.
10. Former
11. SHAFIEE, FATEMEH, KARIM KHAN'S CITADEL, A PLACE WHERE ART AND ARCHITECTURE AND BEAUTIES ARE DISPLAYED.", page 27
12. NAVAEE, ABD AL-HOEEEIN, "KARIM KHAN ZAND", page 263 and 264.
13. DANESH PAZHOUH, MANOUCHEHR, "SHIRAZ" page 112 and AFSAR, KERAMAT ALLAH," THE HISTORY OF THE OLD TEXTURE OF SHIRAZ", page 217.
14. ASEF, MOHAMMAD HASHEM, "**ROSTEM AL-TAVARIKH"**, Page 372
15. RASOULI, HOUSHANG, Page 58
16. **KHORMAEE**, MOHAMMAD KARIM, " SHIRAZ, THE MONUMENT OF DECEASED", Page 34
17. KALANTAR,MIRZAMOHAMMAD,"THE NEWSPAPER O**F MIRZA MOHAMMAD KALANTAR** " Page 68
18. ASEF, MOHAMMAD HASHEM, "**ROSTEM AL-TAVARIKH"**, Page 372
19. **KHORMAEE**, MOHAMMAD KARIM, " SHIRAZ, THE MONUMENT OF DECEASED", Page 107

ASSESMENT OF RIVER GHANATS SHUSHTAR

Fatemeh Zaker hosseini[1], Samaneh Abdoveis[2], MaryamCheraghi[3]

ABSTRACT

In Khuzestan province due to the existence of 34 percent of the country's surface water, ground water has received less attention. Despite all these issues, people in this province, owing to the hot and dry climate, for using surface water need to transfer it to urban areas and farmlands higher than rivers. The result of the diligent people's efforts leads to drilling river (Softeh or Ghomsh) and underground (Kariz) Ghanats with unique characteristics. Of the important areas with river Ghanats are Shushtar city and its suburbs. In this city existed both surface and under ground water transfer. These Ghanats are 130 to 2000 years old. The present study assesses 8 Ghanats, out of them 5 are identified for the first time.

Key words: Ghanat, Softeh, Hydraulic, Shushtar, Gargar, Darioon.

INTRODUCTION

By the civilization development in ancient Iran, the use of wells with animals' force does not meet the progressive needs of people. From several thousand years ago, therefore, people innovated a new technique by the using the earth gravity to collect ground water and bring it to the surface. Besides drilling Ghanats which feed from ground water, they dig canals resembling Ghanats with different names such as Softeh, Kahriz, Kariz, Ghomsh, or Komesh to transfer water to the areas that had difficulties to access surface or ground water. In this study, it is attempted to assess the two types of Ghanat mentioned above in shushtar in order to identify these hydraulic structures that transferred water around shushtar and also open a view for researchers to assess ancient irrigation regime and find stable one for better irrigation.

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HYDRAULIC VIEWPOINT OF GHANAT PERFORMANCE

Ghanat comprised of a number of vertical wells linked by means of underground canals in which water flows due to the slope related to the main canal length and the height difference between farmland and the bottom of the main canal. Ghanats usually feed from underground layers filled with water, rivers, and infiltration of surface water. From hydraulic viewpoint Ghanats can be divided into 3 areas of inundated, semi-inundated, and seepage.The inundated area follows the deep drainage pipes hydraulics but the semi-inundated area follows the open drainage canals hydraulics. Water in these sources flows in the underground canal with suitable slope under the influence of the earth gravity and then it is used by the people after draining out of the land [8]. Non-agricultural buildings and facilities related to Ghanats are briefly explained.

1. In certain areas, the slope of the Ghanat horizental canal of the Ghanat was established in a way to operate with the power of water in the mills. [3]
2. In certain areas of the city, by using Ghanat water and a handle or on the main Ghanat people built bathrooms.[3]
3. In order to provide water for people to meet their needs, facilities called tailwater were built on the Ghanats. Each tailwater comprised of a curved channel reached to the main canal for water transfer.[3]

CLASSIFICATION OF GHANATS

Ghanats are classified based on length, discharge, depth, and feeding source. In this assessment only the classification based on feeding source will be considered.

1. Ghanats feed from groundwater.
2. Ghanats feed from surface water (such as rivers, springs, ponds, and lagoons) which are called Softeh in the local accent of people in Shushtsr.[1]

RIVER GHANATS

In the past time, these kinds of Ghanats called Kariz were found in Khuzestan province in galore. It means that water was not abstracted from the water table (aquifer) but from the river. This technique was used when the topographic condition of the land did not allow establishment of open channels for transferring water. Therefore in order to reduce excavation cost, Ghanat system was used as the continuation of irrigation canals originated from rivers. A large number of these Ghanats are found in certain cities of Khuzestan as Izeh, Behbahan, Dezful, Andimeshk, Shushtar, Ramhormoz, and Baghmalek[1]. These kinds of Ghanats were drilled in rivers with hard and vertical banks in each side or areas in which establishing channels was not possible due to the variations of heights. By drilling Ghanats in these areas water can be transferred to remote areas. There are two ways for drilling Ghanats:

1. In the first, a well is drilled near the river bed. The water entered this well from the river will be transferred to remote and low lands via certain horizental canal of the Ghanats. "Figure 1a"

2. In the second, Ghanats are drilled at the same level as the feeding river. Most of the Ghanats (Kariz) are drilled in this way [1]. "Figure 1b"

Therefore in order to reduce excavation cost, Ghanat system was used as the continuation of irrigation canals originated from rivers [4].

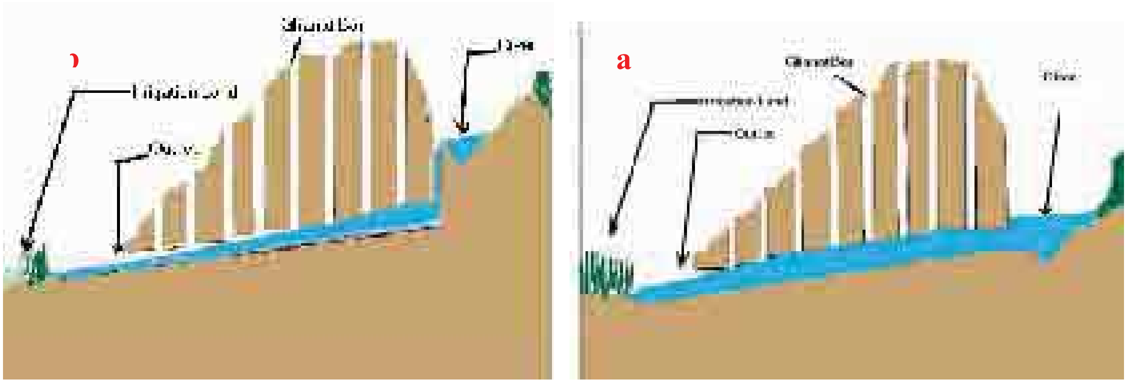

Figure 1 A. First class Softeh **B**. Second class Softeh

ASSESSING GHANATS AND SOFTEH IN SHUSHTAR

In north of Khuzestan province specifically in Dezful and Shushtar cities, drilling Ghanats was common due to the special topography of the area and the existence of high flow rivers. These Ghanats fed from the rivers in stead of groundwater. Low level of rivers, by considering the level of farmlands and the cities, followed the innovation of these special kinds of Ghanats. These river ghants or Kariz were called Softeh and Ghomsh in Shushtar and Dezfull respectively [5]. Some of the Softeh in Shushtar were dried and destroyed after about a century; only one of them and certin parts of the others are available now. Identifying these structures and their capabilities in transferring water to remote and higher areas and saving the costs of establishing channels and other structure can be an appropriate pattern for the same areas. Unique specifications of these Ghanats deserve an accurate identification and assessment.

CLASSIFICATION OF SHUSHTAR GHANATS ACCORDING TO FEEDING SOURCE

1. River Ghanats (Softeh): Gargar Softeh including right bank Softeh (Softeh Bagh Khan Bozorg) and left bank softeh (Softeh Bagh Agha Bagher), Shoteit Softeh, Karun Softeh (Galoogerd), Softeh Pol Band Mahibazan, Sofyeh Pol Band Dokhtar.
2. Ghanats feeding from groundwater: Jijal Ghanat (Pirgoori), Abid Ghanat (Abid village)

HISTORY OF RIVER GHANATS(SOFTEH) IN SHUSHTA

Although it's a long time that these Ghanats are dried, well bars are still available in the Gargar, Shoteit, and Karun rivers. Establishment of these Ghanats goes back to the Sasanid era and the time of Shadorvan weir establishment. The possibility of its establishment in Sasanid era is more because Shadorvan weir established for irrigating and cultivating lands. Nevertheless establishment of this weir had no economical values by taking into account the costs, time and available facilities. The existence of Darioon canal which goes back to 2000 years ago and comparing it with the Shadorvan weir proves this fact [2].

GARGAR SOFTEH

In order to irrigate the downstream lands of Gargar River, Gargar Softeh was established in the Gargar River bank due to the fact that irrigation was impossible during hot and low flow seasons. These Softeh fed water from beneath of the Shshtar waterfalls called Sika located at the 32", 02', and 45° northern and 50", 51', and 48° eastern geographical coordinates. These Softeh consist of two parts:

1. Left bank Softeh called Bagh Agha Bagher Softeh had approximately 1-1.5 km length. At the present time, 5 bars are available and others are not visible due to the total destruction or coverage with sediments. Measuring the length of this Ghanat both, inside and outside, is impossible due to the damage and destruction of the walls [9]. This Ghanat not only transferred water but also fed the ground water because at this time it has a good discharge by taking into account that certain parts has fallen down and filled. Also through performing some chemical experiments the Gargar River has a better quality (comparing with this Ghanat). In the Table no. 1 you can compare the quality of water in Gargar River and Gargar Ghanat (Softeh). In the other words, through the length of the Ghanat, water enters the Ghanat from the Aghajary formation that has a negative effect on the quality of water and the difference in water quality shown in the table 1 is due to this fact. At the present time this Ghanat has 3 to 4 l. discharge and feed from the aquifer. Figure 2a illustrates one of the bars of this Ghanat. Figure 2b illustrates a part of the Ghanat horizental canal of the Ghanat.

Table 1. The results of Gargar river and Ghanat chemical assessments

row	location	10^6 * EC	PH	T.D.S P.P.M	CATIONS(Milli Equiv./Liter)					ANIONS(Milli Equiv./Liter)				S.P.	S.A.R	CLASS	C_2^*
					Ca	Mg	Na	K	SUM	HCO_3	CL	SO_4	SUM				
	Gargar Sofleh	3083	7.9	2587	15.4	11.3	11.60	1.83	40.13	2.60	11.4	25.82	39.82	28.9	3.2	C4-S1	—
	Gargar River	955	8.4	570	2.36	1.34	5.3	0.18	9.08	1.96	5	2.09	9.25	57.9	3.9	C3 - S1	0.22

Figure 2- Pictures from Ghanat in the left bank of Gargar called Bagh Agha Bagher Ghanat

a) Ghanat bar b) Ghanat horizental canal of the Ghanat

2. Right bank Softeh called Softeh Bagh Khan had supplied water for irrigating lands called Bagh Khan and a bathroom called Khan Bathroom [9]. The length of this softeh (Ghanat) is 500 m. After transfer, water in this Ghanat collected in a pool and when other parts of the land required water, they opened the pool. At the upper part of this Ghanat, in a place called Khan Bathroom, water transfer was performed by using a tool called Charkh dool or water wheel.

DARIOON GHANAT (CANAL)

This large canal used for irrigating 33 thousand hectares of Mian Ab lands is located in 32° 03' north and 48° 01' east. This canal is known as Darioon Ghanat or Softeh. It is placed between Mizan weir and Shadorvan weir. This Ghanat goes back to about 2000 years ago based on the new drillings, Ashkanid era. The general shape of this water supplier canal has 2 canals drilled beneath an old castle called Salasel which is like a hill at the present time. These 2 canals joined after getting out of the castle and formed one canal. After passing a curved path about 700 to 800 m. in a form of a closed conduit, before Shadorvan weir, it continues its path in a form of an open canal. This canal continues about 2 km. in a form of one canal and then in a place called Khak weir divided into two branches. Khak weir is one of the important hydraulic structures of Darioon system that had a significant role in controlling floods, and other applications such as water storage and water mill. This weir was the bypass of Darioon canal in the curved part of this canal [7]. The first branch of Darioon canal continues to the west and after about 33 km. enters Shoteit River in a weir called Arab Hasan. The minor branch called Raghat after passing a short way (5 km.) reaches the Gargar River. At the Salasel castle, this canal has several tail water for water abstraction, two are inside and the rest outside of the castle; out them, two are without any damage. By taking into account the appearance, the first tail water inside the castle probably was used in hot summer. Many canals were drilled beneath this castle and the water marks on them prove the fact that water had passed through them. The reason for drilling these canals is unclear, but it can be assumed that they were used for water abstraction due to the fact that in places like tail water, ladders can be seen with wide areas probably for water abstraction. The geographical coordinates of the two tail water that are in shape are as follow:

The tail water inside the castle: 32”03’14° north and 16”51’ 48° east.

The tail water outside the castle: 32”03’15°north and 48”51’12°east.

This large canal doesn't have the known characteristics of a Ghanat, e.g. due to its large dimensions and long horizental canal of the Ghanat no one considers it as Ghanat. But by a closer look, we can consider that it is oriented from other Ghanats of Shushtar which is used for irrigating 33 thousand hectares of Mian Ab farmlands and until 2000 had the main role in water supply for Mian Ab. Recently Khuzestan Water and Power Authority has revived this canal for irrigating farmlands in Mian Ab.

GALOOGERD GHANAT

This Ghanat or Softeh for the first time introduced in a book Water and Technology [2]. The main water supplier of this Ghanat is Karun River. The end of the Ghanat, the place were water comes out of the Ghanat, is located approximately 2 km upstream of Karun divergence to Shoteit and Gargar (Sabzeh Meidan village) in order to irrigate farmlands in Mehdi and Maleki villages. As it is quite clear from the pictures, taken in 1964, it seems that this Ghanat was in operation until this year. According to the local people, before the entrance of sewage water from Shoshtarno area and coastal town, this Ghanat was a resting place for livestock. This Ghanat or Softeh destroyed and changed to a settling area. Based on the 1964 pictures(Figure 3), the length of the Ghanat was 2 km. and it had 94 bars and most parts of it had drilled in Aghajari formation.

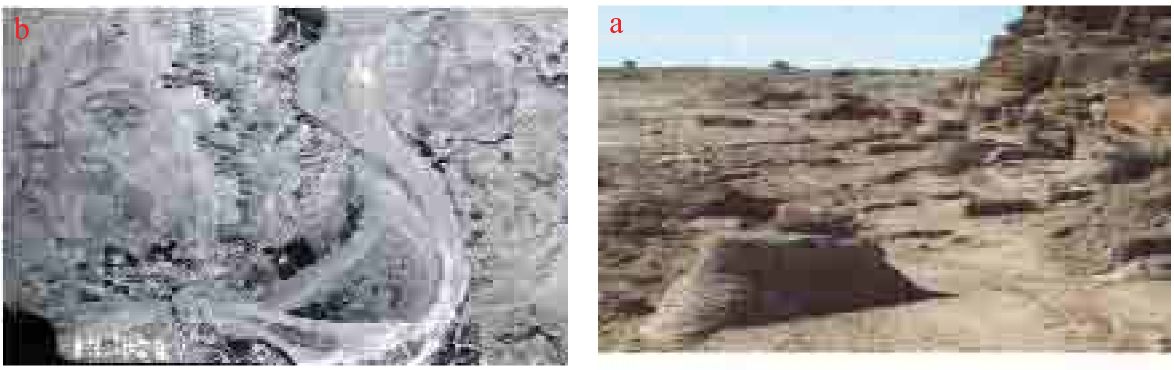

Figure 3 A)Bars of galoogred Ghanat [2] b) The aerial pictures of Ghanat and under irrigation lands(red points).

MAHIBAZAN WEIR

Approximately 4 km. downstream of Shushtar, a natural sand and stone layer has covered all over the width of Gargar stream that protrude out of water during summer. The natural condition of this layer indicates that the primary residents of this area were familiar with dam construction technology. Therefore they constructed a weir and bridge from stone and 3 of its pillars are still present [2]. The condition of this structure is the same as other Sasanid structures. The goal of its construction was not only crossing the river but also supplying water for both sides of the river. The water enters underground canals (that are like Ghanat or Softeh) and in a slightly far distance flows on the ground. Its shape and water supply process resembles Arjan weir on Marun River near Behbahan city [3]. But at the present time no structure was found to be similar to Softeh or Ghanat and the river route has changed during past years, right bank has enlarged, left bank has ruined and changed to bed. There are only three pillars located in a fish farming basin completely stick out of water. The condition of the mentioned sand stone layer is apparent in this weir. Just one point should be taken into account which is the existence of a spring with high discharge near this weir. This spring is supplied by the river and perhaps the high flow is from one of the above mentioned Softeh which is routed to this point. It also should be pointed out that this spring now is used for growing rice and moreover its discharge almost has no change during a year. Since several years ago certain parts of this structure were present and it was used as a resting place, but it is completely wiped out due to the construction of Gargar fish farming basin in its right bank.

DOKHTAR WEIR

Of other Ghanats which had existed in Sushtar were Dokhtar weir Ghanats but at this time none of them are present. Only in some books there are indications of these Ghanats. Certain parts of a large weir still exist in north of Shushtar known as Dokhtar weir that are assigned to Anahita, the goddess of flowing water [4]. Dokhtar weir had stored Karun water in a reservoir and after that water flown out of this weir from 4 Ghomsh or Softeh on both sides of the weir and irrigated the farmlands at both sides of the Karun River. Certain wells of these ghants are still present around the Karun River.

JIJAL VILLAGE GHANAT

This Ghanat is located 8 km. east of the Shushtar in 32° and 01" northern, 48° and 56" eastern geographical coordinates. The exact length of this Ghanat is not known and about 84.3 m of its length is in Aghajari formation. The history of this Ghanat goes back to the period before Islam by considering other stone Ghanats in southwest of the country, at the time of the Shushtar progress in Sasanid era. This Ghanat which is the sample of past people hard labour and is an honor for people today, was not completely active and water goes out through bars. According to the owner of the Ghanat, it has 3-4 liter discharge now. (Table 2 shows the quality of this Ghanat in 7 samplings). Although stone Ghanats are less in number they have a significant role. A number of these Ghanats are found in southwest of Iran which have a main well and some bars in stone and other in alluvium. Jijal Ghanat is one these stone Ghanats.

Table 2. the results of chemical experiments of Jijal Ghanat water.

num	10^6* EC	PH	T.D.S P.P.M	CATIONS(Milli Equiv./Liter)					ANIONS(Milli Equiv./Liter)				S.P.	S.A.R	CLASS	C_3^2
				Ca	Mg	Na	K	SUM	HCO	CL	SO_4	SUM				
1	2232	8	1757	11.20	7.30	7.80	0.17	26.47	2.40	3.90	19.90	26.25	29.50	2.60	C3-S1	—
2	2120	8	1736	11.7	6.80	7.70	0.14	26.34	1.80	3.70	20.62	26.12	29.20	2.50	C3-S1	—
3	2110	8.6	1731	10.6	7.90	7.70	0.14	26.34	1.81	3.70	20.61	26.52	29.20	2.50	C3-S1	0.4
4	2126	8.5	1733	11	7.30	7.80	0.13	26.33	1.60	4	20.21	26.21	29.70	2.60	C3-S1	0.38
5	2110	8.2	1727	10.9	7.50	7.70	0.14	26.24	1.80	3.70	20.52	26.02	29.30	2.50	C3-S1	—
6	2150	8.3	1739	10.42	8.03	7.30	0.13	25.88	2.26	3.70	19.70	25.66	28.20	2.40	C4-S1	—
7	1970	8.4	1698	9.70	8.70	6.85	0.11	25.36	1.80	2.90	20.43	25.13	27.01	2.30	C3-S1	0.22

ABID GHANAT

The ruins of this system are located somewhere between Dezful and Shushtrar cities near farmlands in Abid County where traces of Aghajari and Bakhtiary formations are found. One of the Ghanats in this system is at N 32º 17´ and 48º 42´ E, however, the geographical location of two other Ghanats is not known yet. This system dates from 1847. Three Ghanats have been established in this area while only two of them have been investigated through observations. The local residents believe that the water supply to the system was a surface supply, but due to the extensive changes to the surface over years the hypothesis is very difficult to measure. The remainders are now only consisted of several bars. Based on the observations and evidence it can be concluded that these Ghanats contained water until 18 to 20 years ago. Even today some of the bars still hold small quantities of water. It should be noted that over time this system has been buried under alluvial yields from Bakhtiari formation. The depth of the horizontal canal of the Ghanat is estimated to be 2 to 3 m. Also the remains of the old water mills using the water supplied by these Ghanats can be seen in the area indicating a high discharge at the Ghanats.

Discharge & covered area of Ghanats

"Table3" the high discharge from Shushtar's Ghanats and softeh and their relatively vast covered area.

Table 3. Discharge rate and the mentioned Ghanats and Softeh under irrigation lands.

num	Name of Ghanat	Average discharge (lit/sec)	Length of Ghanat (m)	irrigation lands (km2)	Source
1	***Jijal***	10	84.3	——	Water grand
2	**Abid**	250	3000	1	Water grand
3	**Darioon**	6556	200	330	Shotate river
4	***Gargar***	70	800	0.03	Gargar river (Rhite)
5	**Gargar**	70	1500	0.15	Gargar river (lefte)
6	**Galoogerd**	520	1200	2	Karoon river (Rhite)

CONCLUSIONS

Applying knowledge and complicated water structure of the time such as softeh (Darion and Gargar), Ghanats (Galooard and jijal), dykes (Band-e Mizan and Band-e Khak,) weirs (Shadorvan and Lashkar), water storages (Aghili), water mills (Shushtar waterfalls) bathes (Khan bath), traditional streams (Darion irrigation network), ancient Iranian engineers in Shushtar supplied water to satisfy various drinking water, agricultural, health, etc, demands through an proper and efficient management practices. These hydro structures can be of interest to water science investigators and engineers. Water demand in residential and agricultural areas above the water supplies level (mainly rivers) led to the invention of river karizes in Shushtear and Dezful with unique characteristics in order to exercise a proper management over land farms and efficient use of surface water resources. Recently, eight different Ghanat systems were recognized across Shushtar district, 4 of which were fed by Karun River. While theses Ghanats display an interesting ancient engineering and architecture, they have been severely damaged and disappeared in recent years due to the exceeding use of pumps, wells and other water structures in the area. Through extensive, yet careful investigations it will be likely to use these cost-effective and easy-to-build systems or a mix of them as alternatives to the current high-cost irrigation water network and municipal water system projects with least probable disturbance to the ecosystem and environment of the region.

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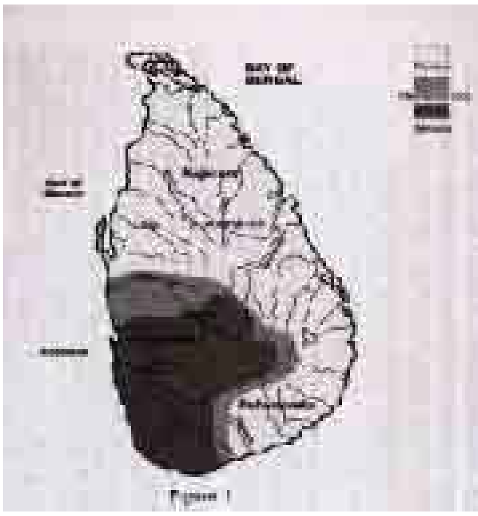
ANCIENT WATER AND SOIL CONSERVATION ECOSYSTEMS OF SRI LANKA

D L O Mendis[1]

INTRODUCTION

Background: Sri Lanka is an island in the Indian ocean, located between 6 and 8 degrees latitude north of the equator, at the southern tip of the Indian sub-continent. It's area is approximately 65,000 sq. kms or 25,000 sq. miles, and it experiences two monsoons, the northeast monsoon between October and March, and the southwest monsoon between April and September, with inter-monsoon rains as well. The southwest monsoon rainfall is largely intercepted by a south-central hill massif, and then blows over the northeast region as a dry wind, whereas the northeast monsoon rainfall is spread over most of the island. Consequently, a wet zone and a dry zone, with an intermediate zone lying in between, is recognized in the country today. In ancient times, however, there were three regions described as Rajarata (King's country), Ruhunurata and Mayarata. On account of the rainfall pattern and the topography, many of the 103 rivers in Sri Lanka rise in the central highlands and flow in a radial pattern to the sea. Perennial rivers are called *ganga,* and non-perennial rivers and streams are called *oya, ara* or *ela* in Sinhala, (the Sinhalese constituting 74% of the population), and *aru* in Tamil. (Figure 1).



Sri Lanka is unique in that it has a written history, that goes back to the mid first millenium, BC. The actual writing was done on what are called ola (palm) leaf manuscripts some centuries into the Christian era. These are confirmed by contemporaneous stone inscriptions and other sources recognized by historians. (History of Ceylon, 1959, 1960). We learn that, beginning in about the mid first millenium BC, an extensive system of water and soil conservation had been created, that is still in use, and it is recognized as a wonder of the ancient world. Its purpose was to conserve the excess rainfall of the northeast monsoon for agricultural production, mainly irrigated rice, which is a water intensive crop, and tropical climatic conditions in Sri Lanka are ideal for its cultivation throughout the year.

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Features of this water conservation system were river diversion structures, and storage reservoirs, in the ancient Rajarata and Ruhunurata, the modern dry zone. The former included stone anicuts (anicut being a word derived from the Tamil language) or weirs, called *amuna* in Sinhala and *tekkam* in Tamil, that diverted stream flow for irrigated agriculture, and for storage in reservoirs, as well as small earth dams called *vetiyas*. These latter structures were designed and constructed to check surface runoff from rainfall, in small non-perennial or seasonal streams, the *oya, ara*, and *ela*, the runoff being stored in the earth itself. The storage reservoirs were small, medium and large scale, and there was a symbiotic relationship between diversion systems, vetiyas, and storage reservoirs. The functions of the systems were irrigation, flood control, and drainage, as well as conservation of the environment, both flora and fauna, the latter after the advent of Buddhism in about 223 BC. (Weeramantry, 2000). However, the predominant function down the ages has been irrigation, and these human-made ecosystems are usually described as irrigation systems. Three important aspects of these water and soil conservation ecosystems are, their

- evolution and development over a period of more than 15 centuries beginning in the mid first millenium BC
- stability and sustainability over this long period
- final apparently irreversible decline after about the 12th century

A comprehensive statement on the ancient irrigation system of Sri Lanka is a 1997 judgement in the International Court of Justice (the World Court) by its Vice-President Dr C G Weeramantry, the *Separate Opinion* in the Gabcikovo – Nagymaros case (Danube dam case) (Weeramantry, 2000). It strengthened awareness of the damage done to ancient water and soil conservation ecosystems of Sri Lanka, in the name of development, that leads to mal-development and conflict, discussed in this paper.

Hydraulic engineering vs. Water and soil conservation ecosystems, perspectives:

A hypothesis (Brohier, 1956) that was re-published by Joseph Needham in 1971, described the evolution and development of the ancient irrigation systems in four consecutive stages. (Figure 2, alongside). This hypothesis is based on a simple hydraulic engineering perspective, for the sequential development of storage reservoirs according to increase in size. An alternative seven stage hypothesis based on an ecosystems perspective (Figure 3, page 4) was proposed by this author who was then invited to work at the Needham Research Institute in Cambridge, England, in the 1980s and 1990s, under Dr Joseph Needham, who wrote: *"My treatment of the subject can be improved upon and I am counting on you to do it"*.

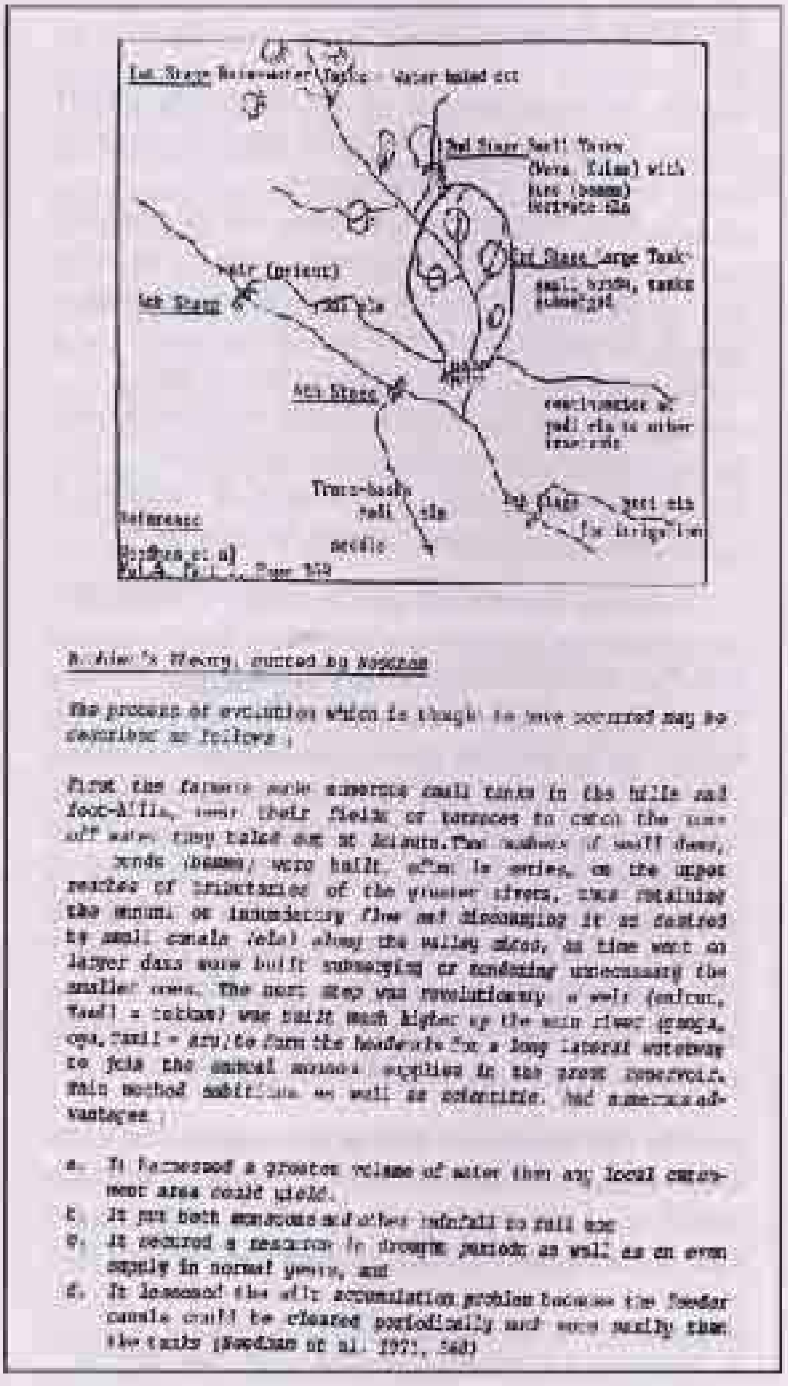

Figure 2

The hydraulic engineering perspective is well illustrated by the following extract from an Irrigation department Reconnaissance Report for construction of a new large reservoir, Heda oya, which however has not been constructed for other reasons. (Kahawita, 1950):

The development of Heda oya is recommended as it compares very favourably, from technical and financial viewpoints, with other major schemes already undertaken by government. There does not exist any doubt as to the need to achieve self-sufficiency in food. This is an achievement that cannot be realized by spending large sums of money on tiny village tanks which do not have the staying power in a drought nor can a better standard of living be taken to a people depending on them. Vagaries of the monsoons and resulting destitution can be fought only by spending public funds on large schemes and not by creating little evaporating pans and relief works. The age of the village pond has passed away and the time has come to embark on large projects like the scheme under review.

Two comments are necessary. Firstly, the scathing reference to ‘little evaporating pans’ shows a type of contempt that is born of the urban citizen’s ignorance of the sociological significance of the village tank, which is recognized as the heart of the dry zone village in Sri Lanka. Indeed the name of a village is most often synonymous with the name of its village tank. Secondly, the ‘other major scheme’ referred to is the Gal oya project in the southeast of the island, the first large scale project imposed on ancient water and soil conservation ecosystems in recent times. The model for planning this project in the 1940s, was the Tennessee Valley Authority of USA, not the ancient irrigation systems of Sri Lanka.

[However, when TVA failed to deliver as promised, it became discredited in the USA, and this reflected adversely on the work of the USBR, the United States Bureau of Reclamation (Reissner, 1986). This news has never reached Sri Lanka, however, and Irrigation engineers continue to visit the USBR in Denver, Colorado, in connection with their work, to the present day. I think it should be the other way around - USBR personnel should visit Sri Lanka, and join us in studying the sustainability and stability of Sri Lanka’s ancient water and soil conservation ecosystems - many of which are still functioning as intended after more than two thousand years. This latter fact was also mentioned by Judge Dr C G Weeramantry in his celebrated Separate Opinion in the Danube dam case in the World Court in 1997, a judgement now much cited in the field of modern Environmental Law].

Contrasting consequences of the two perceptions are summarized in Table 1:

Hydraulic Engineering vs. Water and Soil Conservation Ecosystems

	Hydraulic engineering (Hard technology/Transferred knowledge)	**Ecosystems perspective** (Soft technology/Traditional knowledge)
1. Water	inanimate, active	animate, passive
2. Small tank	"inefficient" stage in evolution and development - to be replaced by large reservoir	micro-irrigation ecosystem - essential part of total complex of man-made ecosystems
3. Large reservoir	"efficient" system in combination with channel distribution irrigation system	macro-irrigation ecosystem with micro-irrigation ecosystems in its command area
4. **Diversion Channel**	built to augment a large reservoir - last stage in irrigated agriculture system	earliest stage in irrigated agriculture and evolution of ecosystems
5. Vetiya	"abandoned small tank"	deflection structure - micro water and soil conservation ecosystem
6. Downstream development areas	must be cleared of all vegetation to lay out channel distribution irrigation systems	designed as a series of micro water and soil conservation ecosystems
7. **Forest areas**	limited to catchment areas	not only in catchment areas - interspersed with fields in development areas for better nutrient flows

Table 1

The stability and sustainability of the ancient systems from the time they were built to the present day, may be explained in terms of the ecosystems perspective of irrigated agriculture, but not in terms of the hydraulic engineering perspective. However, in modern times, the hydraulic engineering perspective has held sway.

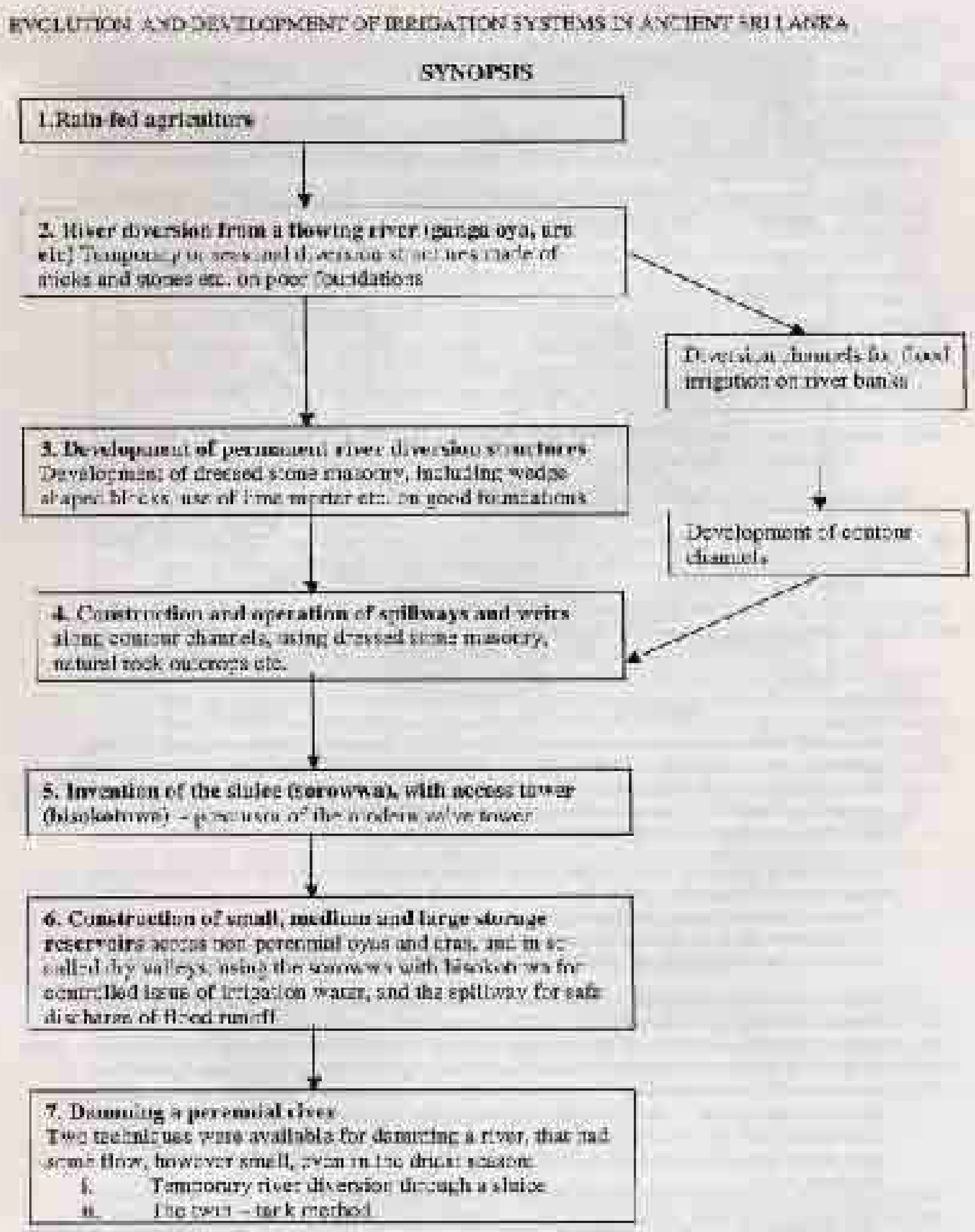

Figure 3

Water Resources Development Plan, 1959: A map titled the *Water Resources Development Plan* published in 1959, is based on the 4 stage hypothesis. Only the largest of the ancient reservoirs and diversion systems are recognized and included in this map. Smaller systems are ignored, or worse still, will be submerged under new large reservoirs identified on one mile to an inch topographical survey sheets, following the third stage of the 4 stage hypothesis. (Figure 2)

MODERN DEVELOPMENT AND UNDERDEVELOPMENT: ANCIENT RUHUNARATA

Ancient development – small tanks and vetiyas:

The topographical survey of Sri Lanka, then Ceylon, was a comprehensive ground survey completed in British colonial times. The one mile to an inch "topo" sheets, as they are called, give a wealth of information about ancient irrigation works. Unfortunately these topo sheets have been replaced recently by new metric sheets, based on aerial surveys, which do not carry the wealth of detail given in the older ground survey sheets.

An important one among the older topo sheets is the Timbolketiya sheet in the southern area, the ancient Ruhunurata, which shows the middle reaches of the Walawe ganga (perennial river). The Mau ara (non-perennial river) in the left bank of the Walawe basin has long been an enigma as shown in Figure 4 alongside and Figure 5.

Figure 4

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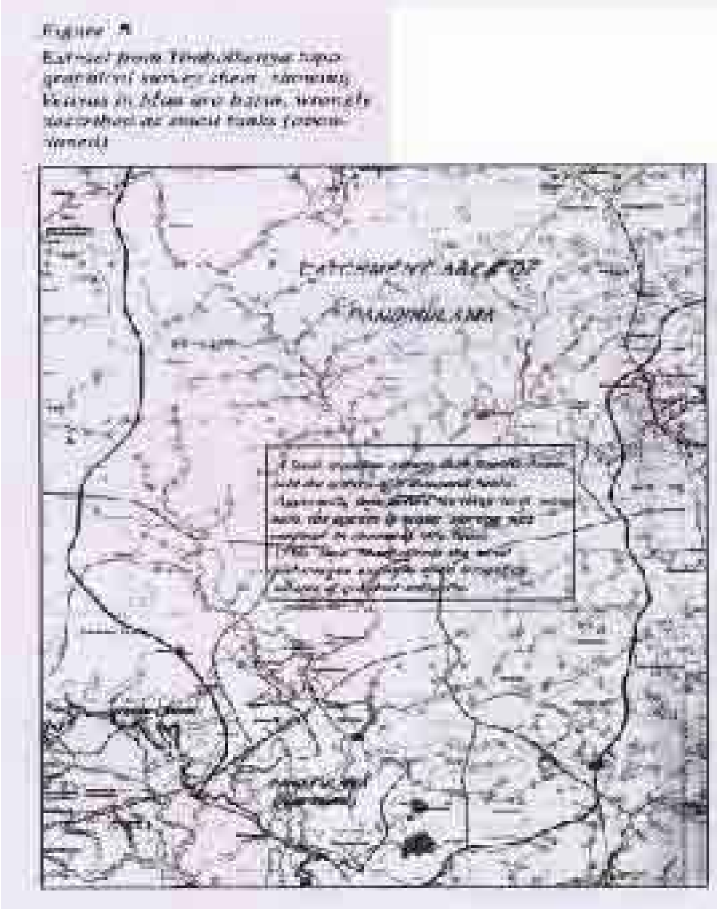


Hundreds of small breached earth embankments called bunds were found in the Mau ara basin, as well as three large breached reservoirs. (Figure 5) The small bunds were assumed to be the embankments of abandoned small tanks.
(see Box in Figure 5)

However, in recent times, it has been established that these breached structures did not have any sluices (Mendis, 1997 etc).

Furthermore, it was found that these earthworks are well known to local people as the *vetiya*, (Figure 4) an unique small embankment, built across non-perennial oyas and aras to check rapid runoff of rainfall and raise the water table in the reddish brown earth (RBE) soils in the surrounding area during the rain season.

Uda Walawe reservoir project:
The first new large reservoir identified from the Water Resources Development Plan, 1959, to be taken up for construction was the Uda Walawe reservoir. During construction of this project, in 1965 – 68, an alternative upstream location at Ukgal Kaltota, for a large reservoir in the Walawe ganga basin, was identified by this author in 1967 and given publicity. (Figure 6, alongside). (Mendis, 1968). This was the first serious critique of the *Water Resources Development Plan, 1959*, and it was not well received by engineers when presented at the annual sessions of the Institution of Engineers, Sri Lanka, then Ceylon. (Transactions, 1968). However, today there is general agreement that the upstream site is a better location for a large reservoir in the Walawe ganga basin, and such a location will fit into a long term development plan for the southern area, as discussed below.

Lunuganvehera reservoir, Huratgamuva site, and the proposed Southern Area Plan:

Lunuganvehera weva (reservoir) in the lower Kirindi oya basin (Figure 7) was the next large reservoir, after Uda Walawe, to be selected from the *Water Resources Development Plan, 1959*, for investigation and construction. An alternative location at Huratgamuva (Figure 7), upstream of Lunuganvehera, for a large storage reservoir in this non-perennial river basin, fits into a long-term development concept called the *Southern Area Plan* (Figure 8), prepared by an engineer, M S M de Silva, in the mid 1960s, while Lunuganvehera does not. This plan, also based on a hydraulic engineering perspective, envisages construction of large reservoirs in the southwest wet zone for flood control, and diversion of excess water to the southeast dry zone.

Figure 7
Lunuganvehera wewa and Alternative Huratgamuva site

Huratgamuva site had been identified and brought to the attention of irrigation engineers by Engineer M S M de Silva. This author who worked in the Ministry of Planning and Economic Affairs, at the time, brought the plan and Huratgamuva site to the attention of national planners in the early 1970s, but to no avail: Lunuganvehera weva had been investigated and was taken up for construction after a change of government in 1977, without investigating Huratgamuva alternative.

Lunuganvehera project has been plagued with problems, from the time construction started. Construction time doubled from the original 4 years to more than eight, costs increased exponentially, and civil disturbances resulted in the area. Two attempted insurrections against the government had originated in the southern area, the first in 1971, in the Uda Walawe project area, and the second, much worse, in 1988-89 in Lunuganvehera project area. They were both suppressed with much loss of life and destruction of public infrastructure and private property.

time! The following reference by this author to a 1992 study by Charles Nijman at the International Irrigation Management Institute (IIMI), now the International Water Management Institute (IWMI), describes some adverse consequences, in financial terms (Mendis Ed. 2003):

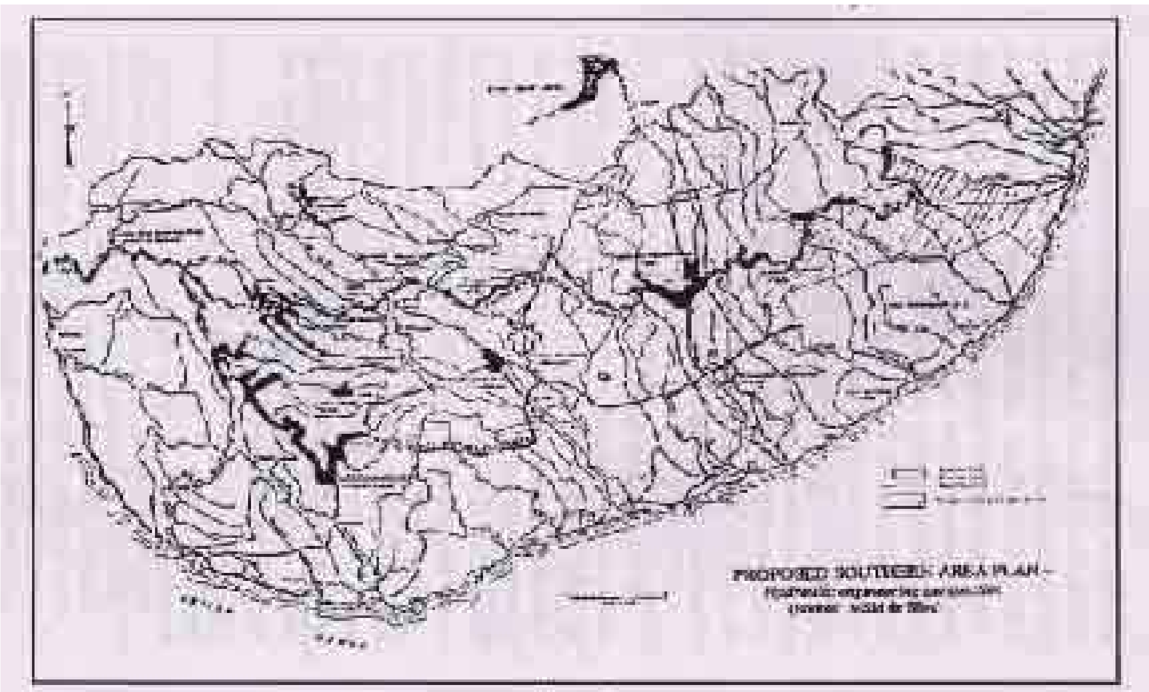


Figure 8

When Irrigation Ministry officials were planning Lunuganvehera project, directions given by the Prime Mnister in her capacity as Minister of Planning to investigate the alternative Huratgamuva site, were ignored, in breach of all norms and the State's Establishment Code itself, allegedly *to save time*! The following reference by this author to a 1992 study by Charles Nijman at the International Irrigation Management Institute (IIMI), now the International Water Management Institute (IWMI), describes some adverse consequences, in financial terms (Mendis Ed. 2003):

> *"In 1977 ADB approved a loan of $ 24 million and the Sri Lanka contribution was $ 6.5 million. Nijman says: 'In 1982, two years after construction activities started, the project was re-appraised due to cost escalations, and the cost was estimated at $ 106 million. Because the financing gap was considered too large to be met from available sources, and because of implementation delays, the government agreed with the Bank and the co-financiers to implement the project in two phases' ".*

Later, when various, diverse problems surfaced in the Lunuganvehera project, attention was focussed on shortage of water only, in accordance with the hydraulic engineering perspective, and a proposal to divert an adjacent river, Menik ganga, to augment Lunuganvehera reservoir was proposed and investigated. Following Amory Lovins in his Soft Energy Paths (Lovins, 1977), the question was then posed: *"If technology is the* *answer, what was the question?"* The point is that when hydraulic engineering is the cause, it is futile to seek a hydraulic engineering solution to these very problems.

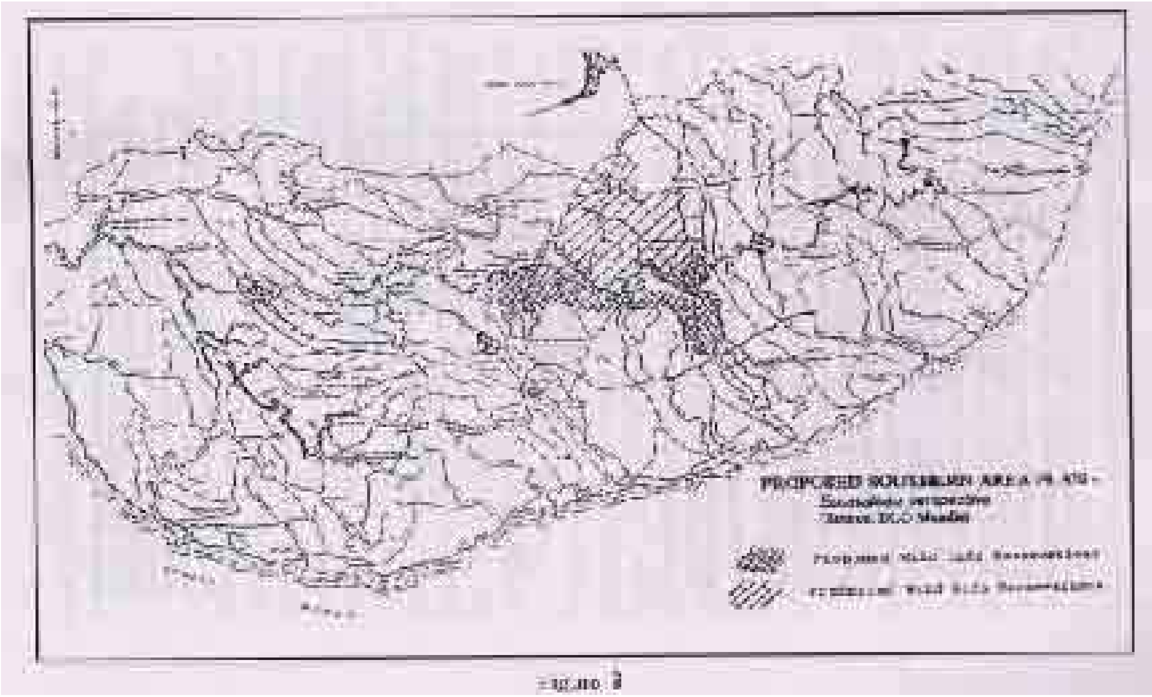
Instead, Huratgamuva, must be investigated, sooner rather than later, and another reservoir built there.

Storage in this new reservoir will irrigate new lands above Lunuganvehera, and the full supply level at Lunuganvehera, will be reduced year by year. Surface area of Lunuganvehera at FSL is over 10,000 acres. When reduced in stages, after Huratgamuva is built, land so released will also be cultivated. Also, the gigantic embankment of Lunuganvehera could be used for extensive housing and settlement, because it covers a very large area. A precedent for such a reduction in full supply level is the Allai Extension Scheme, where Allai tank is located close to the sea, south of Trincomalee, famous for its natural harbour. This author was an assistant engineer in Allai when this was achieved in the 1950s.

Other obvious benefits from construction of Huratgamuva reservoir will include regular re-use of irrigation water, availability of grazing land for cattle (Ruhunurata was once famous for its curd and honey), and conservation of the coastal mangrove swamps and wildlife reservations that are presently endangered, and causing much heartburn among nature lovers and environmentalists.

Huratgamuva also fits into the Southern Area plan which has a lot of potential for restoring the ancient water and soil conservation ecosystems in the area, and relieving the ever increasing conflict between the local peasants and wildlife, especially elephants, whose numbers are said to be decreasing at an alarming rate. This then would be the final permanent solution to a problem that will grow in intensity with the passing years unless faced with courage, especially by engineers, and resolved from an ecosystems perspective, sooner rather than later.

As preparation for this final solution, the Southern Area plan has been modified from an ecosystems perspective. This essentially envisages restoration of abandoned ancient small-scale reservoirs or wevas, vetiyas, and diversion systems, in the southeast dry zone, and relocation of the Uda Walawe National Park, (said to be home to nearly 300 elephants) prior to construction of large reservoirs in the southwest wet zone, as shown in Figure 9, below.



ANCIENT RAJARATA

Ancient development in western Rajarata:

R L Brohier had shown in a Royal Asiatic Society lecture in 1935, that all the ancient large reservoirs in ancient Rajarata were interconnected by means of human-made channels, natural rivers, and streams. (Figures 10 and 11). This was developed further by Nicholas and Paranavitana in 1960 (Figures 12 and 13). The outstanding feature on the western side of Rajarata, of this interconnected trans-basin system built down the ages, is the Kalaweva – Jayaganga ecosystem described as a cultural landscape (Mendis, 1997) (Figure 10). Systems of small storage reservoirs (called tanks after the Portuguese *tanque*) in Anuradhapura district in western Rajarata, had been constructed in cascades, when Anuradhapura was the capital city from about the 3rd century BC till about the 8th century. (Figures 14 and 15). Brohier had already discovered and documented these cascades, which he described as chains of small tanks, in his seminal 1935 R A S lecture as follows:

"The Jayaganga, indeed an ingenious memorial of ancient irrigation, which was undoubtedly designed to serve as a combined irrigation and water supply canal, was not entirely dependent on its feeder reservoir, Kalaweva, for the water it carried. The length of bund between Kalaweva and Anuradhapura intercepted all the drainage from the high ground to the east which otherwise would have run to waste.

Thus the Jayaganga adapted itself to a wide field of irrigation by feeding little village tanks in each subsidiary valley which lay below its bund.

The ancient water and soil conservation ecosystems of Rajarata are far better known than the ancient systems in Ruhunurata. Nevertheless, they were treated with disregard in two instances. On the western side of Rajarata it was the proposal to mine the Eppawala phosphate deposit to exhaustion in 30 years that would have destroyed the Kalaweva-Jayaganga cultural landscape. On the eastern side it is the proposal to implement the Moragahakande project that would destroy Parakrama Sagara. (Fig. 16)

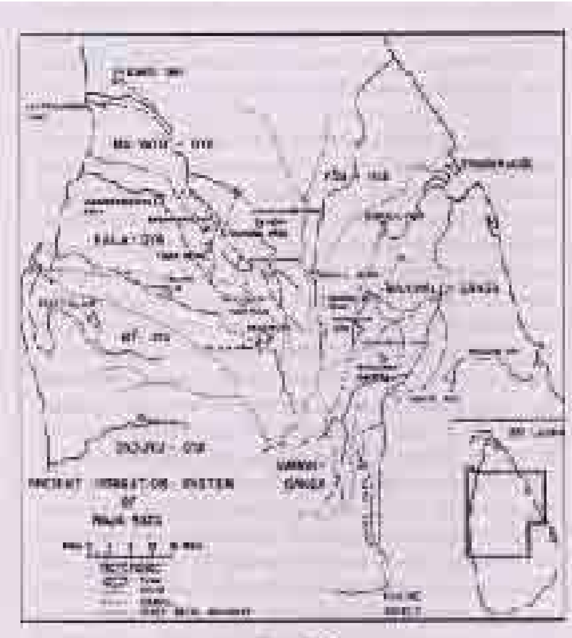
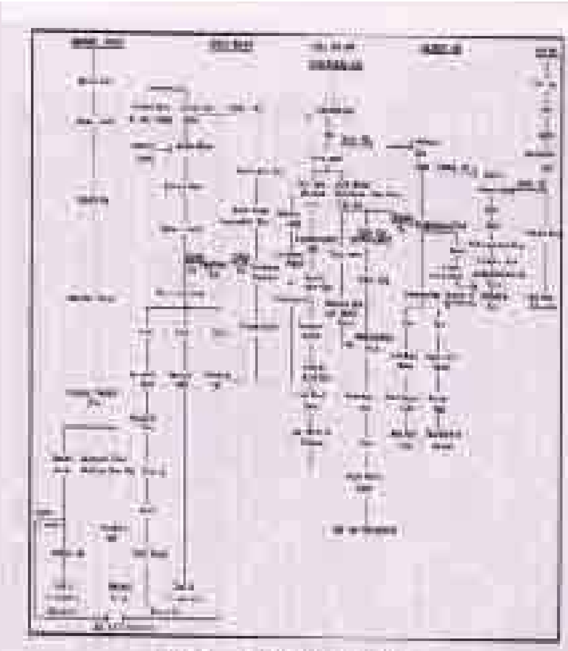
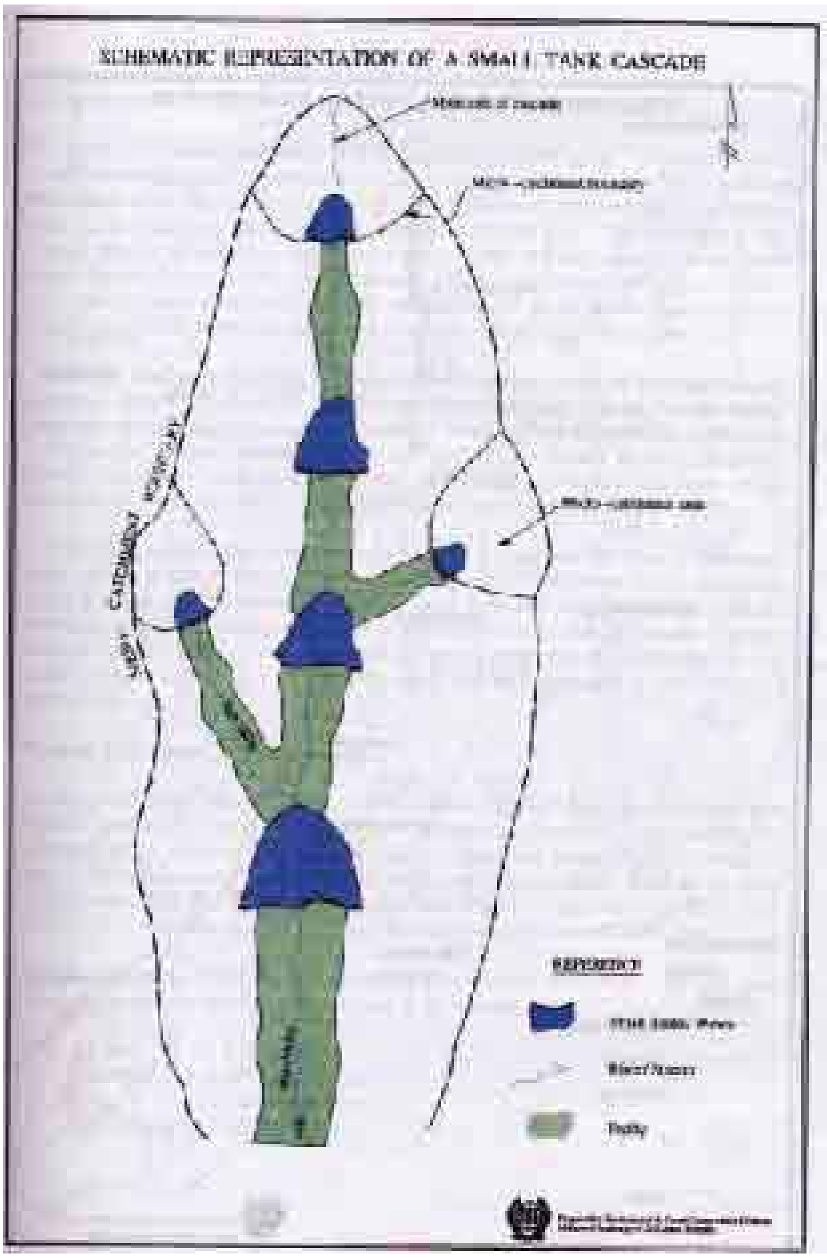


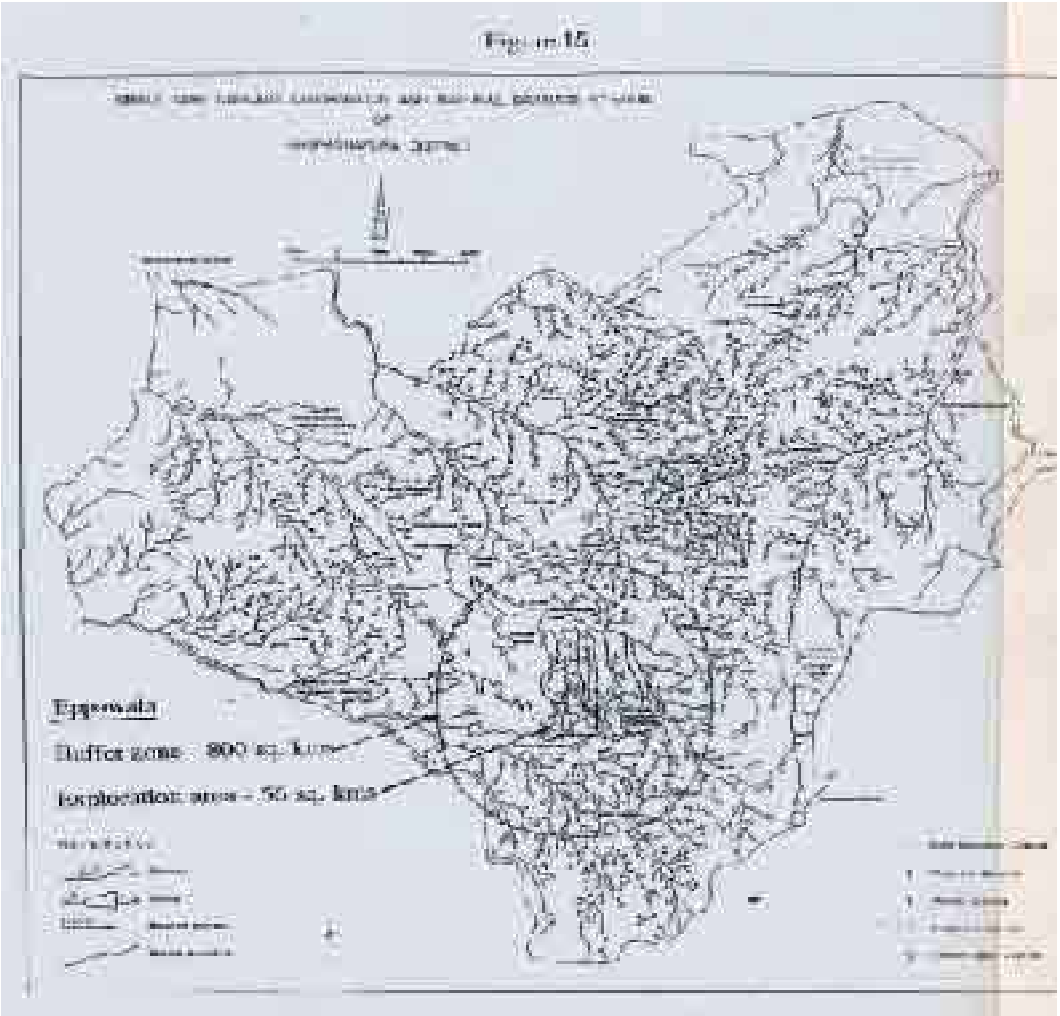
Figure 12



Eppawala phosphate rock deposit in western Rajarata:

A massive deposit of igneous phosphate rock was discovered by the Geological Survey and Mines Bureau in the western area of ancient Rajarata in the early 1970s. A proposal to mine this deposit to exhaustion was made in the 1990s, that would have destroyed the ancient water and soil conservation ecosystems in the area (Mendis, 1999). (Figure 15). A Fundamental Rights case was filed in the Supreme Court of Sri Lanka by local people, and a now much-cited judgement was given in favour of the plaintiffs. (Law Reports, 2000). Rice yields are known to be consistently higher in this area than elsewhere in Rajarata, and a research project to study the impact of the Eppawala phosphate rock was published by this author (Mendis, 2000), that was cited in the historic Eppawala judgement.





Ancient development in eastern Rajarata:

The eastern area of ancient Rajarata was the scene of truly spectacular development of water and soil conservation ecosystems over an almost unbelievably long period of eleven hundred years. The ancients made use of natural geological formations, and the rainfall and runoff in the area, in a manner that has surpassed anything modern engineers have developed. It is this fact, combined with a certain arrogance on the part of modern engineers, that has created problems in this area.

As shown in Figure 16, alongside, the topography in eastern Rajarata consists of anticlines and synclines located approximately north – south. A perennial river, Amban ganga, springs in the central highlands and flows initially in a northerly direction. Near the anticline called the Konduruweva range it turns eastward and breaks through the anticline. Further down river it breaks through the next anti -cline, Sudukande, and still further down it joins the main river Mahaweli ganga, the longest river in the island with the largest amount of runoff.

Figure 16 Source: Brohier, 1941

Development began in the 1st century, when King Vasabha (65 – 109) built a diversion weir, at Elahera on the Amban ganga just beyond the Konduruweva range, and the Elahera canal from Elahera to Konduruweva, (about 20 miles) (Figure 16). This channel intercepted in succession seven seasonal streams (oya and ela) from the Konduruweva range, namely Kongeta oya, Heerati oya, Bakumane ela, Kottapitiya oya, Attanakadawela oya, Hegolla ela, and Radakegey oya. For over two centuries this ***river diversion water and soil conservation eco-system*** irrigated more than 10,000 acres between Elahera canal and the western side of the Sudukande range, and generated enormous economic surpluses that were used to construct and maintain the irrigation ecosystems themselves, and also to build numerous religious edifices, stupas, temples etc. during this period (History of Ceylon, 1960), all of which are in evidence, and some in use, to this day.

In the 3rd century, King Mahasen (276-303) built Minneriya and Giritale reservoirs at the tail end of the Elahera canal as it then was, and it became the Elahera - Minneriya canal - in its entirety an unique water and soil conservation ecosystem at the time.

For the next three centuries or so, this eco-system generated more enormous economic surpluses that enabled extension of Elahera – Minneriya contour canal beyond Minneriya, crossing the non-perennial Gal oya, Alut oya, Kaudulu oya and Kitulutu oya seasonal rivers, in succession, (see Figure 11), harnessing their waters for irrigated agriculture on the eastern side of the canal. (King Aggabodhi I (576 - 608) is given credit by historians for constructing the Elahera - Minneriya canal extension, but it may have been built in stages over the years).

King Aggabodhi II (608 - 616) who succeeded Aggabodhi I, built Gantalawa weva (Kantalai tank) at the tail end of the extended Elahera-Minneriya canal, just as King Mahasen had built Minneriya weva at the tail end of the Elahera canal.

Finally, King Parakrama Bahu, (1153 - 1186) improved the Elahera-Minneriya-Gantalawa canal and strengthened its headworks to make the canal navigable from Elahera to Tambalakamam bay via Minneriya and Gantalawa (Kantalai). A British administrator Hugh Neville said that the improved headworks formed the second Sea of Parakrama, (Brohier, 1934, I, pp. 28-33), now identified as the **Parakarama Sagara** or **Koththabadhdhanijjara,** the second **Sea of Parakrama** of the Culavamsa (Geiger, 1959, 1960), (Mendis, 1977, p. 60). It consisted of seven reservoirs at different levels since there is a total drop of about 60 ft. from Elahera to Minneriya, and these reservoirs were interconnected by short lengths of canal which had canal locks incorporated to make it navigable.

It is thus seen that the Elahera - Minneriya - Kantalai system, was an extraordinary water and soil conservation ecosystem, comparable in every respect to the better known Kalaweva - Jayaganga ecosystem. In fact it may prove to be an even more incredible achievement than the latter, when all its finest aspects are studied and understood in a multi-disciplinary research study by modern scientists and engineers that is to be done under the *Science and Civilization in Sri Lanka* project in the Institute of Fundamental Studies.

MODERN DEVELOPMENT AND UNDER-DEVELOPMENT:

Moragahakande reservoir vs. Ancient Parakrama Sagara or Koththabadhanijjara:

The next large reservoir to be identified for construction from the *Water Resources Development Plan, 1959,* is Moragahakande reservoir and the North Central Province canal or *NCP canal*. Here is another dramatic example of the ignorance of history and a certain arrogance on the part of the engineers who prepared that plan, as will be seen in the following statement of facts.

Referring to Figure 16 and Figure 11, the Elahera-Minneriya-Kantalai canal was restored in modern times, on a crude hydraulic engineering basis, doing great damage to its original water and soil conservation ecosystems basis. Aqueduct crossings were constructed for the channel that did not harness the waters of the cross drainage streams. (Brohier, 1941). (The Herati oya crossing road bridge alongside the aqueduct crossing, for example, has some five spans indicating the huge volume of water that runs to waste under it).

The ancient Elahera canal thus became just another hydraulic engineering structure merely delivering water from the Amban ganga source to Minneriya and Giritale reservoirs at its ends. However, about ten years after this construction, all the aqueduct crossing structures were demolished and replaced by level-crossings as in ancient times. However, the ancient rock-cut spills and sluices had all been virtually destroyed when the hydraulic engineering restoration of Elahera-Minneriya canal been done. Later, extension from Minneriya weva was also truncated without rhyme or reason, from Gal oya, to augment the ancient Kantalai reservoir, under a project described as the *Kantalai Augmentation scheme*. (Figure 11). This description was suggestive of an application of the 4th stage in the four stage hypothesis for the evolution and development of the ancient systems, as shown in Figure 2.

- At this point, it may be repeated that irrigation is only one function of the ancient water and soil conservation ecosystems. But, so also were flood control, drainage, and soil conservation, for example, so that the term *ancient irrigation systems* is inappropriate and can be misleading - Some features of the evolution and development of these *water and soil conservation ecosystems* will now be presented using the example of the Elahera - Minneriya - Kantalai ecosystem.

When King Vasabha (65-109), built the Elahera anicut in the first century, some perennial river flow in the Amban ganga was diverted into Elahera canal for irrigated agriculture in the valley between the Konduruweva and Sudukande ranges. The Elahera - Minneriya canal is a contour channel with a single embankment on the eastern side, originally designed to also capture and divert water from the cross drainage streams rising in the Konduruweva range of hills in the west during the NE monsoon season. The excess flow was allowed to escape over channel spills built in the natural rock at appropriate points on the canal, as vividly described by the intrepid British surveyors Adams, Churchill and Bailey (Brohier, 1934, I, pp. 28-33). The Surveyors' Report was seen by the Governor of Ceylon, Sir Henry Ward, who then inspected the site himself and incorporated the Surveyors' report in his inspection Minutes. (Ceylon Almanac, 1857, reproduced in Brohier, 1934).

After a few centuries of this diversion irrigation system, Minneriya weva and also Giritale weva, were built at its tail end, by King Mahasena (276 – 303). At this stage the system was comparable to the better known Kalaweva - Jayaganga built later, but with one difference - there was no reservoir at its head end. There was still excess of water at the tail end Minneriya weva, and the Minneriya - Kantalai extension was therefore built. The extended system functioned like the Elahera - Minneriya canal, as a water and soil conservation ecosystem. Thereafter it must have been observed that there was still excess of water at the tail end of the Minneriya -Kantalai canal, which was why Kantalai weva was built at its tail end, three centuries later, and channels were built to reach the sea from this last great reservoir.

This system functioned for five centuries more amid various vicissitudes, including invasions and internal strife, until Parakrama Bahu I (1153-1186) unified the country, and consolidated the existing water and soil conservation ecosystems. He raised the original Elahera anicut and strengthened the channel bund to form Parakrama Sagara, the second Sea of Parakrama or Kottabadhdhanijjara, (translated by Geiger as a weir furnished with a reservoir, or a reservoir whose flood-escape was walled up), between the Konduruweva range and the Elahera canal. This must rank

as one of the greatest feats of hydraulic engineering in our history, equaling if not surpassing even the epic Kalaweva - Jayaganga ecosystem built some centuries earlier.

The Sea of Parakrama was not really one great reservoir, but a '*series of lagoons'* as the British Surveyors had described it. (Brohier, 1934, I, p. 28). This was because there is a drop in elevation of about 60 feet from Elahera to Minneriya, and the streams that spring from the Konduruweva range of hills met the Elahera – Minneriya channel at different, decreasing levels. The lagoons were joined by short lengths of channel in which the incremental difference in elevation was accommodated in ancient times by means of canal locks to permit water transport. Evidence of this is still available in the form of new shoots growing from the ancient *Orubenda Siyambalagaha* - literally, the '*tamarind tree on which the boats were moored'* (Ibid, 28). Dr Needham was very interested to know whether there was any evidence of locks on canals to facilitate canal transport in ancient Sri Lanka, as in China. I am ashamed to say that I had not recalled this evidence at the time that I worked under him at the Needham Research Institute.

This background of our cultural and economic heritage is unknown to those who have dismissed all this on account of a misguided sense of their own cleverness. These foolish engineers may be reminded what Henry Parker a British engineer who served in Ceylon from 1870 to 1901, wrote:

> *"If we rashly think, after a mere glance at the site (in comparison, on the other hand, with the actual practical experience of the Sinhalese for nearly 1000 years), that we can change all that, and effect untold improvements on the general designs of the ancient works we may find, when too late, that they were right and we are wrong. Experience constantly impressed on me that if there was one subject which these wonderful old engineers understood better than another, it certainly was the irrigation of paddy fields, and the designing, at least in outline, of the great structures which were needed for the purpose".* (Brohier 1934, I, p. 27)

There is no better example of what Parker has called "rash thinking" than the proposed *Moragahakande reservoir and NCP canal*, which has been launched on January 25, 2007. It is a meaningless alternative to the ancient river diversion cum reservoir ecosystem, built in stages in the Amban ganga region over a period of nearly eleven centuries, starting 20 centuries ago in the 1st century, as described. It should also be mentioned that there is a belief amongst some not so well informed people that the *Moragahakande reservoir and NCP canal* will transfer Mahaweli water to northern areas, even up to the semi-arid Jaffna peninsula. As a result, anyone who opposes this project may be accused of not wanting *"good Sinhala water to go to Tamil areas"*. (Mendis, 2002, p. 187) But it should be realized that even if water is not the limiting resource, this would involve lifting and pumping and create an unnecessary and unmanageable situation of sharing water in northern areas, when a far better alternative is available. This is the proposal called **A River for Jaffna - the Arumugam Plan**, already partly implemented. (Figure 17) which is not presented at this symposium.

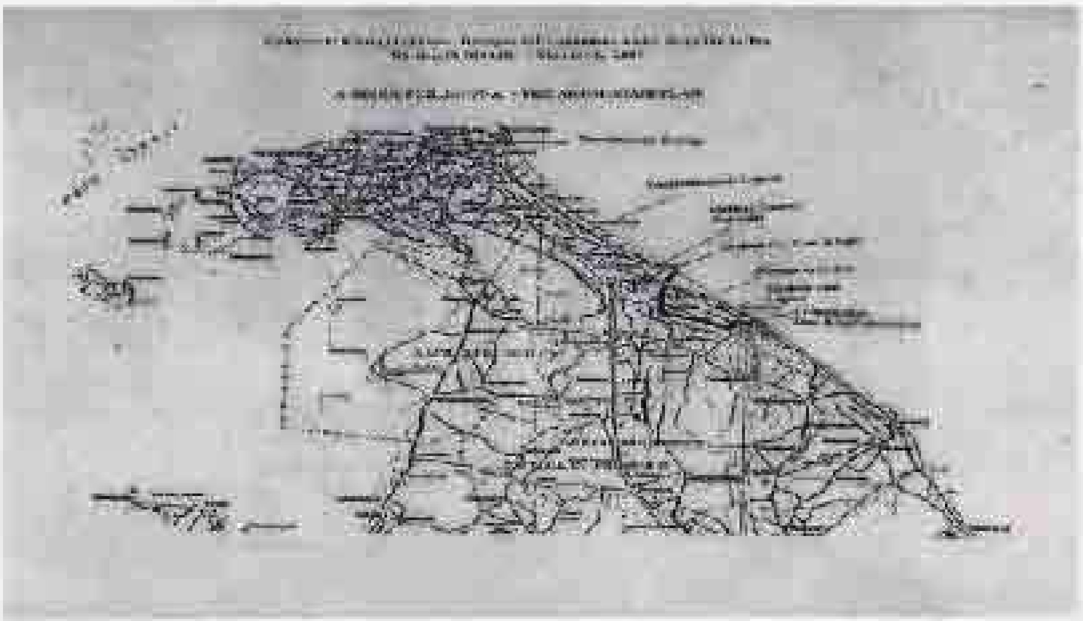


Figure 17

CONCLUSION

It is appropriate to conclude this paper with a reference to the truly arid lands of west Asia where water conservation has been practiced with a deep understanding of nature in accordance with Islamic law from ancient times. The following quotation is from the website islamonline.com.

WATER AND ISLAMIC LAW

The harsh desert climate of Arabia, the Near East, and Saharan North Africa makes water a highly valuable and precious resource. Islamic Law, the Shari`ah, goes into great detail on the subject of water to ensure the fair and equitable distribution of water within the community.

The word *Shari`ah* itself is closely related to water. It is included in early Arab dictionaries and originally meant “the place from which one descends to water.” Before the advent of Islam in Arabia, the shari`ah was, in fact, a series of rules about water use: the *shir`at al-maa’* were the permits that gave right to drinking water. The term later was technically developed to include the body of laws and rules given by Allah. Water is a gift from God. It is one of the three things that every human is entitled to: grass (pasture for cattle), water, and fire. Water should be freely available to all, and any Muslim who withholds unneeded water sins against Allah: “No one can refuse surplus water without sinning against Allah and against man.” The hadiths say that among the three people Allah will ignore on the Day of Resurrection there will be “the man who, having water in excess of his needs refuses it to a traveler.”

There are two fundamental precepts that guide the rights to water in the Shari`ah: *shafa*, the right of thirst, establishes the universal right for humans to quench their thirst and that of their animals; *shirb*, the right of irrigation, gives all users the right to water their crops. The Qur'anic metaphors in which water is used to symbolize Paradise, righteousness, and Allah's mercy are quite frequent. From numerous Qur'anic references to cooling rivers, fresh rain, and fountains of flavored drinking water in Paradise, we can deduce that water is the essence of the gardens of Paradise. It flows beneath and through them, bringing coolness and greenery, and quenching thirst. The believers will be rewarded for their piety by (rivers of unstagnant water; and rivers of milk unchanging in taste, and rivers of wine, delicious to the drinkers, and rivers of honey purified) (Muhammad 47:16). The water in Paradise is never stagnant; it flows, rushes, unlike the festering waters of Hell. The Qur'an also equates the waters of Paradise with moral uprightness: (In the garden is no idle talk; there is a gushing fountain) (Al-Ghashiyah 88:11-12).

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A SEVEN CENTURY OLD CHANNEL IN AZARBAIJAN

Navid Basseri[1], Kaveh Bijad [2], Farid Ghassemlou[3]

ABSTRACT

During the short period of Ghazan khan's government, the seventh king of Ilkhanid Empire (1293-1303 A.C.). There were some efforts to improve economic and social condition under Ilkhanid's government. These adjustments and revision actions were in the follow of slump, declining economy and decadence which happened after Mongol attack to Iran. After the destruction of economic infrastructure and massacre of Iranians and during the first wave of attacks, in trace with that menace society by starvation and epidemic disease. In this time Ghazan khan begun his adjustments and correction of tax flow. For this purpose he started to lease the land for long time period. This method named Siorghal. He tried to equalize unit and weight measuring system. It is also amazing that in this time, paper money issued this happen for first time in the world after publishing in china. Another infrastructure task of Ghazan khan was improvement of agriculture condition. He ordered to repair irrigation channels. This channels ruin after attack of Mongol to Iran and set aside because of poor maintenance and bad management. In category of repair and development of channels, one set is Parchi channels and their network. These channel located in Azarbaijan in North West of Iran at Ghotur River. The length of Parchi is about 30 kilometers and their duty are convey and provide water for irrigated land under these channels that estimated to be about 3500 hectares. In compare with today scales, design and build and maintain such a long channel is important by any way structure and maintain. This set is a great task in view point of engineering. In this article, after a short report from Ghazan khan adjustments in repairing and managing of channel and Qanats, authors will introduce Parchi channel and present the hydraulic characteristics of it. There will be also a glance to Khoy and its history.

1-INTRODUCTION

Along Silk Road and in the north west of Iran at Azerbaijan province a small city placed that named Khoy. This region is important geographically; historically and also important in agriculture product. Among long history of this city so many trade journeys, troops transport and war happen here. This region from west is neighbor to

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turkey and in the west neighbor to east Azerbaijan province and at the north near to Azerbaijan country Armenia and Nakhajavan. Khoy city consist of five parts that named Ivoghly, Chaipar, Safaeeieh, Ghotour and central part. from geographical sight Khoy placed in the vast prolific region that surrounded by high mountain because of lower elevation of Khoy relate to around in local language this area named Khoy Chokhory that in Azeri language means deep and dished. By elevation sight to this area height is decrease from west to east and south to north. With a little distance to Uremia Lake but in hydrologic sight this field is belong to Aras River and Caspian see. Khoy area in regionalism of country equal to 556093 hectares that the minimum level equal to 500 meter and maximum equal to 3622 meter

Khoy water resource provided from rivers, Qanats and deep wells. a river at Khoy environs that named Ghotour. This River emanates from turkey south mountains and after passing glen border between Iran and turkey come to Iran land.

For garden and champ irrigation of khoy and villages nearby several channel separate from river.some of this named as Shahr Arkhi, Badal-Abad arkhi, Beik Arkhi and Parchi. This channel get water separately from river beside that they may be in common in their path to farmland and garden they never each other in any reach of channel. One of the most important channel between these channel is Parchi this channel separate nowadays in place of Sonour diversion dam from Ghotour river. Based on an unwritten intense tradition among local people that Parchi channel have seven century age, despite of holly number seven outers of this article try to find out the archaism of this channel from cumulative evidence. Parchi channel has duty of providing water for Parchi village and area path to this village.In channel trajectory some building and one bridge seen that belong to bygone.

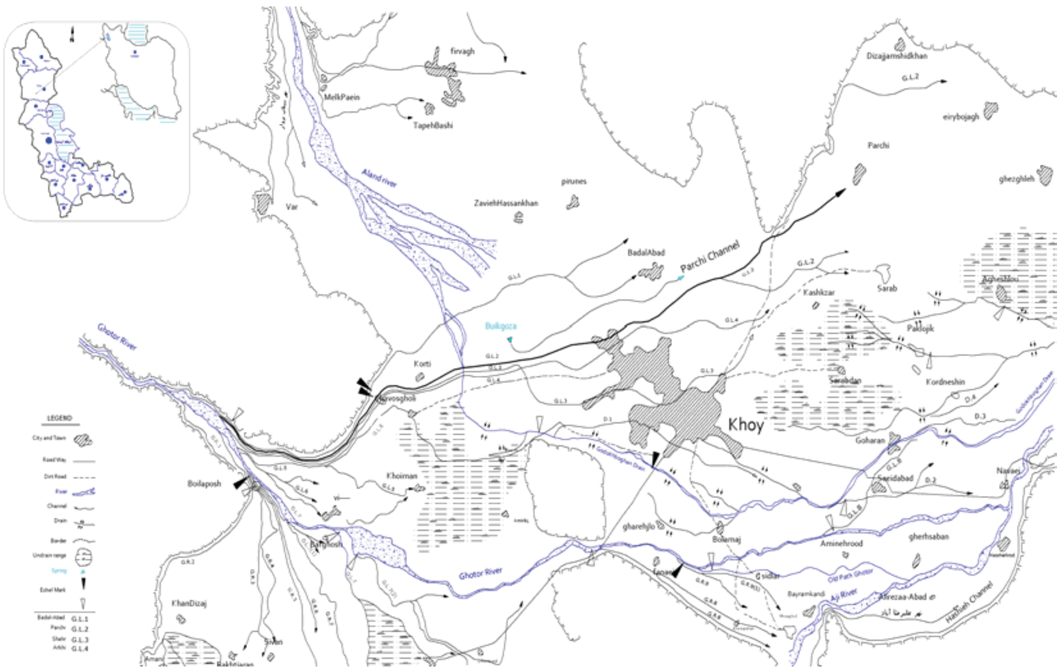

Figure 1- waterway plan of Khoy

In outers opinion of this article Parchi channel is one of miscellany channel work that done by Ghazan one of Iran Ilkhanan in years (1293-1303). Notwithstanding of many local and territory historical written about this time and scrutiny carefully but all historical source don't mention any thing about Parchi channel and related channel on Azerbaijan rivers due to this reason outers decided account for this hypothesis

1-Based on above writing at this area people have very strong verbal tradition and they believe that this channel construct seven hundred years ago at Magnolia Time. Important note that must be mentioned is nomination of place. In this area one of the rivers called Ghazan River the name of Ghazan khan ruler of Mongol in Iran at that time

2-Due to available evidence Parchi village is very ancient and parchi's people have occupancy life style and they lived there by planting and farming and almost they hadn't another way for reaching to water unlike Parchi channel and two or three Qanats. Nevertheless surprised about few number of structural construction from one side they hadn't enough reach and in other side this area have large earthquake that destroy many time all city and village. It is said verbally after one of earthquake from south gateway, north gate way had been seen and the last and most reason is number of war and troops transportation from there.

Figure 2- Khaton bridge

3-Ghazan rule in perilous time from Mongol government to Iran. Destroyed agriculture texture and economic infrastructure, insufficient maintenance of Qanats and dredging of channel network cause agricultural condition totally ruin. Ghazan notice to this qualification and decide do something. He with his wise assistant rashealdin fazloalah proceed some doing for improvement of Iran condition that will mention. This proceeding similar to construction of Parchi channel. some of these action are consist of diversion of channel from some famous river for example he ruled to diversion water from Dejleh and Forat and Karoon for increasing efficiency in agricultural field.

Main question that must be reply is based on dimension of Parchi for what reason in no historical reference we don't find any thing about Parchi channel and all history source are silent about Parchi channel first reason can put on table relate to amount of water that Parchi convey to farm and second reason is writing resource poverty and historical document that existence in Khoy area whereas several important historical and geographical documentary reference after Ghazan time like Mobarak Ghazani Tarikh Vasaf and Nezhatoalgholoub Hamdollahe Mostofi report some happens, works and constructions about important city and state like Gilan, Rey and Esfahan and define history about that time.

2-GHAZAN REFORM

Ghazan govern in time that first set of Mongol attack finished.In first attack period from years1283 A.C. and after first Mongol offense during downfall and ruin of city and village some Mongol treatment cause dimension of catastrophe become manifold. The new Mongol governor unfamiliar with principal technique in agriculture that contributes to Iran mature economy in contrast with morale rancher and nomad life of Mongol raider.Erroneous overtax naught rest of Iran economic infrastructure.

After this faults Mongol governor find out that a ruin country isn't good placed for administration. Ghazan ruling period belong to second period in the years. when sultan Abosaeed died and Ghazan, Oljaieto and Abousaeed Dominated.Ghazan with Rashidaldin (life 1247-1317 DC) guide try to rehabilitation destroy economy. Among the rest of reformation Ghazan done equalization of weights and dimension. Several weight and dimension vogue locally and cause many problem in trading with this based in year 1301 he ordered to equalized all weight by making some iron weight and send to all regions of country for make trade off with this weight. In trace of this reformation he order to register all estate transfer must be done with document and theme. For unique document registration this registration done after washing the last document and write new one with present of judgment and theme and they certify new document this rule is set because all estate have one landowner and one document. Also in tax gathering Ghazan set some new rule. He order to adjust old tax gathering law named Siorghal for land owner and tenant that is a Mongolian tradition. He order gather tax only two time in year in spring and autumn and all other tax omit for in this way for increase interest make commerce tax half.

One other work that done by Ghazan was organized financial turnover. He order make new unity coin in all country with same alloy and try prevalence bill for financial use. This bill in year 1294 D.C. available instead of coin and named Chav. At Mongol period this rectangular shape with some written in Persian and Mongolian propagated and cost from half Dinar to ten Dinar. From that point this Chav written by hand and set rule for cheater that killed with each member of their family and their possession lockup by government. Chav currency lead to a great inflation that an ancient country that ever had seen. After this inflation Ghazan ordered to gather all bill.

Without reformism action in agriculture and water resource that done by Ghazan it seems other action didn't have any success to improve people livelihood. Despite this action they didn't get strong to solve their problem. Based on writing of historian from this period in year 1298 A.C a great drought happen in middle period of Ghazan government that cause from deficit of rainfall. according to Rashialdodin Fazloallah in his written Tarikh Mobarak Ghazani that similarly repeated by Vasaf Alhazar this drought kill a large number of people and price of bread rise several time also according to this historian writing after drought starvation dominate and in follow cholera become epidemic in large region of Iran. Fazlollah also reported only from this disease several thousand of people died in Shiraz.

Ghazan and Rashid found out that if they want going out from problem they must revised in irrigation and convince of water and regenerate land ownership. According to experience that gather from century Iranian people take the water for their need by two way first by Qanat and second by river network. For dredging Qanat and action that they done we know something. For example Rashid in several place in his writing mention that Ghazan eager to dig and dredged Qanats. In conveyance field that connect this article to parch channel it can be counted by two samples from most important action that they did. one of this about digging a channel that order by Rashid to take water from Dejleh river and the same one done on Forat river. This knowledge about this conveyance channel gather from letter that Rashid written to his son, Jalaleadin the ruler of Rome. In one of this letter he order to his son on Forat river nearby Maliteh city dig a channel that convey water behind dam that construct on Forat river for this aim and irrigate lands nearby this city and after all convert extra and drain water to Forat river.

The same project must be done on dejleh river nearby Mosel city that conveyance channel almost length 160 km.

Petroshefski counted these actions as the most important perform that done by Ghazan and Rashidoldin for rehabilitation of Iran irrigation system and agriculture base.

It seems that Parchi channel is the same project that have done on Dejleh and Forat river but this river isn't famous as other and cause to prevent the construction of this channel come to historical book in Mongol period and then after That in Iran.

Figure 3 Ghotour river in Sonour

Of course this probable that Parchi channel construct along ages but regard to this subject this channel must be construct for convey water to Parchi village and nearby with other hydraulic slope and it isn't useful that get water from here from this high level position to send water locally, and in other side it doesn't need to construct with this dimension.

Figure 4 Parchi width view

Parchi channel has 30 km long and according to its slope and soil texture has different width from 7 to 3 meter and provides water need at least for 3500 ha downstream farm and garden. In this land cultivate sunflower wheat oily nuts and others.

Quantity of water use depend on right of use according to handwritten between villager and this water belong to them hourly.

Figure 5 Enter sediment to Parchi

3-HYDRAULIC PROBLEM OF PARCHI CHANNEL

Parchi channel to almost 30 years ago was only water provider for convey water to Parchi village farm land, after several dormant years and destroying tradition land management and after land reformation and situation of inefficient modern management that doesn't relate to cultural local society this channel set aside not completely but without any maintain until 15 years ago construct a diversion dam on sonour placed because of faulty design and entering sediment to Parchi channel this diversion dam can't do its duty and moreover seriously damage to nearby road and enter sediment to channel, after that people decide to destroy this diversion dam and build temporary dam like the last they could convey water to their farm land.

According of entering sediment to Parchi channel, bad maintenance, siphon clogging Parchi channel will died.

As mentioned Parchi channel has duty to covey 4 cubic meter to 3500 ha of Parchi villager farm land and more over to this channel three other channel convey water parallel of this channel without any unit management and separate in downstream farm land never gather together these channels in common path and make good lining for these channels and villager also prefer bad separate channel to nothing.

With digging well and deep well along last years in this area and come down the water subsurface almost all Qanat dried and farmer by deep their well try to get more water.

Nowadays wells and its equipments outwear and the wells slump down every day and it seems only one way can save water for them is regenerating Parchi channel some of farmer get this point and try do that lonely and owned budget that lead them to battle with each other and engaged them with hatred

4-SUMMERY AND CONCLUSION

Despite of long history behind water conveyance facility in parchi channel nowadays it needs use with good management and care. In long time it have shown people use this facility have best responsibility to that and government can make this situation better by organized them. One of the best formations is user. The user after formation around their requirement can get guide for better doing and using their potential effectively

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TRADITIONAL WISDOM IN MEDIEVAL WATER MANAGEMENT OF AURANGABAD CITY

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ABSTRACT

In the history of Aurangabad, the system of canals is ancient and memorable, which is introduced by Malik Amber in 1617 A.D. Aurangabad town always faced scarcity of water and there were no big dams or water reservoirs in the vicinity. Owing to hard rock & dry land, it was very difficult to construct the pillars to supply water to the town. This was the great feat of ancient engineering achievement. Malik Amber in 1617 A.D. discovered subterranean water table of mountainous elevated valleys in north of Aurangabad. He practically manipulated and procured a stable perennial water supply for a population of 7 lakh by constructing his unique Wonderful aqueduct by name KHAIR – E- JARI. The old water supply system is the reminiscent of medieval period. The city of Aurangabad was having number of Nahars of pu\re mineral subterranean drinking water. This practice of construction of such aqueducts continued from the period of Malik Ambar up to the time of Aurangzeb and Asif Jan (1803) for a period of about two centuries. On the high lands around the city from North, East and South wherever the circumstances allowed the engineers of the period brought down Nahars in Aurangabad city. Personalities like Malik Amber Shah Mehmood of Panchakki and shah Ali Nehri are founders, designers and planners of these three famous, wonderful easy and useful aqueduct system of Aurangabad. In order to cope up with growing population despite Ambri Nahar (canal) they dug several canals and they still exist. During the long period of three and half centuries this unique, God gifted old water supply system prevailed and lasted up till now, The inhabitants of Aurangabad were being benefited by this water supply system since three hundred years regularly without any tax. In our paper, the technical details of neher system is discussed in depth.

INTRODUCTION

In the history of Aurangabad Malik Amber in 1617 A.D introduced memorable system of water supply. Aurangabad city always faced scarcity of water and there were no big dams or water reservoirs in the vicinity. Owing to hard rock and dry land it was very difficult to construct the pillars to supply water to the town. So this was the great feat of

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medieval engineering achievement. Malik Amber in 1617 AD discovered subterranean water table of mountainous elevated valleys in north of Aurangabad. He practically manipulated and procured a stable perennial water supply for a population of 7 lakhs of people by constructing his unique Wonderful aqueduct by name KHAIR – E- JARI. The old water supply system is the reminiscent of medieval period. When we enter the town, we find numerous buildings, palaces, tombs, mosque, fortifications around the town, but same time, we see high rectangular or round pillars erected in the palaces. These high pillars are called "distribution chambers" which clearly indicate the medieval system of supplying water.

The city of Aurangabad was having number of Nahars of pure mineral subterranean drinking water. This practice of construction of such aqueducts continued from the period of Malik Ambar (1617) up to the time of Aurangzeb and Asif Jan (1803) for a period of about two centuries. On the high lands around the city from North, East and South wherever the circumstances allowed the engineers of the period brought down Nahars in Aurangabad city.

Personalities like Malik Amber, Shah Mehmood of Panchakki and shah Ali Nehri are founders, designers and planners of these three famous, wonderful easy and useful aqueduct system of Aurangabad. During the long period of three and half centuries this unique, God gifted old water supply system prevailed and lasted up till now, the inhabitants of Aurangabad were being benefited by this water supply system since three hundred years regularly without any tax.

During the military activities, Malik Ambar discovered the Kham river valley and its large natural basin of about 150 sq. miles over head of a well planned and layout city. Malik Amber has designed the construction of the aqueduct like that of Nahare Zubeda in a very simple appearance and natural way underneath the river bed of Sawangi and Kham river which has got number of man holes over head called Abgir Nali upto Gaimukh. An earthen dam was constructed on the river Kham on the north of Aurangabad city.

PLANNING DESIGNING AND CONSTRUCTION OF OLD WATER SUPPLY SYSTEM:

The old system of water supply was dependent on the canals. If we try to find out the origin of these canals out side the town we will find only huge land fields. At the origin there is neither any construction work nor deposit of water. As the origin of these canals are either in the lap of mountain or in the vicinity of river. Under the principle of gravitational power these canals were dug in the porous levels of land and they flow in the natural way. Geographically the town is surrounded by the mountains from all sides. The town is located in the valley. Hence most of the canals start from the mountainous field and end in the town. The most interesting and absorbing thing is the simplicity and uniqueness of these canals. There is no technical complication but still it is running successfully.Each canal is divided into two parts. First is conduit (Large pipe or water way) and the second part is a net of masonry pipes on which they erected rectangular or round pillars some times they are higher in a size and some times smaller. The cross sectional area of these conduits is based on the old engineering hydraulic & design system is an engineering marvel. In order to cope up with growing population despite Ambri- Nahar (canal) they dug several canals such as;

Nahar – e – Palsi, Nahar – e – Nasarullah, Nahar – e - Pan-chakki, Nahar – e - Lal Mahal, Nahar – e – Kiradpura, Nahar – e – Garkheda, Nahar – e – Koila, Nahar – e - Durga – Shab Ali Nahri, Nahar – e – Chausar, Nahar – e - Darga Hazrat Shab Noor Hashmi, Nahar – e – Begampura and Nahar – e – Chavni.

They utilize the local material and the peculiarity of these canals lies in the principle that the water stores and filters into it.

MalikAmbar was the commander of the Nizam Shahi Kings and Subedar of Daultabad: He was dynamic commander and a great engineer His system of water supply is first of its kind and also the last. In the year 1604 MalikAmbar made 'Khadki" present Aurangabad as his head-quarter and named it as Fateh Nagar. He introduced the system of water-supply for the public utility and this well-organised system is known as canal Ambari or Nahar-e-Ambari. In 1653, when Aurangzeb was appointed as the subedar of Deccan he made Fateh Nagar as his capital and named it as Aurangabad. When he became th emperor of the Mughal Empire he declared Aurangabad as the capital of the Mughal Empire. Owing to this reason the population of time grew faster and acture scarcity of water was felt. In order to supply water to the growing population he extended the system of water supply of Ambari and new canals were also dug. It is described that at the peak of Aurangazeb's reign the population of Aurangabad was about two lakhs. Besides nahar-e-Ambari there were 12 (twelve) canals which were sufficient to supply ample water to the town some of them are still functioning properly and rest of then can become permanent source of supplying water after the minor repairs.

NAHAR-E-AMBARI

Nahar-e-Ambari is a living memorial of Malik Ambar. He constructed this canal in 1029 A.D. and died in 1035. This is the biggest of all canals and still exists. In the northen direction of Aurangabad there is a range of mountains, but the most famous mount is Ju-ban. Adjacent to this mountain the Sangvi town is located. A mile away from this town is the origin of this canal. The total length of this canal is 14615 ft. or 2 ¾ mile. There was no distinct mark on this canal before 1322. but after 1322 Fateh Bhai, administrator of Aurangabad marked on this canal from beginning to the end. He also constructed in his supervision high & strong man holes. Due to these man-holes the cleaning & maintenance of the canal was easy. At the beginning of this site there is a man-hole & at the end of it is Gaye-Mukh. The difference of height these sites are 140 feet from the highest point of the town its starting point is 160 feet high. So the flow of this canal is based on the natural process of gravity modern engineers think, that it is underground streams of water. At the beginning man-hole was buff with porous bricks so that large quantity of water enter into if & the flow of natural underground streams of water also continues. At the complete length of this canal there are 100 man-holes through these the cleaning of the canal is performed. Savangi river is almost parallel to this canal. On one side of the river is canal Ambri & on the other side which is comparatively higher is Nahar-e-Nasrullah. The floor of the canal is lower at many places, the canal is dug in the porous layers of the ground so that large quantity of water may be supplied by the percolation. The peculiarity of this canal is that the water filters into it and the quantity of water also increases. At the beginning, they confined the natural underground flowing water and diverted into the canal subsequently so that the canal flows permanently.

The canal is in fact an underground stream of water. Its sectional area at the length of the canal is different, sometimes it is broader & sometimes it is narrow. This difference is due to the slope of land. Its shape and cutting is normally rectangular but sometimes it is trapezoidal the average width is 2 ½ ft. and height is from 2 ½ ft. to 15 ft. the canal is dug very deep under the ground but there is no masonry work on its two vertical sides. But above the vertical sides an arch of lime & brick is built. Bricks are red in colour and smaller in size. The rise of the arch is not more than 3 or 4 inches. The conduit of this canal is like a tunnel. Above this arch, earth filling is done so at some places the agriculture is also done. Man holes are strong and high rectangular tanks on which are stone coverings are fitted. So that the time needs if can be removed easily and the man could enter into it and clean it. There is a network of masonry pipe from Gay mukh. There is a particular reason because from have the land is uneven so it was not possible to supply water by the syphon system. There were two branches of the pipe lines one used to go upto Bara Dari Khurd-e-Kallan and second used to supply water to the remaining population of the town. The clay pipes are round were and its radius is 7 to 8 inches at the ends of these pipes are sockets by which they were connected and then they become solid and also the size of the pipe becomes longer. On the line of pipe in the town there are some hollow pillars made up of bricks & line & they are called Air-tower.

The purpose of the construction of these air-towers was that the air of pipes should be passed because these pipes all weak and they cannot bear the pressure of water secondly each air tower created pressure in water and in order to create velocity in the forward line of pipes so that it could get head of water and maintain balance. These air towers are often circular or rectangular. Out of these some are higher and some are less high for the pressure and head of water. According to the weather, the pressure of water and height decreases. In the solid towers, at the proper distance, there are many holes for the distribution of water. Irrespective of weather, the water was distributed in the different streets through these holes to the taps. Whenever they wanted to close these holes, the lids of wood were fitted. Out of these towers, they are some main (principal) towers & some are branch tower. The branch towers were connected to the common tanks and houses. Each tower has two vertical lines of pipes & they are parallel from pipe the water comes up and falls down from the other pipes and flows faster forward. For common people there were tanks in each street rayal & rich people used the pipe connection and tap water stored water in the tanks of their garden.

From Malik Ambar's age to Aurangzeb age about 100 years no canal was constructed. But during Aurangzeb's times some canals were constructed on the same principles. From Aurangzeb's time to the Age of Asfiya dynasty was the period of no activity in the regard. But after 250 years Nawab Mir Osman Alikhan Asif Jha Sabe paid attention and established protected water supply scheme in Raichor, Gulbarga, Warangal, Adilabad, Nanded, Bidar, Jalna, Osmanabad, and Nizambad. In the history the name of Nawab Mir Osman Ali Khan along with Malik Ambar, and Aurangzeb will be remembered. The recent water supply system of Aurangabad is a link of this chain. In this recent system the whole length of the canal is kept like the past upto Gayemukh but they some changes e.g. in the town instead of clay-pipe the new system pipes are laid down. This modern system of the net of taps is a part and pareel of Ambari system. Initially there were proposals of constructing a huge dam for the water supply of the town. But this scheme was very expensive and there were no huge sources of water like dam, river and wells in the town. So keeping in view the high expenditure required for this project the director of the water supply Mr.Ahmad Mirza continued Nahar-e-Ambari as a source of water which is completed in the supervision of the chief and Asst. Engineer. After the cleaning and restoration of the Nahar-e-Ambari canal at some distance of Gaye Mukh a setting tank is constructed. First the water stores in this tank and accumulates into clear water chamber and then by the chemical action it is cleaned and then falls down into service reservoir. Distribution reservoir is made inside Delhi Gate. In this reservoir filtered water is deposited and the from here it is distributed in the town cleaning of water is done either by the bleaching powder or chlorine. Although there is no heavy rains in the recent years and while cleaning the canal all the old principles were not followed, with which the ancestors were familiar. However, the Nahar-e-Ambari is being utilised for the supply of water except a few Hanes which are at the highest level. In older times the water was distributed permanently. But in recent times it is done intermittently and that is two hrs in the morning and two hrs in the evening. From Gaye Mukh to inside city instead of clay pipes the metallic pipes are put so that they could bear the pressure of water. In these pipes the main pipe of R.C.C. is put and others are metallic. Another small distribution of water supply was made little away from the Paithan gate at Kala Chabotra. From this centre the water was supplied to a number of lanes. This Kala chabotra is constructed by Malik Ambar. He uses to check his military from here. This reservoir is at higher level so the pump was used to fill the reservoir. For common people in the various lanes common tap or public stand post were founded. In the hours of rich needy the connection of water was given by the iron pipes.

When we compare our water supply system with the present system, we find a huge difference in indigenous system a single paisa was not spent abroad, but the whole amount was spent at the same place and if is utilized in the vicinity where there was no extra expenditure in filtering, depositing, cleaning or distributing the water. The water supply system of Aurangabad is on a very large scale but for the maintenance hardly little amount is spent and despite the meager spent on this old project, it continues to supply water over 300 years.

NAHAR-E-PAN CHAKKI

Around the town of Aurangabad Aurangzeb Alamgir constructed fort wall. In the western direction of the town, a river flows along the city wall. At the bank of the river, there is tomb of Baba Shah mastan and Hazrat Baba Shah Musafir Nagshbandi. Both the saints are buried at one place under a tomb. This site is known as Pan-Chakki. In ancient time a flour mill was run by the power of water. For this purpose, the nahar was brought from the distant mountain. The water of this canal falls through a wall which is constructed like a pillar. The water falls into a big tank. This monument is the wonderful specimen of the medieval engineering feat. It dates back to 17th century A.D. Rich people contributed in this regard and constructed different part of this monument. In the Panchakki water is brought down from the Kham river, which is about 8 k.m.

away from there in a mountain. The total length of this nahar is 4 km. it originates in the bed of kham river. The water is brought through clay pipes by the siphon system. The water ultimately forms an artificial water fall through a wall & stored in a big tank. The flow of this nahar is 1.78 MLD.

NAHAR-E-PALSI

The village Palsi is located in the East of Aurangabad. This canal enters through the Roshan Darwaza. There is a river near the village & this canal is dug from this river. This river is the memory of Aurangzab. Water was distributed by this canal to the neighboring lanes. This canal is in ruinous condition needs the attention of the present Govt. If necessary restoration will be done on this canal some area may get ample water though it.

NAHARE-E-BEGUMPURA

This nahar is known as Kishan Rao thathe's Nahar. In olden times this nahar was reserved only for Begumpura. Now it supplies water only to Bibi-ka-Magbara. The quantity of in coming water had diminished & so water flows only for six months.

NAHAR-E-NASRULLAH

This canal was constructed to supply the water to Roshan Bagh (Garden). It is constructed in the memorial of son in law or daughter of Aurangzeb. Formerly Roshan Bagh was watered by this canal but now it is in poor condition. Adjacent to Juban mound this canal starts from Savangi River from the starting point the river 1 ½ or 2 miles away is the site of Nasar ullah nahar, which is little away from Mahadev Kund in the north-east direction of savangi river. The traces indicate that river's trend were confined & transferred into the river. Owing to this reason it flows in every season although the river is located away from Nasrullah Nahar but at some places at the complete length of the canal is parallel. This canal passes from its starting point to Roshan Bagh through twelve small and large streams. The total length of the canal is about 2 miles. This canal is covered with small arches of bricks and lime 10 feet below the ground level. In the total length of this river, near ventilation no. 4 is a big nalla. Where the level of the arch and floor of nalla is similar. On this nalla the canal is broken and water wastage continues. The interior part of the canal is filled with silt. Here the ground dug area is 4 x 2 ½ ft. The ventilation number is temporary from its point of beginning there is no regular ventilation on this canal. Only a few pits at some places are the vague marks which serve the purpose of the ventilation. The conduit ends at ventilation no. 8. At this man-hole, a tank is made in which at higher is a tap of clay. From here till Roshan Bagh, the clay pipe of 7 inches radius is laid down. In the complete length of the pipe, there are eleven nallas. Syphon of pipes are made at two places at nallas and often build the two ends man-hole like a tank of air tower and these pipes are passed safely through it. On these pipes also two syphon and 17 raw man-hole and at the end is Air tower. From this last Air-tower till the man-hole no. 10 of Nahar-e-Ambari the connection is possible. This pipe between the man-hole & nallas have broken at several places due to old age & no maintenance has been done. The canal and pipe's alignment is not straight, on the contrary, it angle changes. In this canal, two more branch canals meet near man-hole no. 4 the dug are is 4 x 2 ½ ft.

NAHAR-E-DAGAH HAZRAT SHAL NOOR HAMVI

Hazrat Shah Noor Hamvi popularly known as Hamami attained 300 years age. He died during the time of Aurangzeb. This canal was constructed during the time of Aurangzeb for his Darghs. This nahar is in good running condition.

NAHAR-E-DARGHA HAZRAT SHAH ALI NAHRI

Hazrat Shah Ali Nahari was the saint during the time of Asif Jha I. he constructed the canal for himself. Hence he is famous as Shah Ali, Nahari, The dates of this brith & Death is 'not kwon' but the son of Asif Jha I. Nawab Syed Mohammed Khan Zafar Jung Bhadur gave some donation for maintenance of this canal in 1171 Hijri. So it proves that this canal was constructed before 1171 Hijari.

CONCLUSION

The 350 year old water supply system is working effectively without any maintenance, without silting and corrosion. The life of present water supply system is 30 to 50 years and with maintenance. The methods and materials used for neher system is available locally and constructed by local skilled and unskilled labour. This will helpful to solve water problem in developing countries.

REHABILITATION OF ANCIENT DIVERSION DAMS OF KOR RIVER IN FARS PROVINCE, IRAN

Masomeh Zand[1], Farshid Morshedi[2], Mahmud Javan[3]

ABSTRACT

The ancient hydraulic structures constructed on Kor (Araks) river are examples of the magnificent water engineering works achieved by the old Persian engineers. These structures were built centuries ago, yet some of them are still functioning well in controlling floods and diverting water to the farmlands. In this study some of the stability issues encountered in the rehabilitation process of Tilakan and Feizabad dams are discussed. Scouring depth and materials used for construction are evaluated in this study. The load conditions under which these stability analysis were made are also discussed.

Keywords: ancient dam, Iran, Kor river

INTRODUCTION

Iran is located in a semi-arid region of the world. Water shortage has always been a challenging problem for its people. Therefore, they have always been trying to find the proper solution. Many dams were constructed and underground galleries (Qanats) were excavated by ancient Persians. There are traces of irrigation canals about 6000 years old in the ruins of Sialak, near Kashan, in central Iran. Cyrus the great King of Persia after defeating the Babylonian Army in 539 B.C. built an earth dam for irrigation on Diala, a tributary of Tigris. He ordered excavation of 30 canals for water distribution works. The Persian King Darius the Great (521-485 B.C.) from Achamenian dynasty built dams on River Kor, south of Persepolis while he was in power (Javan, 1996).

Many of the ancient Persian hydraulic structures which were located in the Fars Province of Iran are introduced by Javaheri and Javaheri (1999, 2001).

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DESCRIPTION OF THE AREA UNDER STUDY

The Marvdasht and Korbal plains are located near the city of Shiraz, in Fars province, southwestern Iran (Fig. 1). The average altitude of the area is about 1590 m. The area is a semi-arid region with an average precipitation of 340mm per year. From agricultural and economical aspects, these two plains are very important in Fars province. The ancient palaces of Persepolis and Estakhr city have promoted tourism industry in these plains. Kor and Sivand rivers are the major rivers of the region. Sivand river flows into Kor river at Pol-e-Khan (Khan bridge) and discharges into Bakhtegan lake. In the last 80 kilometers of Kor river, six diversion dams had been constructed during the past centuries (Fig. 2). The dams were constructed of cut stones with Sarooj mortared joints (lime and ash). These multipurpose dams raise water level in the river and divert irrigation water to the farms. They also create the necessary head for several water mills and act as bridge between the banks of the river.

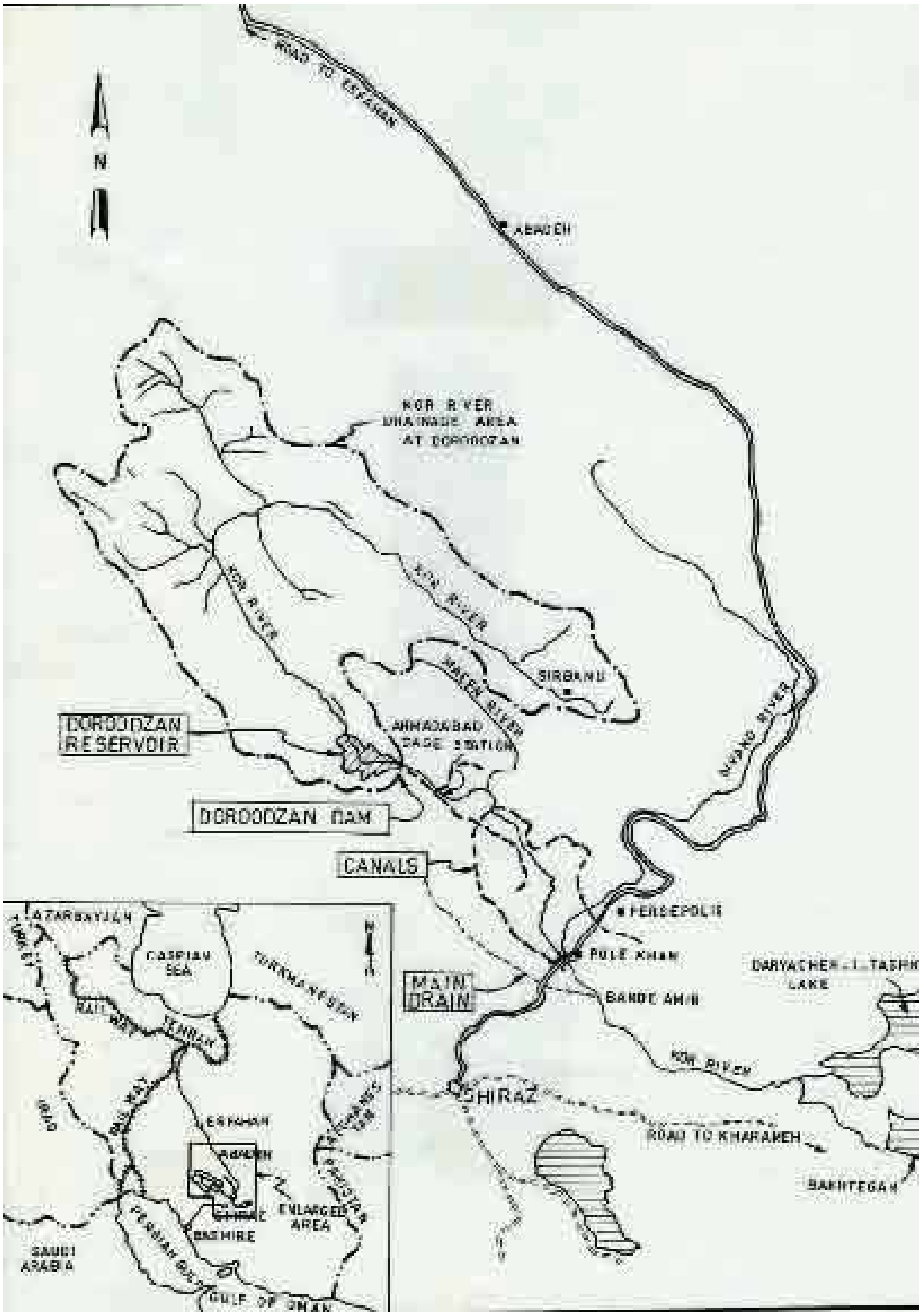

Figure1. Location map of the area under study

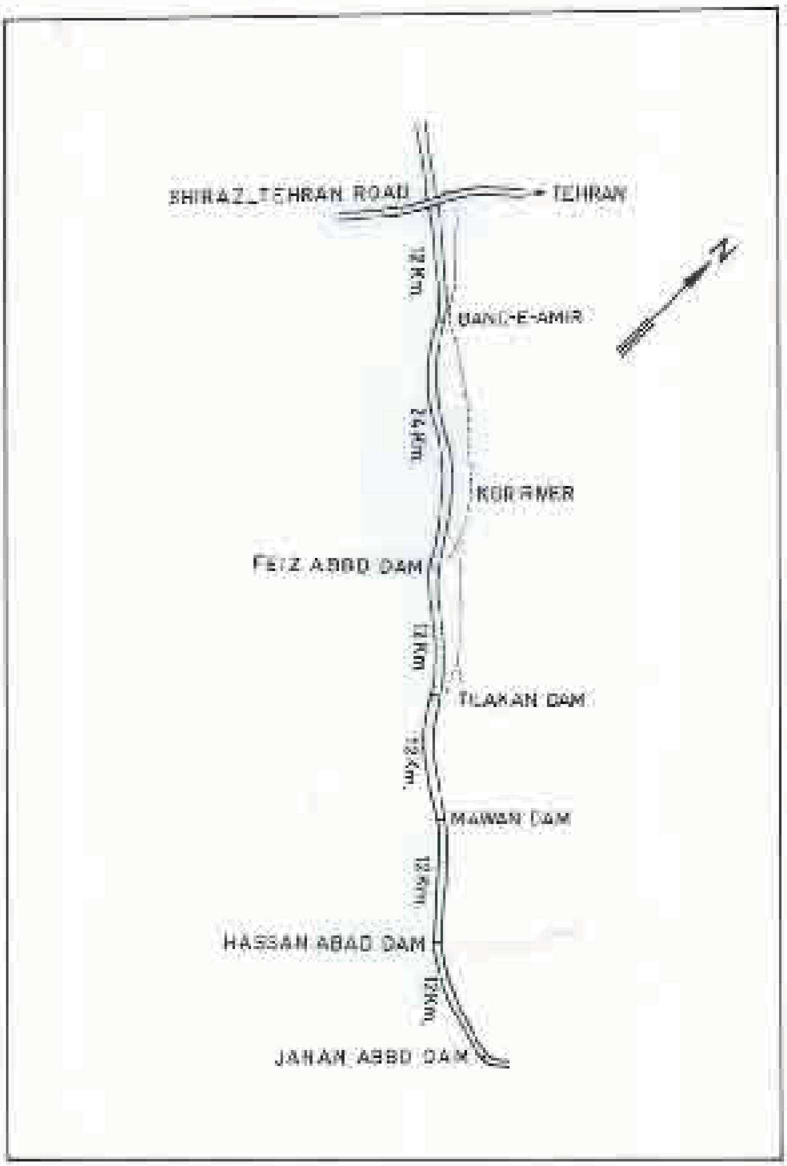

Figure2. Location of Kor river dams

REHABILITATION OF THE OLD DAMS

Rehabilitation of four dams (out of six) has been completed so far. These include Band-e-Amir, Feizabad, Tilakan and Mawan. In this paper rehabilitation of Feizabad and Tilakan are discussed.

FEIZABAD DAM

This dam is located at 23 km downstream of Band-e-Amir. It was reconstructed by Atabak Chaveli about 700 years ago. There were 22 watermills along this dam. The average length of the dam is 250 m while 200 m of the dam is located in the river. Small canals with 0.3 m depth and 0.5 m width divert water to the mills. The dam width varies from 4 to 12 m. At present the spillway crest height is increased about 1.8 m. Only 40 m of the dam length is across the river width and the remaining dam length is constructed along the river (Fig 3). This is due to following reasons:

- The small width of the river and existence of watermills.
- Not enough spillway crest length to pass the flow at high discharges.

At the right bank of the dam there is one meter deep and 1.5 m wide canal. This canal was constructed on the spillway to convey water to downstream at low flows (discharge of less than 10 cubic meters per second). The dam becomes submerged at flows of 90 m^3s^{-1}. Full submergence occurs at discharge of 150 m^3s^{-1}. The average depth of water behind the dam was about 5.5 m. Before rehabilitation, the safety against overturning under earthquake condition was 2.7 and against sliding was 1.6 (Omran Zamin, 1983). Bearing capacity was calculated to be 0.9 Kg/cm^2 under earthquake condition.

After rehabilitation, stability analysis was made for the following loading conditions:

- During construction
- Normal condition
- Flood condition
- Earthquake under normal conditions

Under the above conditions safety factors were more than the allowable values. However, under earthquake condition safety factor against sliding was 1.3. Under this condition the bearing capacity was estimated to be between 1.1 to 1.3 Kg/cm^2. When the dam was considered to be fully submerged, safety factors were more than 1.7. Under normal conditions, safety factors against sliding and overturning were more than 2.0. Due to the existence of a 2m cutoff and 15 cm thick filter, the vertical exit gradient was calculated to be more than 3 that indicates the dam is safe.

Fig. 3 shows the pictures of this dam before and after rehabilitation.


Figure3. Feizabad dam before and after rehabilitation

TILAKAN DAM

Tilakan dam is located at 14.5 km downstream of Feizabad dam. This dam is also a multipurpose one. The dam is submerged at a discharge of 80 cubic meters per second. However, when river flow reaches 230 m^3/sec, the dam becomes fully submerged. The dam length was about 180 m with 34 openings of 1.7 to 3.5 m wide before rehabilitation. The safety factors against sliding and overturning under earthquake are 1.3 and 2.4 (Zand, 2005). The average dam height from river bed was about 5 m. Fig. 5 shows the dam before and after rehabilitation. Fig. 6 shows the earth canals excavated by the farmers for diversion of irrigation water before increasing the crest height of the dam. The command area before rehabilitation was 11000 ha, while it was increased to 12500 ha after rehabilitation.

The stability analysis after rehabilitation was under the same load conditions as Feizabad dam. However, the safety factors against sliding and overturning under earthquake condition (horizontal acceleration of 0.1 g) were 1.25 and 2.4 respectively. Maximum pressure on foundation was calculated to be 1.1 Kg/cm^2. The Lane weighted creep ratio was 4.9 and shows that the dam is safe against piping on its silty clay foundation.

Figure5. Tilakan dam before and after rehabilitation

Figure6. Tilakan dam and the corresponding canals and farms before rehabilitation

RESULTS AND DISCUSSION

- The six diversion dams built on Kor river were not supplying the designed discharges. They also could not provide the necessary head for conveying irrigation water to the farms. Therefore, the Regional Water Authority of Fars decided to rehabilitate them. The remaining two dams (Hassan Abad and Jahan Abad) will be submerged by Bakhtegan lake in the near future. However,the irrigated areas under these dams will be irrigated by Mawan Dam.
- In rehabilitation of Tilakan Dam, Water Authority in collaboration with consulting engineers made intensive efforts in renovating the dam keeping in mind its historical identities.
- Rehabilitation of Feizabad Dam was completed between 2001 to 2003. This dam could also increase the irrigated area to 14900 ha.
- Since these hydraulic structures are our cultural heritages, efforts must be made in such a way that in their rehabilitation the technical and historical characteristics remain as authentic as possible.
- This study suggests that the ancient engineers had the knowledge of proper site selection. The stability analysis also suggests that the Persians understood the principles of stability. They could design dams that were safe against overturning, sliding and piping .

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MANAGEMENT OF WATER SOURCES AND TRADITIONAL DEVICES FOR SUPPLY OF SUITABLE WATER IN THE QESHM ISLAND (HORMOZGAN)

Daryoush Janakipour[1]

ABSTRACT

Water, this holy element is the cause of life for all living beings on the earth. With the existence of regions with little rain fall, gaining the technology to access water, this element of life, calls for great struggle, something that was accomplished by our ancestors, relying only on the primitive technology of their time.

Existing dams, pool (Berke), aqueduct (Qanat) etc., in Iran speak of the hard work of our ancestors to manage supplying water. This important task can be seen in the Persian Gulf, especially in Qeshm Island.

Opportunity techniques to access water and its distribution management in the hot and humid weather conditions of this Island, with average raining of 200 mm. yearly, by were developed hundreds of years ago by intelligent architects. Unfortunately with the arrivival of modern technology with its values, these old techniques were not only abandoned but also we witness of their destruction at the moment.

In this article, traditional water sources of Qeshm Island like pools (Berke), dams, Koleghs (large holes in hard rock), ox-wells and techniques of their operation are explained.

Also we will speak about the land – sea project to supply water form Bandar Abbas to Qeshm Island.

Finally, we have some suggestions to protect, repair and operate traditional water sources.

1– GEOGRAPHICAL SITUATION

Qeshm Island is the largest Island in the Persian Gulf. It has an area of 1445 km2, it is near to Hormoz strait, with geographical coordinates of 26, 45' north latitude and 55, 47' east longtitude, which is located in the south of Bandar Abbas.

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Form the climate point of view, this region is hot and humid. The average humidity and rain is 63 % and 200 m.m. respectively. There are mountain at different distance of the sea-side. The highest point of the Island is on Kish Kouh mountain at a 350 m. height. This mountain is known as Namakdan, because it contains of salt.

2- GEOLOGY

Qeshm is formed of the young formation belonging to the Cenozoic period. In the west,the Hormuz formation (salt plug), is the oldest formation of the Island. Other formations are Guri limestone, Mishan marn, Aghajari (marn and sandstone), Pliocene conglomerate (fossiliferous) and Quaternar alluvium (Tourian plain).

3- PLANT COVERING

Qeshm Island, according to climatology division is situated in the tropical region, it means that it contains tropical forests.

This Island form the plant covering point of view, is very poor, the reasons are various, including windy and water surface erosion, presence of sand, low depth of humid soil, and other factors like lack of rain and, tropical weather.

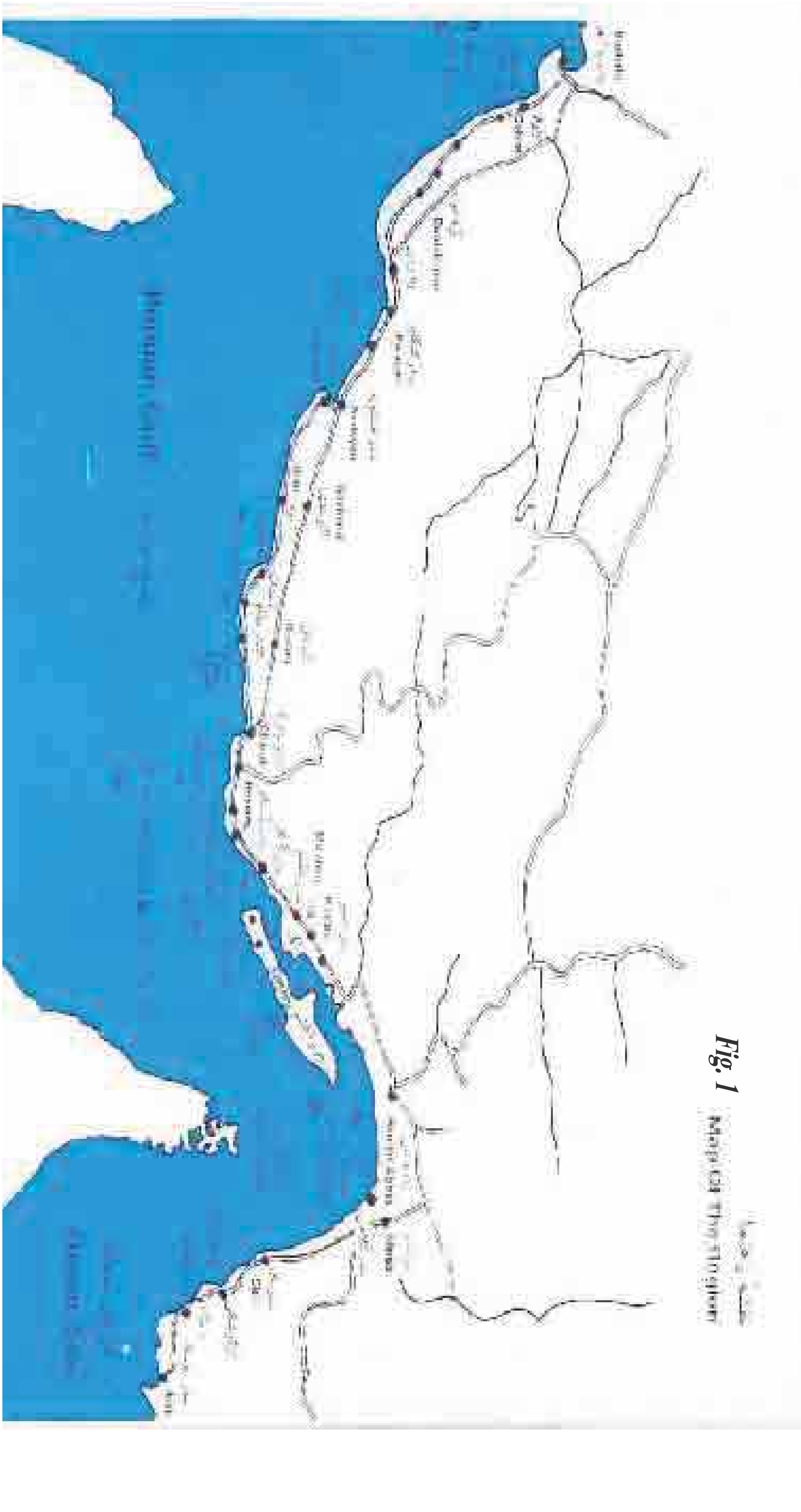


Fig. 1

Important plant species are lotus, sacred fig tree, sun flower, silk – tasseled acacia, tamarisk and mangrove (Hara).

One of the special view of the Island is mangrove forest (hara). This plant is able to make sweet water from salty water of the sea and use it. This type of plant grows between Laft (in Qeshm) and Pul port in the north-west of Qeshm.

4- HISTORICAL BACKGROUND

The name of the Island varied in different times of history, Borekhat, Kavan, Kish, Laft, lar, Byseedo, Keshm, Jask and Qeshm are among them.

Form 3000 B.C or 8000 B.C, Elamites were dominant in the area.

After words Persian Islands were controlled by the Achaemenians, Arsacides and Sassanides dynasties.

During Sassanide dynasty, Tel-Bala and Dem dams were constructed in the north-west of Qeshm.

During the Safavid dynasty. different buildings, dams and Ox-wells were constructed in Qeshm.

5- AGRICULTURE ECONOMY

In this area due to the little rain-fall and shortage of suitable water, agriculture is limited, and mostly is done through dry farming.

The agricultural products of this region include orange, lemon, onion, tomato, dates, etc.

The most important reason for non existence progress and development of agriculture is lack of suitable water.

The reasons for lack of suitable water are little rain-fall, topography and geographical situation of the island.

6– HISTORICAL OBSERVATION OF HORMUZGAN PEOPLE TO WATER

A– Achaemeni and Sassanide periods

When Arian tribes arrived in Iran and settled in Persian Island, as Qeshm, for compensation of suitable water, they made dams and reservoirs.

During Achaemenidae dynasty, they constructed great storages of water, for example in Khoush –Ab, Laft, Kherbes.

During the Sassanide time, great dams like Tele –bala and Dem were constructed, remains of which are still visibility on the north-east and north-west edge of Qeshm.

B– Safavid period

Safavid period is dehiscence era of Iranian architect are in the construction of bridges (Latidan), dam (Goran) and water storages.

In this period water stroges has constructed in the form of berke (in the shape of circular or linear). This type of water storage have been used for collection of raining water.

At present more than 300 brekes are present in this Island; which most of them are used by native people.

In the same time suitable water from Qeshm Island was carried to other Islands like Larak, Hengam and Hormuz.

Fig. 2 :Berke

C- Contemporary period

When modern machinery arrived in Qeshm for the construction of dams, huge changes took place in this area.

At present more than 100 dams are present in this region.

Water authority organization of Hormuzgan in 1983, using modern technology and machinery has constructed soily dams in Khalesy and Payposht regions of Qeshm.

7– OPPORTUNITY METHODS TO REACH SUITABLE WATER AND DISTRIBUTION MANAGEMENT FOR DRINKING WATER AND AGRICULTURE

Special condition of Iranian Islands due to little rain, absence of permanent surface water and lack of ground water aquifer, and from otherside increase of population, the reasons for the people to use different methods of opportunity to water.

Water establishments like, Kolegh, berke, well, water parting, will described as below:

7–1– KOLEGH:

Kolegh ares exposed pools, which are either naturally or dug in the hard ground by people.There are also called Berke by native people. Koleghs are primitive form of Berke. The water from rain is stored here, and people use it for drinking, also it is used for animals. Some examples of Kolegh can be found in, Koleghan hill and Laft. This form of storage belongs to the Media and Achaemenian period.

7 – 2 – BERKE:

In Hormuzgan province and Persian Gulf Islands, we can see some structures, which are used as storage for rain water, and can be used in time of water shortage.

The name of this structure is Berke. These berkes are important structures in the region. These simple and beautiful buildings are about 300 in number, have been built different sizes.

Most berkes have been built by help of charitable (benevolent) people.

They are built in circular or linear formsand made by coral rocks and mortar (colled as Saruj). Unfortunately at the moment due to modern life and developing of the cities, most of houses have sewage systems and they are empitied in berkes, therefore some of them are useless.

Some are historical berkes which are belong to the Safavid period, are still usable, for example Sha-e-shahid or Be-be. Berke is made of different parts including, storage, setting canal, water canal, roof, trap doors for taking water, (elements which belong to religious and social believes of the people of the region).

For taking water and sharing it, there is a custodian of water. The custodian distributes the water of berkes to between all families according to the number of people in each family. He cleans the berke with the help of the inhabitants.

According to a statistical study which was done on 2005, about 300 berkes with 70000m3 store of water exist in Qeshm. This show the important role of this structure in the life of the native inhabitants.

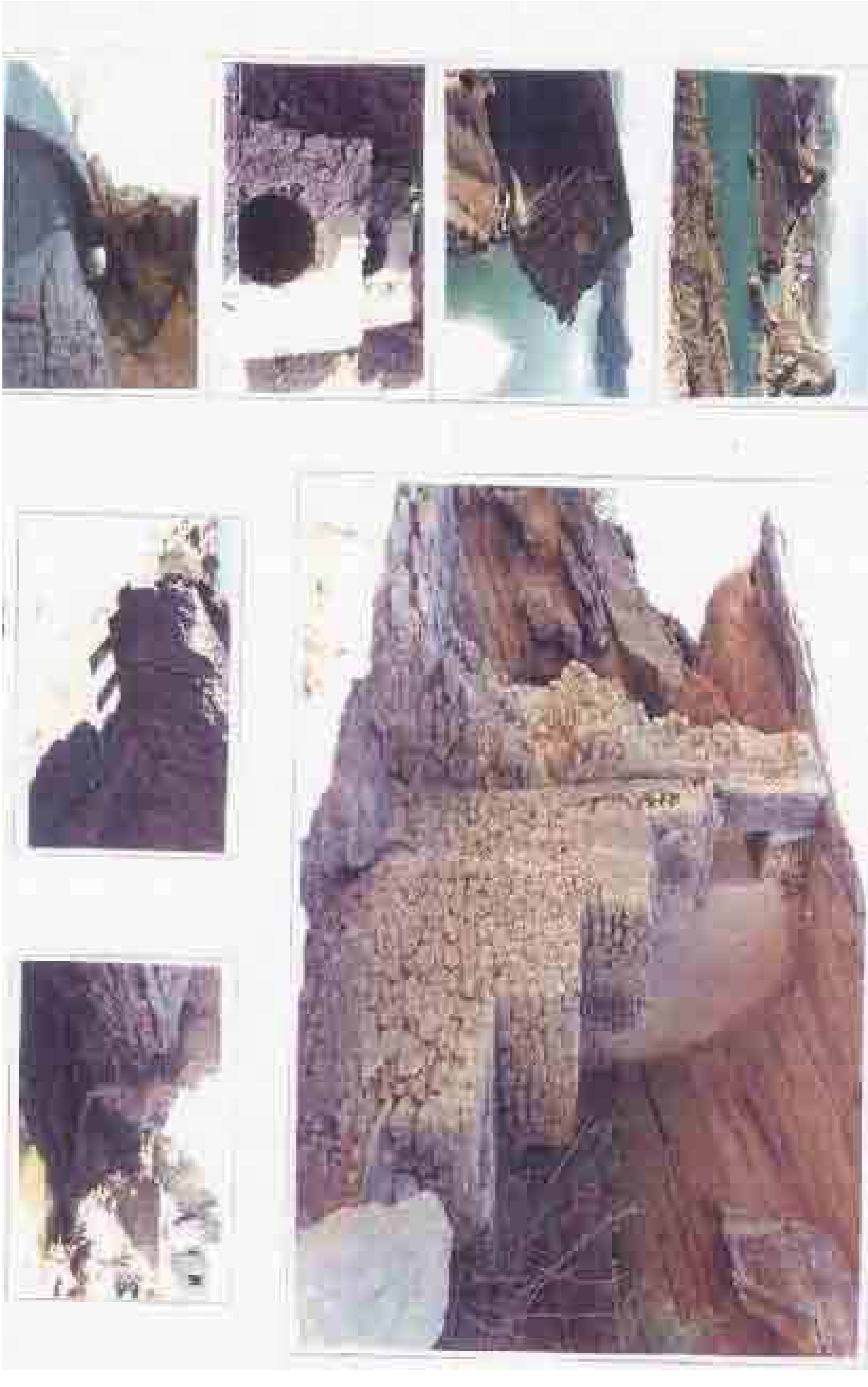
7-3- FLOODGATE:

Floodgates are small soily dams which are used for the storage of rain water. Sometimes, floodgates are made by rocks and mortar or cement.

Floodgates also lead rain water and surface water to berkes or they are used strengthen the aquifers.

Unfortunately in most of the villages of the Qeshm, due to lake of proper management and renovation, most of floodgates have been destroyed.

Fig. 3: Historical Payposht Dam



7-4- DAMS:

Dams are used to store rain water and surface water in large scale, most of them are soil dams, some of them have been constructed by coral rocks and mortar. In the next page we will describe historical dams of qeshm island.

7-5- WATERSHED:

Watersheds are constructed on the way of canals, and they part water for agriculture and filling the berkes.

7-6- WELLS AND OX-WELLS:

More than 300 wells are used in this region. In this island the most important area to have suitable groundwater is Tourian.

Most ox-wells are destroyed and useless.

7-7- DISCHARGE OF SEWAGE AND SURFACE WATER

There are tow ways to discharge sewage and surface water, one of them is directing them to the sea through exposed canals, (historical exposed canals still are visible) and another method is with the help of wells

8- WATER SOURCES.

8-1- SURFACE WATER.

In Qeshm island, there are no permanent rivers, only floodways and seasonal rivers are present. Surface water through floodway is directed to the sea.. The average capacity of rain water in the area is about 200mm, which small amounts of surface water penetration in aquifers. Because of little permeability of the soil and the special geological situation of the region, most of the surface water is evaporated or is delivered to the sea through floodway. Therefore due to this problem, we can understand the important role of floodgates and dams in this region.

Construction of floodgates and dams in Qeshm from long ago, shows their role in controlling and using surface water.

About 100 soil dams are recognized in this area, some of them are from 100 years ago, and others are new.

8-2- GROUND WATER:

Ground water sources of the island, from quality and quantity point of view are not suitable. Important reasons for this problem are climatic conditions, lack of rain, little extent of the water basin, lack of suitable penetration alluvium, trace of geological formation on the aquifer (like marn, salt plug, …) the relation of aquifer with sea.

Tourian is the only plain in the region to have suitable aquifer. It has an extent of 20Km2 and 231 wells.

8-3- CONTROL, MANAGEMENT AND TRADITIONAL USE OF SEASONAL AND SURFACE WATER.

After the first rain, surface water due to rain is directed to farming lands Through exposed canals. Control and management of this water is done by a water distributor (called Mirab). The people have trust in him. The farmers never change the way of canals and respect teach other. If there are complaints, people will refer to a reliable person to solve the problem.

IMPORTANT HISTORICAL DAMS IN QESHM ISLAND:

1- DERHASH DAM:

This dam is located on the east of Giyahdan village. This dam was constructed 200 years ago, and is constructed by limestone, cement of chalk and mortar. This dam has been repaired many times and still is in use.

2- KHALESI DAM:

This dam is located in the same position of new KHalesi dam, near Deyrestan village, which has constructed by Hormozgan water authority organization in 1983.

Fig. 4: Ox - Well

Unfortunately the old dam which was built 100 years ago, was destroyed at the time of the construction of the new dam.

3- SHEYKH ALI FLOODGATE:

This floodgate is located on the west on Selkh village and it was built 100 years ago. Same as the previous dam, construction material are rock and mortar.

4- GAVARZIN DAM:

This dam is located on the north of Gavarzin village, and nearby the new dam. It was constructed 500 years ago and its architect was Ostad Yahya. Some parts of the dam still remain.

5- MOLLA DAM:

This dam is located nearby Salakh village, and is 100 years old. Molla dam is still usable.

6- GURAN DAM:

It is located on Guran village, and was built 100 years ago. This dam is also usable. The architect of Molla and Guran dams was Ostad Yahya.

7- DEM DAM:

This dam is located in Peyposht village and was constructed by rocks and cement of chalk and gravel. It is belongs to the Sassanide dynasty, and same as other monuments of that time was destroyed by floods.

However, this dam was repaired in the Safavid period, but due to some technical problems, it was destroyed again, and at present some parts of this dam still remain.

Unfortunately, most historical dams which are located in this region have been destroyed. However, this structures need restorational and protection, because they are historical heritage of this country.

NATIONAL PROJECT OF WATER CARRIER LINE TO THE QESHM ISLAND.

As mentioned before, Qeshm has limited source of water, therefore for to solve this problem, Hormozgan water authority organization has fixed many installations to change sea water to suitable fresh water.

But with the development of this Island, installations are not sufficient, therefore after the study of the area, the project of water transfer from Bandarabbas to Qeshm has started since 2005.

This project contains tow parts, one in the land (83 km) and the other in the sea, 10km. This water line is not only for Qeshm and Bandar Abbas, but also will supply suitable water to Khamir port, refinery and industrial town.

CONCLUSION

1- The base of opportunity for suitable water in Qeshm was preserving of rain water in structures like Koleghs, Berkes, wells and dams. All these structures helped keep water.

2- Historical water structures in the Island were usable for tow purposes, one for preserving water in the Berkes, Koleghs and two for agriculture (Dams,. Ox-Wells).

3- The Kolegh is the primary form of opportunity to access suitable water and is very old.

4- Water structures in the past, due to being managed, by people was in the control, of the people but at present this management is not functional. The result of this problem is the destruction of water structures.

5- Some of these structures due to urban extension are, completely destroyed and useless.

6- Construction material that were used for water structures include limestone, coral rocks and mortar (Saruj).

SUGGESTIONS

1- Repairing historical dams.

2- Repairing floodgate of village.

3- Construction of exposed Berkes (same as Laft"s well) in those areaswhich have suitable aquifer.

4- Determine limits for water structures like Berkes, dams, ….

5- Determining urban standards and regulations for any constructions near water structures.

6- Changing and re-establishment of historical water structures to cultural and tourism center.

7- Using of pumps instead of hand buckets to take water from Berkes.

8- Re-establishment and support humanity management for protection of historical water structures like as Berkes and dams.

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THE SOCIAL IMPORTANCE AND CONTINUITY OF *FALAJ* USE IN NORTHERN OMAN

Zaher bin Khalid Al Sulaimani[1], Tariq Helmi[2] and Harriet Nash[3]

ABSTRACT

Oman has an arid climate with an annual average rainfall less than 100 mm. Agriculture production in Oman is almost fully dependent on irrigation in which more than one third of irrigation water is supplied by *aflāj*. Prior to the 1970s, *falaj* (singular of *aflāj*) systems were the backbone of agriculture in the northern parts of Oman. There are three types of *falaj* in Oman: *ghailī*, *da'ūdī* and *ᶜainī*. Among these three types, only the *da'ūdī falaj* is similar to the qanat irrigation systems of Iran.

Aflāj are conduits dug in the ground to convey water by gravity from one place to another; there are more than 4,000 *aflāj* in the Sultanate of Oman, of which 3,017 are active. Many *aflāj* in Oman were built over 1,500 years ago and some of them may date back over 2,500 years. There was a major period of construction during the Yaᶜāriba Dynasty, by Imam Sultan bin Saif Al Yarubi between 1,060 and 1,070 Hijri (1,650-1,660 AD). However, several *aflāj* were constructed only 150 years ago.

The *falaj* systems are still focal to agricultural communities in Oman as they represent 36% of the total water consumed in the agricultural sector and 38% of the total available fresh water. Because of their historical and cultural importance, five representative *falaj* systems, together with associated structures such as defensive towers, mosques sundials and buildings for water auctions, have recently been designated as a UNESCO World Heritage site.

Sustainability was the way of life of our ancestors: because *falaj* systems use gravity flow, water use never exceeded water supply. The Sultanate's traditional methods of water management provide important lessons for the future. Using water fairly in times of plenty and times of scarcity is one of these lessons. Matching water use to water availability, a fundamental characteristic of the *falaj* system, is an essential element in planning water management in Oman's climatic conditions.

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1. INTRODUCTION

Oman is an arid country: the climate is characterised by hot and dry summers and mild winters, except for the Dhofar region in the south of the country, which is affected by the monsoon. The average annual rainfall is 100 mm/year but reaches 300 mm/year in the mountains in the north. Groundwater is the main water source representing 92% of the total renewable water resources. Agriculture is the major consumer of water (87% of renewable water resources) using a total of 1,124 MCM/year. The total cultivated area is 65,013 hectares, of which 41% (26,484 hectares) is irrigated by *falaj* systems while the rest is irrigated by wells.

Falaj systems are most commonly found in the foothills and low lands bordering the northern mountains (Hajar Al Gharbī and Hajar Al Sharqī). The locations of the *aflāj* are shown on Figure 1.

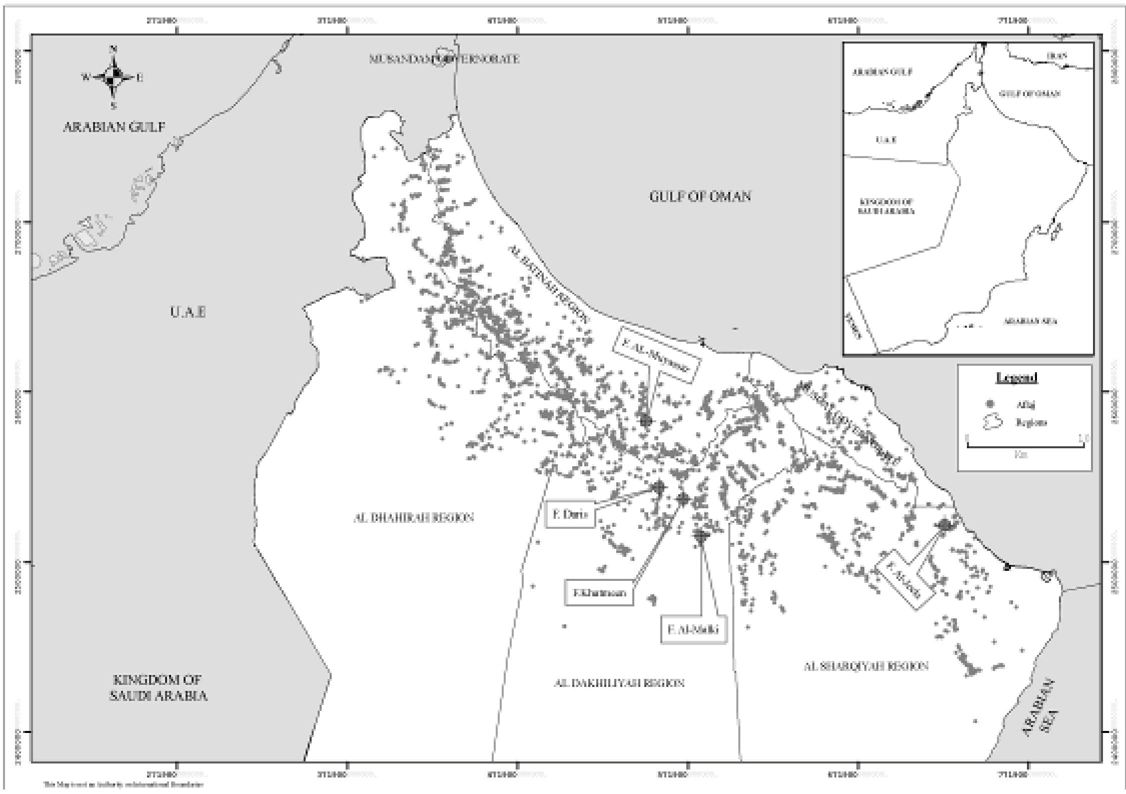


Figure 1. The Location of *Aflāj* in the Sultanate of Oman

2. HISTORICAL OVERVIEW

The network of *falaj* systems in Oman may not be the oldest or the largest in the world. There are probably older systems in northern Iran and that country has many thousands of *aflāj*. Also, this method of irrigation is to be found in many arid zone countries, including parts of China (Xinjiang), Cambodia, central Asia, Pakistan, Turkey, other countries in the Arabian Peninsula and Middle East, in North Africa and Latin America.

It is not known when the first *aflāj* were constructed in Oman. In legend, the *da'ūdī aflāj* were created by the Prophet Suleiman bin Da'ūd (King Solomon), who is thought to have lived in the 10th century BC. He is said to have stayed in Oman for 10 days and, because the land was so dry, ordered the jinn (demons) to dig 1000 *aflāj* (of the qanat type) every day. This explains why the qanat-type *aflāj* are called "da'ūdī" (Wilkinson 1977). There is archaeological evidence that the earliest period of *falaj* construction in Oman dates back to 1000 BC. (Al Tikriti 2002), suggesting a pre-Achaemenid origin and consistent with the legend.

Traditionally, however, the origin of *aflāj* in Oman has been attributed to Persian influence during Achaemenid times (eg English 1997). It is generally accepted that the technique was used in Persia from at least the end of the 8th century BC. During the mid-6th to mid-4th centuries BC. it began to be diffused more widely. This was a period of Persian expansion, especially during the reign of Cyrus the Great, and there is abundant evidence from archaeological and historical records of contact between Persia and Arabia (MRMEWR 2006). Much of Oman came under Achaemenid rule in the mid-6th century BC., and from 226 AD it formed part of the Sassanian Empire of Persia, until the Sassanians were finally driven out of Oman with the coming of Islam in the 7th century AD. It is possible that many *aflāj* were built in Oman in Achaemenid times, and it appears that it was during the Sassanian period that irrigation by *aflāj* reached its widest extent (Wilkinson 1977, 1983).

There was a further period of *falaj* construction during the Ya^{c}āriba Imamates in the second half of the 17th century, when the Portuguese were finally expelled from Oman, which became the first independent state in the Arab world. Falaj Al Hamra was constructed during the Ya^{c}āriba Dynasty by Imam Sultan bin Saif Al Yarubi between 1060 and 1070 Hijri (1,650-1,660 AD) (Al Shaqsi 1996). Falaj Al Khatmeen near Nizwa was also constructed at this time. Some *aflāj* have been constructed even more recently, as in the Ibra area, where Falaj Al Yahmady and Falaj Mudhairib are only 150 years old (MRMEWR 2005).

Regardless of the uncertain date of the origin of *aflāj* in Oman, it appears that these systems have provided communities in this area with water for irrigation and domestic purposes for at least 1500-2000 years.

3. TYPES OF *AFLĀJ* IN OMAN

In Oman, there are three types of *falaj*: *da'ūdī*, *ghailī* and ^{c}*ainī*, as illustrated in Figure 2. The *da'ūdī falaj* (21% of the total number of *aflāj*), is constructed as an underground tunnel conveying groundwater from the mother well to the irrigated (demand) area.

The *ghailī falaj* (46% of the total number of *aflāj*) collects water from the base flow of the wadi and transports it in an open channel to the distribution section. During prolonged dry seasons, the discharge of such a *falaj* decreases, and sometimes ceases.

The ^{c}*ainī falaj* (33% of total *aflāj*) is fed directly from springs. Many springs which rise from limestone in the mountain areas are reliable sources of good quality water.

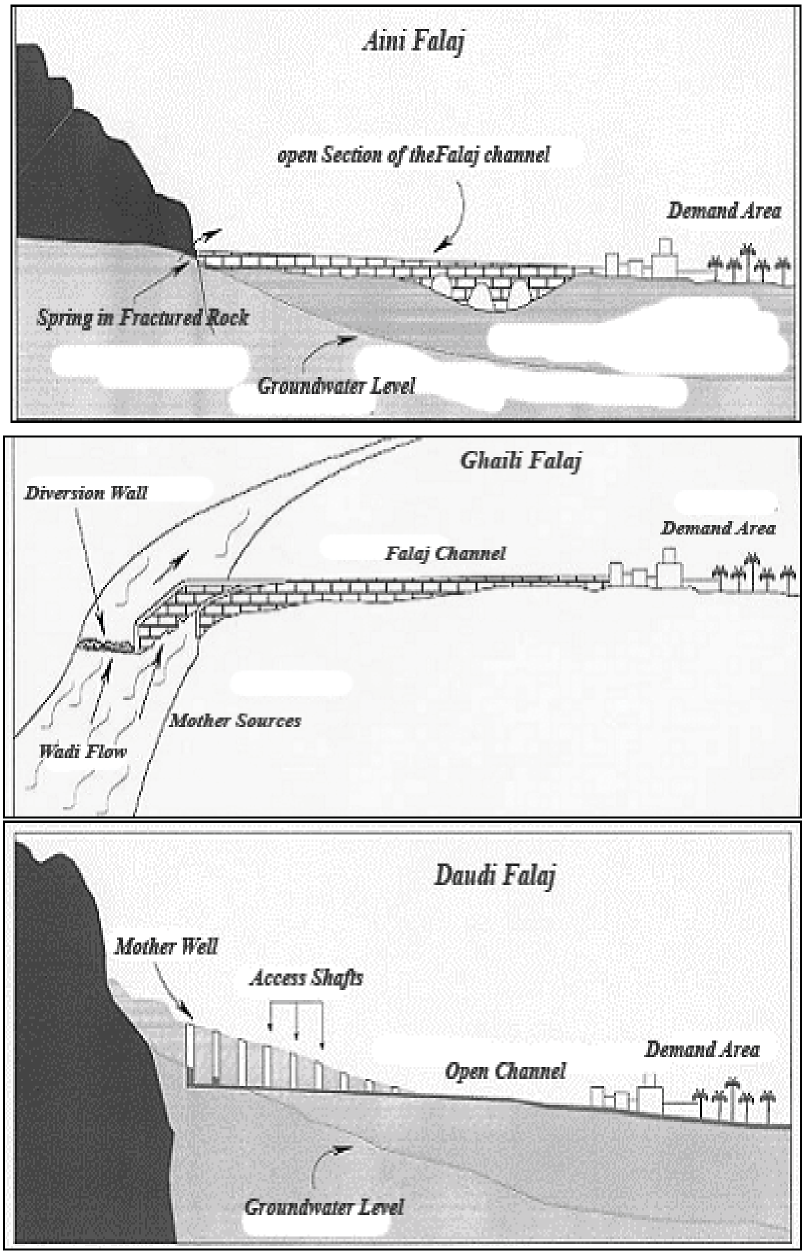


Figure 2 Types of *Aflāj* in Oman

The areas of irrigation have owed their existence to the *falaj* system for hundreds of years. The demand area is the area that is served by distribution channels and could be irrigated if there were sufficient water. The area of irrigation is generally less than the demand area; the area of irrigation varies from a few to hundreds of hectares and changes slightly from year to year according to the *falaj* flow. The most common cultivated crops are date palms, lemon trees, fodder grasses and seasonal crops.

In 1997, a National Aflāj Inventory Project (Ministry of Water Resources 1997) was undertaken, and concluded that the total recorded *falaj* was 4,112 *aflāj*, of which 3,017 were operational. Of the total national cropped area *da'ūdī aflāj* irrigate 22%, *[c]ainī*

11%, *ghailī* 8% and wells 59%. The total area cultivated by the operational *aflāj* was estimated as 26,484 hectares (Table1). Most *aflāj* are found in the wadis leading from Al Hajar Al Gharbi. These mountains are characterized by bold relief and paucity of soil and vegetation: surface runoff is therefore rapid, but is short-lived and does not extend far from the hills.

Table 1 Cultivable area and water demand of *falaj* systems in Oman

Region	**Number of Active *Aflāj***				**Cultivated Area (ha)**	**Water Demand MCM/Year**
	Da'ūdī	**ᶜAinī**	**Ghailī**	**Total**		
Muscat	12	109	52	173	1932	30.1
Al Batinah	153	382	674	1209	6707	95.2
Ad Dhahirah	86	114	273	473	4401	66
Ad Dakhliyah	183	169	149	501	10002	146.8
Ash Sharqiyah	193	215	253	661	3442	57.9
Total	627	989	1401	3017	26484	396

In the past, before the introduction of petrol or diesel pumps for wells in the 1970s, *aflāj* were the only significant means of irrigation. Unfortunately, throughout their history *aflāj* have suffered from various problems (Al Busaidi 2006). Currently, the main physical threats to *aflāj* are flash floods, often leading to damage of shafts, tunnels and channels, and the introduction of mechanical pumping in wells and boreholes leading to the lowering of groundwater levels and the drying up of some systems. The high running and maintenance costs means that the crops are relatively high cost and cannot always compete with imported goods or crops irrigated by wells.

Despite all these threats, *falaj* systems still play a major role in the water budget (404 MCM), representing 36% of the total water consumed in the agricultural sector (Figure 3) and 38% of the total available water. The *da'ūdī aflāj* play a particularly important role as, despite the fact that they represent only about 21% of the total number of *falaj* systems, they provide 53% (214 MCM) of the total *falaj* water

consumed by the agricultural sector.

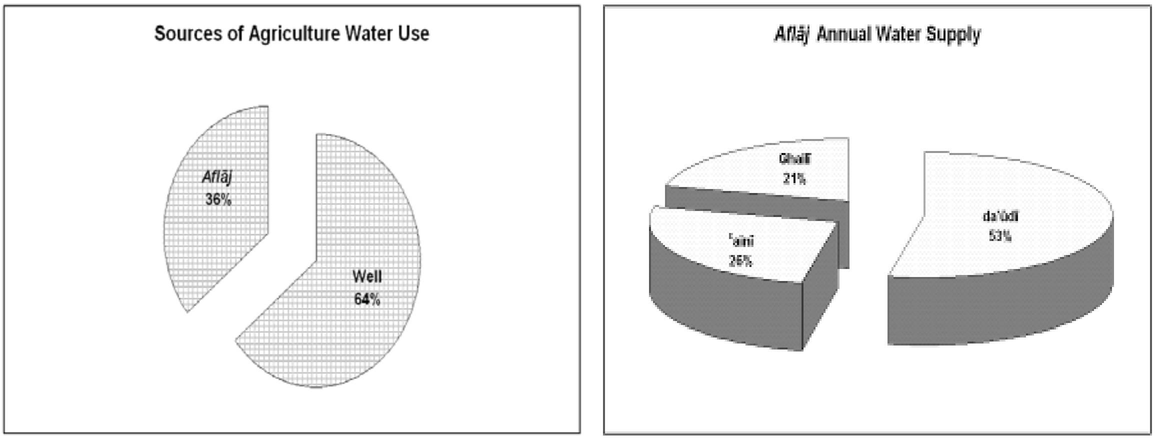


Figure 3 Water Use of *Aflāj* in the Agriculture Sector

4. SUSTAINABILITY OF *AFLĀJ*

The most widely accepted definition of sustainability, as presented in 1980 in the World Conservation Strategy by the International Union for Conservation of Nature and Natural Resources, is:

> "the management of human use of the biosphere so that it may yield the greatest sustainable benefit while maintaining its potential to meet the needs and aspirations of future generations ".

The sustainable management of water resources can only be achieved by a genuine commitment to ecological integrity and biological diversity to ensure a healthy environment, a dynamic economy, and social equity for present and future generations. Sustainability was the way of life of our ancestors: since water in the irrigation systems was abstracted and conveyed to the fields by gravity, water use never exceeded water supply. Life was hard but sustainable. The Sultanate's traditional methods of water management have important lessons for the future. Using water fairly in times of plenty and times of scarcity is one of these lessons. Matching water use to water availability, a fundamental characteristic of the *falaj* system, will also be an essential element in water management in Oman's climatic conditions.

4.1. THE SOCIAL ORGANIZATION OF THE *AFLĀJ*

4.1.1. Water shares

In classical Arabic, the term *falaj* has many meanings, including to divide into shares and running water (Lane 1968), both of which relate to its present day use in Oman where it is applied to the whole system of tapping groundwater, bringing it to the surface and distributing it to fields by gravity flow.

An outstanding feature of the *falaj* system in the Sultanate of Oman is the social and economic structure that has permitted it to function successfully and largely unchanged for centuries. This is based on an accurate system of water distribution which guarantees fair shares to stakeholders. As such it plays an integral role in the socio-economic life of the country. Without it, Oman would never have been able to achieve nationhood, since only the availability of water made it possible for nomadic peoples to adopt a settled way of life, which encouraged the development of agricultural and craft skills. The system is not based on any form of written or statute law, but rather on a traditional system of time-sharing that is passed from one generation to the next. This confers a number of benefits to society as a whole by:

- Maintaining mutual cooperation among those individual who use the *falaj* water for domestic and agricultural purposes.
- Providing a relatively flexible source of family income by allowing shareholders to put their water shares up for public auction or by leasing those shares for specific periods when they are not needed.
- Providing a constant source of water for a variety of crops, especially date palms.
- Encouraging the development of traditional crafts in the towns and villages through which the *aflāj* pass and thereby creating employment.
- Strengthening a sense of community and strengthening social relationships between all those benefiting from the supply of water; which traditionally would have been almost everyone in the community.
- Establishing procedures for settling disputes relating to water shares or maintenance obligations in the form of an autonomous administration responsible for the management of each *falaj*.

The highest executive authority in each system is the *falaj* agent (*wakīl al falaj*), often appointed by the local sheikh in consultation with the shareholders in the *falaj*, or by the *falaj* community. The *wakīl* is responsible for the overall management of the *falaj*: his duties include responsibility for the funds, regulation of the sale and rental of individual shares, and the keeping of records as necessary. He is assisted by one or more ^{c}*arīfs*, who are mainly responsible for the distribution of the water shares and will usually know the time for each person's water. Depending on the size of the *falaj,* other officials may help with activities such as auctioning shares that are set aside to raise money for running the *falaj*.

The distribution is carried out by diverting the water flow by applying or removing sluices at the appropriate times of day or night for the agreed periods. The diversion may be carried out by the ^{c}*arīf*, by the shareholder or by a farm labourer. Before the advent of clocks, the time for each water share was determined by various methods, including the use of sundials by day and observation of the stars at night (eg Al Ghafri 2003). Sundials are still used in a number of villages, while the use of stars continues in only a few.

The time needed to water all of the cultivated land (the irrigation cycle) and the order of irrigation is generally determined by a group of experienced shareholders, who take into account the rate of flow the water in the *falaj* and other factors, such as the tolerance of the crops to drought and the water retention characteristics of the soil. The irrigation cycle commonly ranges from seven to fifteen days and the water is shared among the users on a time basis. One example of the division of time units is given in Table 2. The *badda* and *athar* are widely used but other divisions vary from place to place. The length of the time units may be adjusted to periods of drought and high flow: thus, during droughts the *athar* may be reduced to 15 minutes (*athar ghaez*), or the length of the irrigation cycle increased, usually doubled, so that shareholders receive half of the normal amount of water.

Table 2 Time division for water distribution

Division	Period of time	Equivalent in *athar*s	Division	Period of time	Equivalent in *athar*s
Badda	12 hours	24 *athar*	*Ruba^c^a*	7.5 minutes	1/4 *athar*
Kathba	1 ½ hours	3 *athar*	*Thāmin*	3.75 minutes	1/8 *athar*
Athar	30 minutes	-	*Qiyās*	1.25 minutes	1/24 *athar*

4.1.2. Water Trade

The trade of water can be effected in a number of ways. People are free to buy, sell and even mortgage their water shares. Water surplus to requirements, and water shares belonging to the *falaj*, used to raise funds for *falaj* maintenance, may be auctioned either every irrigation cycle or annually. The prices at auction were found to be influenced by the following factors in Falaj Al Hamra (Al Shaqsi 1996):

- Prices increase during dry seasons and decrease during wet season.
- Prices increase if the shares are during day time, and decrease if the shares are during night time, especially after midnight.
- Prices increase if more than one person wants same shares auctioned.

In Al Hamra, the price of one *athar*, for one irrigation cycle of seven days, may vary between 0.5 US$ (0.19 O.R) during the wet season to 90 US$ (35 O.R) during the dry season. The price of a permanent share is not influenced by the seasons but by the long term rate of flow of *falaj* water.

4.1.3. Domestic use of *falaj* water

Traditionally, many *falaj* communities took all of their domestic water from the *falaj* system. The first point of use was the *sharī^c^a*, where drinking water for people and animals was obtained. Though rarely used for drinking water now, these access points are usually well maintained and protected, and are often used for other domestic purposes. Bathing and washing of clothes and dishes is still carried out in many *falaj* channels, and several communities have built bath houses over the channels. These uses still provide points of social contact and a focus for community life in addition to that from agricultural activities. The date gardens are still used, as presumably they always have been, for relaxation and escape from the heat – a popular place for picnics, with children happily occupied playing in the *falaj* channels.

5. THE FIVE NOMINATED AFLĀJ

As part of the Ministry of Regional Municipalities, Environment and Water Resources (MRMEWR) efforts to improve and protect *aflāj*, it has been in close cooperation with the World Heritage Committee of UNESCO to record Oman’s *aflāj* in the World Heritage List. This is so that these hydrological structures can have the international support and recognition they deserve and can continuing to play their role in Oman’s future. The project has started with the nomination and acceptance (inscription) of five *aflāj* which satisfy the international standard for World Heritage sites. The five *aflāj*, with all of their water structures and associated traditional buildings, included in the World Heritage site, were selected as representative of the total stock of irrigation systems, demand areas and *falaj* communities in the Sultanate of Oman. Their inclusion in the World Heritage List is very welcome to the government of Oman and its citizens. This is one way of showing the rest of the world some of the wealth of Omani culture and history, and helps in Oman's efforts to increase tourism, which is of growing economic importance. In recent years, the revenue from the tourist industry has increased as a result of attractive marketing strategies and the plan to lift tourism revenue to three percent of GDP by 2020.

5.1. FALAJ AL KHATMEEN [*FALAJ* INVENTORY NO. 3071]

This *da’ūdī falaj* is fed by the Wadi Al Meaidin, which is notable for its abundant flow during periods of rain and its continuous (though not constant) flow throughout the year. The total length from mother well (source) to *sharī^{c}a* is 2,450 m. For most of its length the channel runs underground.

The open channel runs through the small town of Birkat Al Mawz near Nizwa, and passes beneath one of the renowned Omani forts, Bait Al-Redada, which was built during the Ya^{c}āriba Imamates period (1649–1711). At the entrance to the town the channel is split into three equal sections, one of which irrigates the holdings of the local people and the other two the agricultural land belonging to the State Treasury (*bait al māl*). The water for each of the three channels is very accurately controlled: it has been shown that if three balls of the same size and weight are thrown into the channel before it splits, each will run automatically into a separate branch channel. The water quality is high: electrical conductivity 440 µS/cm, pH 7.61, temperature 30°C. The flow rate varies between 800 and 100 l/s, depending on the level of the water table.

The total demand area is 1,004,345 m^2 of which 723,124 m^2 is cultivated. Most of the demand area is *bait al māl*. Dates, lemons, bananas, fodder crops, seasonal crops such as onion, sweet corn, wheat and sugar cane are the most commonly cultivated crops. The demand area is an important tourist attraction known for its history, *falaj* water distribution system, traditional buildings and its proximity to Jabal Al Akhd□ar, another well known tourist attraction.

Falaj Al-Khatmeen: The *sharīᶜa* passing beneath Bait Al-Redadah Fort (*left*).

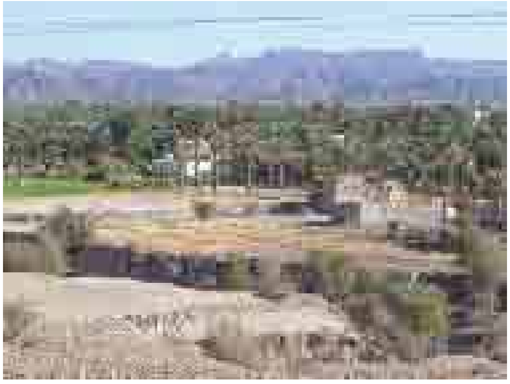
Distribution point at the end of the *sharīᶜa* (*right*)

5.2. FALAJ AL MALKI [*FALAJ* INVENTORY NO. 0606]

Falaj Al Malki is one of the largest *aflāj* in the Sultanate: it is a *da'ūdī falaj* and its total length from mother well to *sharīᶜa* (including all of its 17 branches) is some 14,875 m. It is believed to have been built during the major *falaj* building in the Yaᶜāriba Imamates period. The *falaj* splits into two branches, supplying the former towns of Nazar and Al Yaman in the area of Izki.

Recent intensive building in the area has resulted in severe pressure on the aquifer and this effect, coupled with a scarcity of rain has led to a decrease in the water flow of the *falaj*, especially in periods of drought. However, the state of conservation of the *sharīᶜa* and the feeder channels remains high. The water quality is high: electrical conductivity 764.5 µS/cm, pH 7.82, temperature 30°C.

The agricultural demand area covers 1,572,730 m^2, of which 1,132,472 m^2 is cultivated. Dates, fodder crops and seasonal crops are the most common products. The municipality now does not allow the construction of new buildings in the place of date palms that have been removed. It is hoped that this measure will help to reduce the rate of decline of the *falaj* flow.




Falaj Al Malki: Traditional houses *(left)*. Watchtower *(right)*

5.3. FALAJ DARIS [*FALAJ* INVENTORY NO. 0500]

The largest in the Dakhiliyah Region, this *da'ūdī falaj* is thought to be the oldest active *falaj* in the Sultanate, built early in the Ya^{c}āriba Imamates period. The total length of its three channels is 7,990 m. Most of the water derives from the Wadi Al Abiyadh. The water flow reaches over 2,000 l/s, but the aquifer has been affected as a result of development pressures and so the flow rate falls during periods of drought.


Falaj Daris: General view of the agricultural demand area (*left*). *Sharī^{c}a* (*right*)

The structure of the channel is in excellent condition, and the *sharī^{c}a* has been the object of some simple but elegant landscaping and interpretation. The water quality is high: electrical conductivity 477 µS/cm, pH 7.30, temperature 37°C.

The cultivated area of the town of Nizwa that it supplies is 1,715,502 m^2, whilst the total demand area is 2,382,642 m^2.

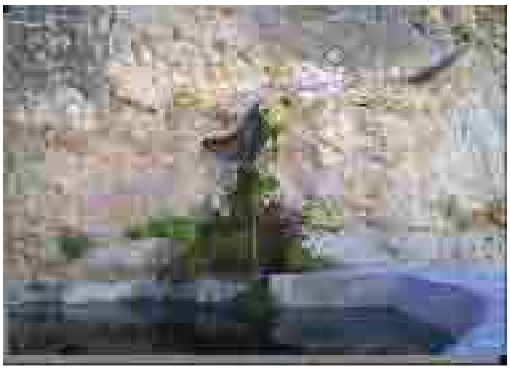
Efforts are being made by the government to preserve the *falaj* and demand area through implementation of strict restrictions regarding the removal of palms and construction of new houses in their place. A wastewater collection system will be constructed within the demand area in addition to the existing potable water distribution network, in order to protect the quality of water in the *falaj*. Dates, fodder, sugar cane are the most common crops.

5.4. FALAJ AL JEELA [*FALAJ* INVENTORY NO. 2750]

The ^{c}*aini* form of *falaj* is represented in this nomination by Falaj Al Jeela. It is a located in a very small town in a remote and barren mountainous area of Wilayat Sur. The water comes from a spring of the Wadi Shab, which is located in Tertiary limestone above the town, and is conveyed by means of tortuous open channels and a small bridge over 161 m long to a collection basin in the town itself.

The *falaj* water is very pure (electrical conductivity 378 µS/cm, pH 7.87, temperature 29°C), with an average flow of 44 l/s. Like other ^{c}*aini aflāj*, Falaj Al Jeela maintains a stable flow rate throughout the year and is barely affected by rises and falls in groundwater levels.

The water is used principally for irrigating palm and pomegranate trees and tropical fruits. All the planting is high on the edge of the wadi, and there is a protective wall against mudslides. The planted area is 10,034 m^2, out of a total demand area of about 14,000 m^2. The demand area is limited in size by the surrounding mountains and makes a very attractive tourist destination.



Falaj Al-Jeela: Water collection basin (*left*). Irrigation water distribution system (*right*)

5.5. FALAJ AL MUYASSAR [*FALAJ* INVENTORY NO. 1446]

Another *da'ūdī falaj*, Falaj Al Muyassar originates from a mother well 50 m deep in a mountainous area of Wilayat Al Rustaq. Including its branches, the *falaj* is 5,783 m in length. The water is very pure (electrical conductivity 508 µS/cm, pH 7.61, average temperature 31.9°C). The flow is relatively stable, but it can sometimes be affected by the flow in the nearby Wadi Al Fara and Wadi Al San, rising occasionally to 900 l/s and falling as low as 100 l/s.

Falaj Al Muyassar: Distribution channels of the *sharīᶜa* (*left*). Old houses with mosque (*right*)

The total cultivated area is 1,133,698 m^2 by means of two main branches. Dates, lemons, fodder and seasonal crops are the most common cultivated crops. To prevent pollution of the *falaj* and groundwater a wastewater collection system is under construction within the demand area.

5.6. JUSTIFICATION FOR INSCRIPTION

A - Criteria under which inscription in the World Heritage List was proposed

- The *falaj* system in Oman is an outstanding example of an irrigation system of considerable antiquity developed in the Near East and applied widely in the arid territory of Oman. It survives intact and is of immense socio-economic significance in contemporary life.
- Human occupation of large desert areas of Arabia did not become feasible until the *falaj* irrigation system was introduced into Oman. It made possible the development of a successful state which played a vital role in the development of trade between Europe and Asia in the medieval and later periods.
- The *falaj* irrigation system in Oman has produced an exceptionally well preserved example of a form of land-use which found widespread application over much of western and central Asia. It is threatened by lowering of the water table over much of the area as a result of increased contemporary demand for water and by climatic change. From the points of view of continuity and conservation of water supply, and long-term sustainability of agriculture in a region where water shortage through over-extraction will become an increasingly serious problem, the *aflāj* have a number of important characteristics which justify a continuing faith in the *falaj* system and which must be enhanced and not diminished by any changes to it. These characteristics are; water generally of very good (or good) and near constant

chemical quality; no possibility of endangering the water table (in contrast with wells which are easily deepened) unless by a support well; water is brought to the ground surface by gravity, and therefore without any pumping cost; village *falaj* land is long nurtured and of good quality; *falaj* villages are a model of crop water use prioritisation; *aflāj* are the best example of co-operative water management in Oman - a model of self-funding and self-help; the *falaj* committees could form the basis of future local water management organisations (in partnership with MRMEWR and its regional offices).

B - Statement of outstanding universal value

The statement in the Holy Quran that '…we have made from water every living thing' epitomizes the dependence of humankind on water. This is nowhere more true than in the arid lands of Arabia, where permanent human settlement did not become possible until the introduction of irrigation systems that permitted the extension of agriculture beyond the immediate surroundings of springs or wells. Relatively constant supplies of water were ensured for large areas of desert throughout the year, and this in turn led to the growth of permanent urban settlements based on an assured agricultural production and water resources for both people and livestock.

The *falaj* system of irrigation consists of tapping substantial underground water resources and conducting the water by means of deep underground channels, often over long distances, to towns and villages where it is distributed to domestic and agricultural users. The system in use in northern Oman has been developed over many centuries and has resulted in the creation of a strong social and economic structure that has survived intact to the present day.

There are four elements in the Omani *falaj* systems that justify the attribution of 'outstanding universal value'. First, without the existence of *aflāj* there would have been no more than sparse, impoverished settlement in this region (or elsewhere in the desert regions that stretch from Xinjiang to Morocco). Secondly, the technology has been brought to a high level in Oman, and has been functioning successfully for more than two millennia. Thirdly, the organization of the water distribution system is an outstanding example of a traditional structure that is at least a thousand years old and which continues to play a vital role in the social and economic structure of Oman in the 21st century. Fourthly, it is one of the largest concentrations of irrigation systems of this kind anywhere in the world: over four thousand active or defunct systems have been identified.

The agricultural demand area is an outstanding example of sustainable agriculture. The cultivated area is reduced or expanded according to the natural flow of the *falaj*. No mechanical intervention is required. Water distribution structures are constructed efficiently by mean of open channels adapted to the topographical situation. The *aflāj* with their demand areas create a unique environment where the man lives in harmony with nature.

C - Authenticity and integrity

The basic layout of the contemporary Omani *falāj* is wholly authentic. Records and archaeological investigations confirm that this form of water location and distribution has not changed for more than two millennia. Modern techniques are not used in their location, excavation, and design, and modern materials such as concrete are used only for reinforcing the tops of the mother wells and access shafts, at some of the *sharīᶜas*, and in the distribution channels to individual agricultural plots.

The authenticity of the management of the *aflāj* is equally incontrovertible. The traditional system of ownership and management, which is centuries-old, functions efficiently alongside and complements the contemporary administrative and scientific structure for the management of water resources in the Sultanate. It is based on many generations of Omani citizens who have ensured its integrity as a fundamental element in the survival of human society in this arid land.

6. GOVERNMENT ROLE IN PROTECTING *FALAJ* SYSTEMS

When we realise that the total length of *aflāj* in the world is comparable to the distance from the Earth to the Moon (MRMEWR 2005), we understand that a*flāj* are living monuments of the immense effort of our predecessors: The long history of *falaj* use in Oman indicates that community participation in construction, management and maintenance of these systems has been continuous for many, possibly thousands of, years. There is no doubt that *falaj* systems demonstrate, throughout their long history, the modern-day concept of Integrated Water Resources Management (IWRM) (Al Busaidi 2006).

Nowadays, *falaj* systems are affected by many factors which have lead to 25% of them drying up (Al Bakri 2005). These factors include:

- Absence of long-term water allocation or management plans.
- Interference from pumped wells and the impact of other water users in the vicinity of the mother well (source of water) of a *falaj*.
- Expansion of the irrigated areas (increase of water consumption with respect to the annual recharge water available).

Since 1989 with the establishment of the Ministry of Water Resources, currently the MRMEWR, and its *Aflāj* Department, the government has been closely involved in reducing the effect of such obstacles to the survival of *aflāj*, concentrating on the following main issues:

- Establishing protection zones around the “mother well”. the source of water to the *falaj*.
- Assessing *aflāj* affected by drought and over-pumping and providing support wells. Up to the end of 2005 the MRMEWR had constructed some 923 support wells, with a peak in the years 1991 to 1994 which coincided with a prolonged dry period (Al Shaqsi 1996).

- Providing support, both financial and technical, for repair and maintenance. Up to the end of 2006 the MRMEWR had supported 669 project for *falaj* maintenance with a total cost of 5.85 million R.O (14.9 US$).
- Carrying out monitoring of both flow and water quality of 526 representative *aflāj*.

The Ministry has integrated the traditional methods, developed by the *falaj* communities, for the repair and maintenance of *falaj* channels and structures with modern methods and engineering design. The use of mechanical excavation and reinforced concrete means that the works are safer, faster to carry out and last longer. However, with modern methods the cost per unit linear length (m) for underground and open channels is US$ 83-165 and US$ 33-99 respectively (Al Hatmi and Al Amri 2000).

In 2000, the MRMEWR adopted a policy to improve, conserve and protect *aflāj* in order to stabilize the rural population and retain the national heritage through the Water Resources Master Plan vision 2000 – 2020. In outline, the strategic goals are:

- To continue to support *falaj* communities with respect to: maintenance of systems to reduce water losses; and security and protection of water supply flow and quality.
- To increase *falaj* income through optimal usage of water.
- To increase community self-reliance and development.

In order to achieve the above goals, many works and actions through several progressive phases have been actioned:

a. Establish water allocation for each *falaj* in a catchment management plan that can achieve and sustain the water balance.

b. Increase farm productivity through conservation of water and develop irrigation systems.

c. Implement the principle of minimum water quota for each *falaj* which should be sufficient to cover the basic needs of the community served by the *falaj*.

d. Implement the concept of water rights to match demand and this will be based on the sustainable water balance.

In the near future, an agreement with water users is required to improve the management of *aflāj* water. Regulations need to be applied equally to all villages in order to achieve the strategic goals, while control should remain in the hands of the *falaj* communities as they are experienced in overcoming both technical and social problems. The *falaj* committees still play a significant role in water management and *aflāj* maintenance decisions. They also play a significant role in preventing people from sinking new wells that might impact on *falaj* water supply. Therefore it is appropriate that the *falaj* committee should form the basis of new local water management organizations, responsible for both *aflāj* and wells within their locality or sub-catchment.

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QANAT'S ENVIRONMENTAL IMPACT ASSESSMENT IN ARID AND SEMI-ARID AREAS

Pantea Rahbari[1], Mohammad Afsharasl[2]

ABSTRACT

Today, Environmental problems are considered as one of the most important challenges for industrial projects that are harmful for the life of plants and animals. There has been a lot of attempt to decrease the negative impact of operating and maintenance projects and to avoid running conducting projects with high negative impact. This study is an attempt to analyze the effects of qanat - a technique exploiting groundwater used in Iran and most of Middle Eastern countries - on the environment.

Hydrology, pollution, ecology and socio-economical challenges are important parameters in environmental assessment. Because of simplicity and applicability, checklist method was selected for assessing the environmental effect of qanats. In this method of assessment, extended domain of design parameters are considered too. The result obtained from this assessment and data analysis, indicate that qanat has positive environmental effect on soil sediment, soil erosion, ecology and social economy, including income, resettlement and user contribution.

The result of the study shows that the only negative effect of qanat on environment is water pollution, especially with toxic substances, chemical fertilizers and waste water.

Keyword: Assessment – Checklist – Environment – Methodology – Qanat

INTRODUCTION:

Qanats are one of the most important ways for water harvesting that are used from past in Iran. Agriculture and production are influenced and improved by this technique. So, it is necessary to keep this way of water harvesting by scientific and executive approaches for sustainable development. Nowadays, most of institutes and organizations analyze environmental impact assessment for new projects.

Identification of environmental impact, their importance and approaches for decreasing negative impacts are important goals for EIA.

First step at environmental impact assessment is determination of domain and limitation that has done simultaneously by planning. Primary techniques for domain determination are included: Baseline studies, Checklists, Matrices, Network diagrams and Layout.

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Between five appointed methods for environmental impact assessment, checklist is selected because of simple usage, applicable for non-specialists, using extended domain of design parameters, specify the relationship between questions and information in a matrices and representation of results in a table.

This method as an organized procedure with stable framework is utilizable for introduction of projects and their environmental impacts.

In this paper, qanat's environmental effects on hydrology, pollution, soil, sediment, ecology, socio-economic problems are analyzed.

METHODS AND MATERIALS:

ASSESSMENT METHODOLOGY

1-HYDROLOGY

In this part consequence of water flow regime, water table variations and water resources operations during a year are analyzed. According to geographical situation and topography, qanats are recharged in different ways. Some qanats witches are located in highlands and steep valleys recharge from subsurface flows and qanats witches are located in mountainside recharge from groundwater flows. In all cases, cognition of relation between kind of flow and qanat's recharge is important in environmental impact assessment.

1-1-Water shortage regime

Water harvesting from groundwater resources causes water table decline and breaking off relation between plant and aquifer. So, these plants can not supply water with capillary phenomena.

Qanats can prevent from this problem because of its special structure. As qanat's tunnel has constant elevation with decreasing of water table, discharge will be decreased and finally will be stopped. By this technique intensive water table decreasing at upstream of qanats will not be occurred. This subject can decline environmental impact of water table deduction.

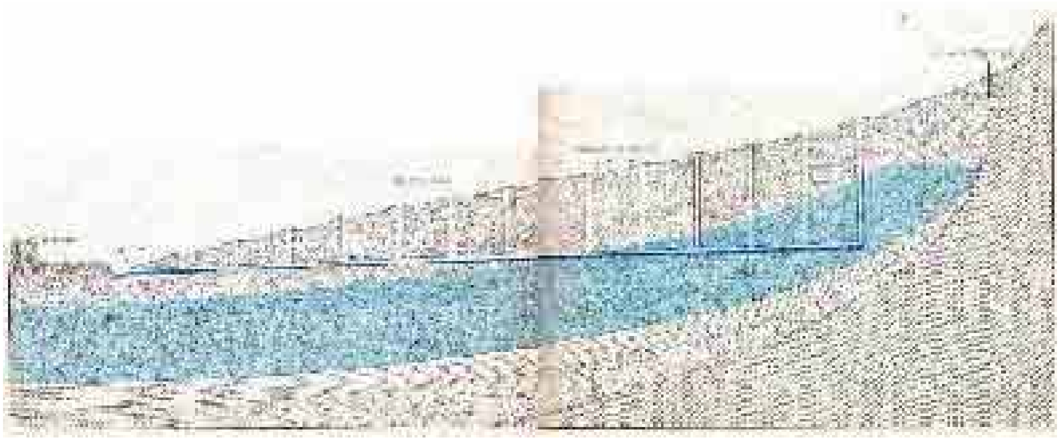

Figure (1) wet tunnel and dry tunnel

1-2- Flood regime

One of the other advantages of this technique is prevention of flood. Since other methods of water harvesting regardless to reservoir volume are only based on water requirement without any limitations, aquifers would be offloaded at draught period. So with appropriate condition for aquifer recharging in wet periods, because of aquifer compaction and macro and micro media deduction, it can not absorb surface water. This problem increases flood occurrence.

Qanats with annual auto control of water harvesting, can prevent fundamental changes in soil media.

1-3- Operation

Continuous flow is one of the disadvantages of qanat's operation. Of course planning for water usage in arid and semi-arid region has solved this problem. There are very different procedures for keeping water, but we can classify all of procedures by two major categories:

Structural preservation:

Ab-anbar and Yakhchal are two important structures that gathering water at un-demanded seasons like winter.

Managerial experience:

Water spreading recharge projects and water diversion toward dessert for irrigation of trees are the most important programs for water usage at winter. Irrigation of trees and plains aquifer recharging will prevent dessert development.

1-4- water table fall

One of the advantages of water table fall before precipitation season is water reservation possibility. Decreasing of water table in waterlogged lands by drainage is useful for agriculture.

Nowadays, non-structural drainage is a compatible strategy for environment. For example Biodrainage that is performed by some trees and plants species. In this context, qanats in addition to water harvesting can perform as a subsurface drain and decrease water table.

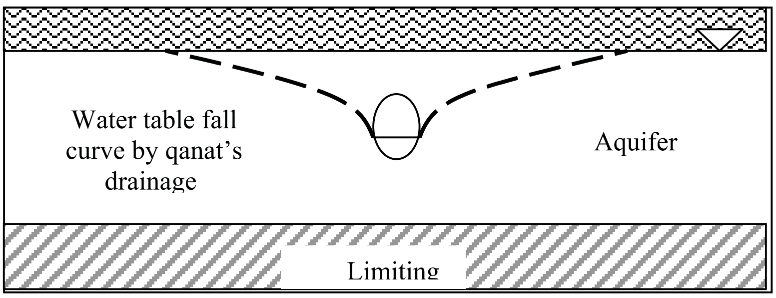

Figure (2) qanat's drainage

In general, wet tunnel in qanats that supply maximum water, perform drainage activity in two parts:

In portion of wet tunnel witch is lied in subsurface, qanat's conduit operate as subsurface drainage pipes.

In another portion of wet tunnel witch is lied in subsurface not completely, qanat's conduit operate as surface drains.

Table (1) Hydrology assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
+						Shortage Regime	1-1	Hydrology
+						Flood Regime	1-2	
				+		Operation	1-3	
				+		Water Table Fall	1-4	
					+	Water Table Rise	1-5	

2- POLLUTION

Today, due to rural development, increasing of agricultural fields and industrial centers and swage entrance to ground waters, qanats are exposed to pollution. Pollution is included three categories:

2-1- Toxic material pollution

This kind of pollution is prompted by factories sewage (in Yazd and Ardekan qanats) and industrial waste water entrance to qanat's conduit. These materials like Arsenic, cadmium and cobalt witch are usually used in textile and dyeing industries and leavening agents and plastics factories. Depletion of these swages in qanat's feeding privacy cause water and soil pollution.

2-2- agricultural pollution

In some areas qanats are installed consecutively. In these cases, swage of upstream qanat transfer dissolution of fertilizers and pesticides to downstream qanats and it can damage water quality and environment.

2-3- Urban swage pollution

Rural and urban development, increase in population and lack of management result in urban swage pollution. So, qanats witch are located in these areas have environmental problems. As a result, for prevention of negative environmental impact, infrastructures are needed for gathering urban swage in qanat's privacy.

Table (2) Pollution assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
	+					Toxic Material Pollution	2-1	Pollution
	+					Agricultural Pollution	2-2	
	+					Urban Wastewater Pollution	2-3	

3-SOILS

One of the most important points in qanat's excavation is soil properties. In case that qanat's conduit pass through gypsy or salty soils, water quality will be unsuitable, qanat's conduit will be deformed and finally it will be destroyed (Kalshour qanat in Neishabur). Ground waters in central part of plains are stagnate and they have abundant dissolved solids but ground waters in mountainsides are fresh and without any dissolved solids.

As a result, water passing through different lands creates two kinds of water: male and female (heavy and light). So, with appropriate route selection for qanat's conduit and transmission of high quality water toward arid and semi-arid region, it will be possible to improve agricultural condition.

Table (3) Soils assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
				+		Soil Characteristics	3-1	Soils
				+		Saline Groundwater	3-2	

4-SEDIMENTS

4-1- Qanat's erosion

Artificial recharge is one of the best techniques for qanat's discharge improvement. For example by constructing small dams in addition to more permeation of precipitation in soil, runoff volume will be decreased. So, usage of this technique at upstream can prevent soil erosion. Other reason for decreasing erosion by qanat is possibility of shrubs and trees irrigation. This parameter causes root accumulation, wind erosion prevention and shifting sand stabilization in desserts.

Qanat's conduit slope is influenced by two parameters: 1) meeting aquifer 2) erosion and sediment.

Annual and perennial dredging is a strategy for qanat's conservation and maintenance, but it is not economical. Nowadays, new procedures are created maintenance costs deduction. For example piscaculture in qanat's tunnel is one of these methods. Fishes movement in qanat's tunnel can control sediments.

4-2- Qanat's morphology

Special morphology of qanat has appropriate compatibility with environment. Always, ground water harvesting comes along with consumption of energy and cost. Qanat, unfashionably uses any energy and cost for pumping water to surface. Furthermore, this technique does not occupy soil surface. As a result, high evaporation in arid and semi-arid region can not influence on transmission efficiency.

Table (4) Sediment assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
				+		Erosion	4-1	**Sediment**
				+		Qanat's Morphology	4-2	
				+		Sedimentation	4-3	

5-ECOLOGY

Most of qanats are installed at dessert edging. Life in these areas is very weak and fragile. So, after qanat's construction in these areas, because of water existence life changed and population increased. Increase in population at dessert edging has beneficial results like prevention of desertification, formation of water habitat and etc.

Also, we can indicate to marine habitats genesis possibility in qanat's conduit. This case can prevent sediment and erosion in qanats and it can be useful for environment.

Table (5) Ecology assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
					+	Land Use	5-1	**Ecology**
				+		Border Lands	5-2	
				+		Plains and Ponds	5-3	
					+	Animals Immigration	5-4	

6- SOCIO-ECONOMIC

Qanat's water in many years with special orderliness has been used by rural people and farmers in arid and semi-arid areas. Today, by installation of deep and semi-deep wells and uncontrolled water harvesting, water table in most plains have been decreased.

So, rural people immigration to big cities will be one of the most important results. This problem will bring large sociological and economical problems in urban management systems.

Table (6) Socio-Economical assessment by ICID checklist

F	E	D	C	B	A	Environmental Impact		
					+	Population changes	6-1	**Socio- Economic**
					+	Incomes	6-2	
					+	People's emigration	6-3	
					+	Further settling	6-4	
				+		Valuable places	6-5	
					+	User cooperation	6-6	

CONCLUSION:

In this study, ICID checklist is used for environmental impact assessment of qanat in arid and semi- arid areas. This checklist is presented by Irrigation and Drainage Committee for irrigation and drainage networks assessment.

However, surveying of a project's environmental impact assessment should be done according to its regional condition, but in this study environmental impact assessment of qanat in arid and semi- arid areas was generally analyzed.

In this methodology, negative and positive environmental impacts of qanat are discussed according to categorized subjects.

For shortage and flood regimes, there is not correct judgment possibility and more researches are recommended. According to this study, pollution has more negative impacts on environment but other parameters have positive impacts.

Table (7) ICID checklist for environmental impact assessments

Judgment is not possible now	Very negative impact possibility	negative impact possibility	Without any impact	positive impact possibility	Very positive impact possibility	**Environmental Impact**		
F	**E**	**D**	**C**	**B**	**A**			
+						Shortage regime	1-1	**Hydrology**
+						Flood regime	1-2	
				+		operation	1-3	
				+		Water table fall	1-4	
					+	Water table rise	1-5	
	+					Toxic material	2-1	**pollution**
	+					Agricultural pollution	2-2	
	+					Urban wastewater	2-3	
				+		Soil salinity	3-1	**soils**
				+		Soil characteristics	3-2	
				+		Saline groundwater	3-3	
				+		Qanat's erosion	4-1	**sediment**
				+		Qanat's morphology	4-2	
				+		sedimentation	4-3	
					+	Land use	5-1	**Ecology**
				+		Border lands	5-2	
				+		Ponds and plains	5-3	
					+	Animals emigration	5-4	
					+	Population changes	6-1	**Socio-Economic**
					+	incomes	6-2	
					+	People emigration	6-3	
					+	Further settling	6-4	
				+		Valuable places	6-5	
				+		User cooperation	6-6	

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RENOVATION AND REHABILITATION OF ANCIENT BAHMAN WEIR IN FARS, IRAN

Farshid Morshedi[1] and Shahab Daneshvar[2]

ABSTRACT

Bahman weir is one of the most famous ancient structures located in Fars province in southwest of Iran. The weir is a masonry rock structure with 7 meters height. The weir dates back to 2000 years ago. It is constructed on GhareAghaj River as a diversion structure to supply Kavar plain irrigation demands. The weir has undergone limited partial repairs several times. The weir has been studied completely in 2002 and its detailed rehabilitation plan has been developed. Site geology, main body geotechnical aspects, weir stabilities against sliding and overturning have been addressed with especial consideration to its age and historical value. The study also encompasses the weir appurtenance structures including its intake structure and downstream conveyance channel. Investigations show that the ancient Iranian had a deep knowledge on site selection, hydraulic structures, and construction materials.

INTRODUCTION

In the ancient periods, when our ancestors understood the value of water for agriculture, they recognized the importance of water control and storage. Actually, the easily controlled water we have nowadays in our dams reservoirs is the pure fruit of an attempt began on those era. In this regard, the Iranian nation has contributed a lot to this issue. One may recognize and appreciate the Iranian approach, methodology, level of knowledge and experiences towards dam construction upon observing these historical workman pieces. Investigations show many similarities between modern and ancient hydraulic structures. Scrutinizing theses valuable historical heritage would help us to resolve the complicated problems we encounter in water resources issue.

Iranian people whose lands are located in a semi-arid climate have prevailed on climatological constraints by incorporating several different techniques originated from their inherent intelligence. Construction of different structures for water control, storage and conveyance such as dams, barriers, water stores (known as "Ab-Anbar") and Qanats reveals their wise attention for optimum water resources exploitation. Most of these

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structures are considered among successful architectural structures, which draw applause and wonder of those who carefully observe them. This article intends to introduce one of these remarkable structures named “Bahman Weir”.

HISTORICAL BACKGROUND AND LOCATION

Bahman weir is one the most ancient irrigation structures in Iran being still operational. Based on conducted scientific investigations, this structure is one of the historical proofs of comprehensive and deep understanding of its designers and constructors regarding geology, structural materials and river hydraulic behaviors.

Bahman weir is constructed on GhareAghaj River in Fars, Iran. It is located 10 kilometers from city of Kavar and 65 kilometers southeast of Shiraz. The weir has been constructed to divert river flow for Kavar plain agricultural lands irrigation purposes. Location of Bahman weir is shown in figure 1.

Figure 1 - Location of Bahman Weir

Date of Bahman weir construction is not known specifically. However, its age is estimated about 2000 years. In fifteenth century, Mostofi has referred to Bahman weir as “a historical barrier” in his book entitled “Nozhat Al-Gholoub”. Forsat Al-Doleh Shirazi has visited the weir about a century ago. He has described architectural and structural states of the weir and its quality at the time of his visit. He has also made a sketch of the weir that is considered as the most important visual reference for technical investigation of the structure. This sketch, which is the general view of the weir, helps us to understand the structural properties and shape of the weir. He has included this weir in his book entitled "Asar-e Ajam". The status of the weir under present conditions and also its former condition in a century ago are shown in figure 2.

GhareAghaj River is one of the most important rivers in Fars province, Iran. The river, after conjunction with Firouzabad River, is called Mond River and runs up into Persian Golf. Length of the river upstream of the weir is about 130 kilometers. The weir basin is about 1600 square kilometers. The basin climate is semi-humid with a mean annual rainfall of 580 millimeters. Longterm river flow at weir site is 7.9 cms. River floods with different return periods at weir site are presented in table 1.

Table 1 - GhareAghaj River Floods at Bahman Weir site

Return Period (year)	2	10	50	100	1000
Flood Discharge (m^3/s)	256	976	1354	2396	4144

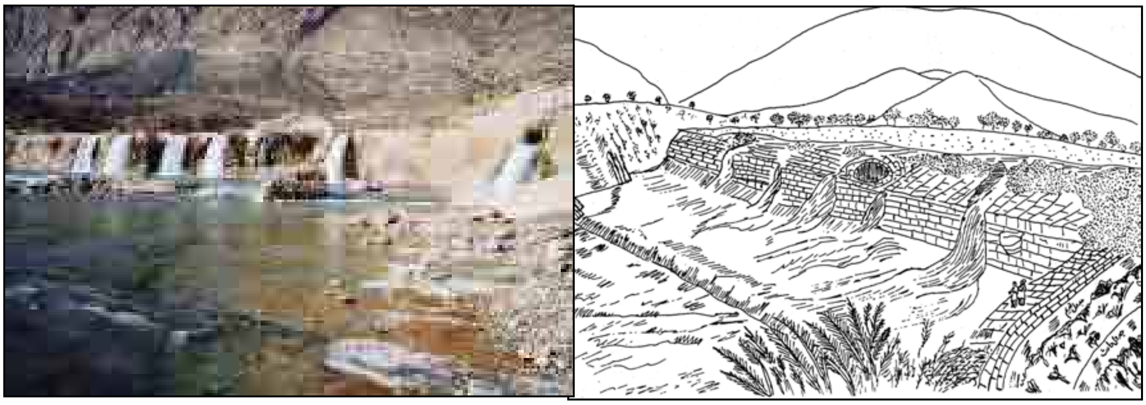

Figure 2 – Bahman Weir “at present” and “a century ago”

GEOLOGICAL AND ARCHITECTURAL ASPECTS

One of the main features of Bahman weir is geology of its location site. In this area, GhareAghaj River passes through Razak formation. Razak formation consists of alternated marlstone and siltstone layers with sandstone slices. Hard sandstone layers are visible in a few 10 meters intervals in river bed and normal to flow line. Bahman weir is constructed over one of these veins, as shown in figure 3. Like other ancient barrages in Iran, Bahman weir is a masonry long crested weir made of large limestone rocks and Sarouj mortar. Length of the crest is 116 meters having 5 open conduits, 2.5-3 meters width each, to allow release of surplus water. However, all crest length is active during flood periods. The weir performance during low and high flows is depicted in figure 4. Width of weir body is not uniform along its length and it follows width of foundation sandstone. Accordingly, crest width varies between 5 to 10 metes.

Geophysical studies have been conducted on 6 positions on weir crest to better understand the conditions of weir body and foundation materials. Upon assessments of the results, 4 boreholes have been dig on crest followed by an experimental grouting. Depths of boreholes vary from 10 to 15 meters so that penetration into the bed rock is assured. Results of tests show that the weir body height varies from 5.4 to 13.2 meters.

Figure 3 – Geological Condition of Bahman Weir Site

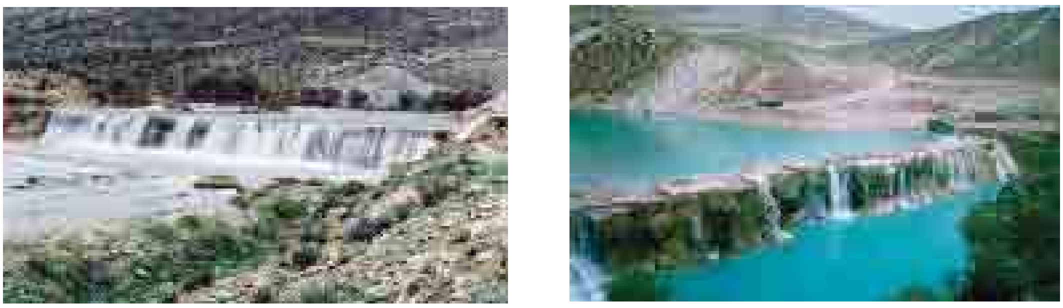

Figure 4 – Performance of Bahman Weir under Low and High Flows

Conducted tests show that quality of weir body materials and foundation bed rock grows less from very good materials in right abutment to poor materials in left abutment. Henceforth, the weak part of the structure is located in its left abutment. Downstream of this weak part there is a mass of rock and Sarouj took out from the main body during floods. The damaged portion has been repaired.

Although there are evidences of many active faults around the weir site, field studies show that there is no fault crossing the site. The closest fault to the weir site is Sepidar active fault located about one kilometer southeast of the site. Investigation of Iran Seismic Hazard Zonation Map prepared by International Institute of Earthquake Engineering and Seismology – IIEES (1999) shows that weir site is located in an area with high earthquake hazard. In this regard, the weir would experience accelerations as high as 0.3g (for a 75-year return period earthquake equal to 50% of occurrence in 50 years) and 0.37g (for a 475-year return period earthquake equal to 10% of occurrence in 50 years). Thereon, considering the 2000-year age of the weir, it is logic to conclude that the weir has experienced heavier earthquakes during its life.

Bahman weir is constructed to regulate water surface in river and to divert the flow to A'zam channel located on its left bank as shown in figure 5. In this area, there is remaining of an old channel that its elevation shows that the crest elevation was lower than where it currently is. Therefore, it would be concluded that the crest had been heightened by maximum 2 meters during its life. The matter is also obvious by observing the changes in body materials textures.

Nowadays, required water of some parts of Kavar plain is supplied by Bahman weir through river flow diversion and conveyance through A'zam channel. The conveyed water is distributed into seven portions irrigating agricultural lands of 16 villages measuring totally about 5000 hectares.

HYDRAULIC CONDITIONS

Assessment of Bahman weir performance requires proper description of its existing conditions and other influencing factors. The right portion of the weir body has been remained unharmed through years of operation. But, the left portion has been damaged and repaired several times through its servicing stage.

Due to flow overfall downstream of weir the loose marlstone layer has been eroded gradually resulting in a natural stilling basin just downstream of the weir. The stilling basin has a depth of 10 meters. There is a hard sandstone layer just downstream of the stilling basin, similar to the vein where the weir is constructed on, forming a natural end sill providing stability of river bed and stilling basin hydraulic performance. The natural sill at the end of the natural stilling basin can be seen in figure 5.

Unfortunately, one of the most valuable and sophisticated structures of the weir has been destroyed under rehabilitation works conducted by farmers and local people in the far past. The structure was a bottom outlet, shaped like a well, having two gates. It was used for evacuation of sediments deposited behind the dam. Forsat Al-Doleh Shirazi has referred to this structure in his book and showed its position in the middle of the weir as shown in figure 2.

At present, sediments have been completely filled out the weir reservoir. Assessment of Bahman weir stability shows that overturning and sliding safety coefficients under flood conditions, with 2 meters head on the crest, are 1.82 and 1.2, respectively. These coefficients under normal conditions are 3.23 and 2.2, respectively.

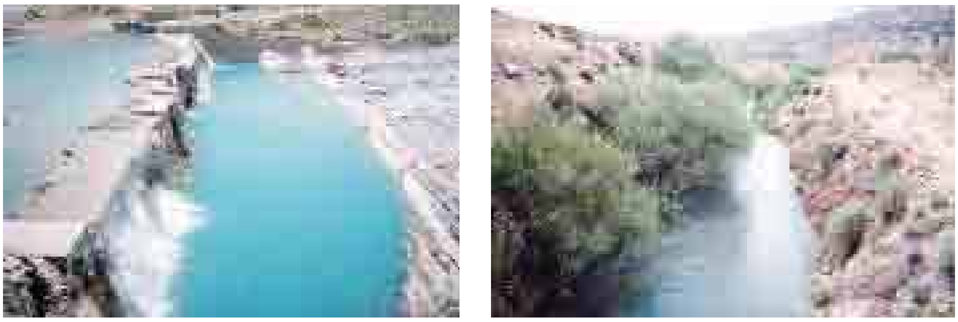

Figure 5 – Bahman Weir with Natural Stilling Basin and A'zam Channel

CONCLUSION

With no doubt, technology development in the ancient civilizations was an answer to mankind needs for optimum exploitation of natural resources, safety towards natural hazards and improvement of individual and social life standards. Man intention to control the environment and exploit its natural resources has resulted in opportunities and challenges leading to increase of his understanding of natural resources and materials and construction of structures. Bahman weir is a significant proof to this claim. The 2000-year old Bahman weir takes us into deep thinking since durability concept of structures has just been taken into consideration in the past two decades. Let's hope that specialists and engineers take proper lessons for correct management of natural resources and environment upon observing and studying such cultural heritages of the world while endeavoring to protect them.

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A HISTORICAL REVIEW ON THE QANATS AND HISTORIC HYDRAULIC STRUCTURES OF IRAN SINCE THE FIRST MILLENNIUM B.C.

Ali Asghar Semsar Yazdi, Samira Askarzadeh[1]

INTRODUCTION

In order to review the situation of Qanats and Historic Hydraulic Structures in the course of the Iranian history, this paper explores some documents on these structures from the first historical records to the present ones. To do so, we try to review the situation of qanats and historic hydraulic structures keeping pace with the history of kings and governments.

First of all, it seems necessary to take up some facts on the geographical and climatological conditions of Iran, for the natural infrastructures had an important role in creating and developing the qanat systems.

Suffice to say Iran has a variable climate, and In general, this country has an arid climate in which most of the relatively scant annual precipitation falls from October through April. In most of the country, yearly precipitation averages 250 millimeters or less. The major exceptions are the higher mountain valleys of the Zagros and the Caspian coastal plain, where precipitation averages at least 500 millimeters annually. In the western part of the Caspian, rainfall exceeds 1000 millimeters annually and is distributed relatively evenly throughout the year. This contrasts with some basins of the Central Plateau that receive 100 millimeters or less of precipitation annually.

ELAMITES (14TH CENTURY. BC)

The oldest hydraulic structure in Iran is the water supplying system of Chagazanbil temple dating back to 3300 years ago when Elamits lived in southern Iran.

This temple is located 30 Km away from east-south of Shoosh city where Elamits used to worship.

The hydraulic system of this temple which provided people with water contains water storage tank, some water transfer canals and a reservoir. In this system, water was transferred from Karkhe River to the water storage tank through a 50 Km long canal and

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then after physical treatment, was transferred to the reservoir. So, this system made it possible for that people to get access to fresh and safe drinking water.

Regarding the Qanats and their antiquity, it is Henry Goblot who explores the onset of this technology for the first time. He stipulates in his book entitled “Qanat; a Technique for Obtaining Water” that during the early first millennium before Christ, for the first time some small tribal groups gradually began immigrating to the Iranian plateau where enjoyed less precipitation than the territories these groups came from. They came from somewhere with a lot of surface streams, so their agricultural techniques used to require more water which was out of proportion to the water available in the Iranian plateau. So they had no way but fastening their hope on the rivers and springs that originated in the mountains. They faced two barriers; the first was the seasonal rivers which were out of water during the dry and hot seasons. The second was the springs that drained out the shallow groundwater and fell dry during the hot seasons. But they noticed some permanent runoffs flowing through the tunnels excavated by the Acadian miners who were in search of copper. These farmers established a relationship with the miners and asked them to dig more tunnels in order to supply more water. The miners accepted to do that, because there was no technical difficulty for the miners in constructing more canals. In this manner, the ancient Iranians made use of the water that the miners wished to get rid of it, and founded a basic system as named qanat to supply the required water to their farm lands. According to Goblot, this innovation took place in the western north of the present Iran and later was introduced to the neighboring area that was Zagros Mountains.

According to an inscription left from Sargon II the king of Assyria, In 714 BC he invaded the city of Uhlu lying on the western north of Uroomiye lake that belonged to the territory of Urartu empire, and then he noticed that the occupied area enjoyed a very rich vegetation even though there was no river running across there. So he managed to discover the reason how the area can stay green, and realized that there are some qanats behind the matter. In fact it was Ursa the king of the region who had rescued the people from thirst and turned Uhlu into a scenic and green land. Goblot believes that the influence of Medeans and Achaemenians made the technology of qanat spread from Urartu (in the western north of Iran and near the present border between Iran and Turkey) to all over the Iranian plateau.

ACHAEMENIAN EMPIRE (550-330 BC)

According to the ancient records, the Achaemenian kings had built some important hydraulic structures in their territory. Some of these structures have completely been destroyed over time, and some of them have been rehabilitated by the next dynasties like Sassanids.

At that time, the most important part of Iran, like the south (Fars) and the west-south (Khoozestan), which had many surface water resources, were the center of Achaemenian Empires' attention. In order to cultivate the mentioned erea, the Achaemenian empires, had constructed several dams in those parts, out of which some are still existing and there are some remaining left from some of them.

Some structures built by Achaemenians, are as follows: the great Kurosh dam, the Daryush dam and Daryush canal, Ramjerd dam and Bahman dam in Fars and also water transfer systems at some temples and palaces.

Regarding the Achaemenians attention toward the dam construction, Herodot, the ancient narrator, writes: "today, the king Daryoush has obstructed the gaps of the mountains and put a big door on each to stem the flow of water. The plain between the mountains has turned into a lake due to the base flow of the rivers coming in. according to the king's order the doors toward the lands need of water should be open until these lands are irrigated. Another order is to direct the water to the farm lands that need less water than the aforesaid lands".[1]

In addition to the dams built by the Achaemenians, one of the important hydraulic structures dating back to this era was the swage system constructed for draining and disposing of the surface runoff at Perspolice in Fars.

The study on situation of Qanats in this period shows that: It was an Achaemenian ruling that in case someone succeeded in constructing a qanat and brining groundwater on to the surface in order to cultivate, or renovating an abandoned qanat, the tax he was supposed to pay the government would be waived not only for him but also for his successors up to 5 generations. During this period, the technology of qanat was in its heyday and it even spread to other countries. For example, according to Darius's order, Silaks the naval commander of the Persian army and Khenombiz the royal architect managed to construct a qanat in the oasis of Kharagha' in Egypt. "Beadnell" believes that the qanat construction dates back to two distinct periods. In Egypt some qanats were constructed by the Persians for the first time, and later Romans dug up some other qanats during their rule over Egypt from 30 BC to 395 AC. In any way the magnificent temple built in this area during Darius's reign shows that there was a considerable population depending on the water of qanats. Ragerz has estimated this population a 10000 people. The most reliable document confirming the existence of qanats at this period has been written by Polibius who stipulates that: "the streams are running down from everywhere at the base of Alborz mountain, and people have transferred too much water from a long distance through some subterranean canals by spending much cost and labor".

Needless to say during this period, not only the experts got access to the hydrological knowledge and could do the accurate and surprising calculations, but also the knowledge on hydraulic structures developed considerably. The examples of this issue are the hysraulic structures constructed at that time, which are still existing and in use, such as Bahman dam in Fars province.

In any way, the era of Achaemenian was a unique period in the history of Iran in terms of building dams.

SELEUCIDIAN ERA (312-250 BC)

During Seleucidian Era that began after the occupation of Iran by Alexander, it seems that the qanats and hydraulic structures were abandoned.

1- Water solution in Fars history, Vol. 1, Page. 73

PARTHIAN ERA (250 BC – 150 AC)

In terms of the situation of qanats during this era, some historical records have been found. In a study done by the Russian orientalist scholars it has been mentioned that: the Persians used the side branches of the rivers, the mountainous springs, wells and qanats to supply water. The subterranean galleries excavated to obtain groundwater were named as qanat. These galleries were linked to the surface through some vertical shafts which were sunk in order to get access to the gallery to repair it if necessary.

According to the historical records left from the ancient times, the Parthian kings did not care about the qanats and hydraulic structures the way the Achaemenian kings and even Sassanid kings used to do. As an instance Arsac III one of the Parthian kings destroyed some qanats in order to make it difficult for Seleucidian Antiochus to advance further while fighting him.

The only hydraulic structure built in this period is the canal of "Nahr-ol-malek" or "Nahr-shahi", divided from Forat River.

SASSANID ERA (226-650 AC)

The historical records left from this time indicate a perfect regulation on both water distribution and farmlands. All the water rights were recorded in a special document which was referred to in case of any transaction. The lists of farmlands - whether private or governmental - were kept at the tax department. During this period there existed some official rulings on qanats, streams, construction of dam, operation and maintenance of qanat, etc. The government proceeded to repair or dredge the qanats that were abandoned or destroyed by any reason, and construct the new qanats if necessary. A document written in Pahlavi language[1] pointed out the important role of qanats in developing the cities at that time.

At this era, especially at the time of Shahpur I, there was a boom in the industry of dam construction. At that time, Shooshtar one of the principle cities of Iran, was the center of governments' attention, and many dams were built there across the Karun river. Also, there were some extensive irrigational canals in Shooshtar and its surroundings. For example, the canal of Gargar, left from Ardeshir-Babakan, and the canal of Darion, left from the Great Dara, are a part of that irrigational system.

Besides, the Sasanid dynasty cared about the maintenance and rehabilitation of the hydraulic structures. At that time, there was a county named as "Kast-Fozood" that was responsible for the maintenance of water canals and dams, the construction of dams and ditches.

Some important bridges and dams built at the Sasanid era are as follows:

The great bridge and dam of Shooshtar (Shadorvan), Mizan dam, Gargar bridge and dam, Shooshtar water mills, Dezful bridge and dam, Dokhtar dam, Shahrestan bridge, Aghili dam, Ayar dam, Mahi bazan dam, Dara dam and Ghir dam, Lashgar bridge and dam, Shah Ali bridge and dam, Karkhe dam, Khak dam, Argan dam, Shahre-loot dam, Darvaze dam and Izad-khast dam.

1- an ancient branch of Persian language that was spoken during Sassanid era

AFTER ISLAM (621-1921 AC)

In Iran, the advent of Islam that coincided with the overthrow of the Sasanid dynasty brought about a profound change in religious, political, social and cultural structures. But the qanats and hydraulic structures stayed intact, because the economical infrastructures such as qanats were of great importance to the Arabs. As an instance, M. Lombard reports that the Moslem clerics who lived during Abbasid era such as Abooyoosef Ya'qoob (death 798 AC) stipulated that whoever can bring water to the idle lands in order to cultivate, his tax would be waived and he would be entitled to the same lands cultivated. Therefore, this policy did not differ from that of Achaemenians not getting any tax from the people who revived the abandoned lands. Arabs' supportive policy on the qanats was so successful that even the holy city of Mecca gained a qanat too. The Persian historian Hamdollah Mostowfi writes: "Zobeyde Khatoon (Haroon al-Rashid's wife) constructed a qanat in Mecca. After the time of Haroon al-Rashid, during the caliph Moghtader's reign this qanat fell into decay, but he rehabilitated it, and the qanat was rehabilitated again after it collapsed during the reign of two other caliphs named as Ghaem and Naser. After the era of the caliphs this qanat completely fell into ruin because the desert sand filled it up, and later Amir Choopan repaired the qanat and made it flow again in Mecca."

There are also other historical texts proving that the Abbasids were concerned about qanats. For example, according to the "Incidents of Abdollah bin Tahir's Time" written by Gardizi, in the year 830 AC a terrible earthquake struck the town of Forghaneh and reduced many homes to rubble. The inhabitants of Neyshaboor used to come to Abdollah bin Tahir in order to request him to intervene, for they fought over their qanats and they found the relevant instruction or law on qanat as a solution neither in the prophet's quotations nor in the clerics' writings. So Abdollah bin Tahir managed to bring together all the clergymen from throughout Khorasan and Iraq to compile a book entitled "Alghani" (The Book of Qanat). This book took up all the rulings on qanats which could be of use to whoever wanted to judge a dispute over this issue. Gardizi added that this book was still applicable to his time, and everyone made references to this book.

One can deduce from these facts that during the abovementioned period the numbers of qanats were so considerable that the authorities were prompted to put together some legal instructions in terms of qanats. Also it shows that from the ninth to eleventh century the qanats that were the hub of the agricultural systems were of interest to the governments. Apart from The Book of Alghani which is considered as a law booklet focusing on the qanat related rulings based on the Islamic principles, there is another book about groundwater written by Karaji in the year 1010. This book entitled Extraction of Hidden Waters takes up just the technical issues associated with qanat and tries to answer the common questions such as how to construct and repair a qanat, how to find a groundwater supply, how to do leveling, etc. some of the innovations described in this book had been brought up for the first time in the history of hydrology, and some of its technical methods are still valid and can be applied in the qanat construction. The content of this book implies that its writer (Karaji) did not have any idea that there was another book on qanat compiled by the clergymen. Mohammad bin Hasan quotes Aboo-Hanifeh that in case someone constructs a qanat in an abandoned land, someone else can dig another qanat in the same land on the condition that the second qanat would be 500 zera' (375 meters) away from the first one.

According to the historical records, related to Ale-Booye dynasty, there were a lot of involvements in the hydraulic structures. Abbas Garoosi, in the first chapter of his book "history of water and irrigation in Kerman" quoted some issues on some 11th century historians and writers as recited below:

Moqdasi describes the prosperity in the exploitation of the rivers in Khuzestan at the time of Ale-Booye. Aboodalaf also refers to the water wheels in Shooshtar, and Mostoofi explains in his book "Nozhatol Gholoob" a big water wheel bringing up the water of Dez River to a height of 25 meters in order to supply water to the city of Dezfool and its farm lands.

At the beginning of 11th century, Narshakhi names 12 rivers running in Bokhara, and each has supplied water to lots of villages. He writes: "each river as mentioned covers many villages, and it is said all the rivers were dug by people except for the river of A'a and Khatfar which were already created by the flow of water".

These evidences confirm that the kings of Ale-Booye were concerned about the hydraulic structures. Also, the dam of Amir in Fars dating back to Ale-Booye period is ranked among the most important dams in Iran. In this regard Nasery writes: "this dam is one of the wonders of Fars. This dam was constructed by the king of Azadol dowle Deylami in the year 944 A.D. My tongue as well as my pen is not able to express my wonder in its magnificence and greatness".

Felanden, the French scientist and explorer who visited this dam in 1220 A.D, says: "so efforts were made in constructing this dam that it could have lasted even until now. This dam is called as the dam of Amir (king) … shows that the ancient kings were very wise, for they knew that the prosperity and dignity of the country would bring more dignity and pride to them. Therefore they did their best to improve the infrastructures of their territories, which eventually could lead to the prosperity of the country. The king whose name has remained is Azadol dowle Deylami ruling in the 11th century. The peasants still pray for his soul when they harvest their crop".[1]

In addition to the dam of Amir, the dams of Feyz Abad, Tilkan and Movan are ranked among the structures of Ale-Booye era.

Ms. Lambpton quotes Moeen al-din Esfarzi who has written the book Rowzat al-Jannat (the garden of paradise) that Abdollah bin Tahir (from Taherian dynasty) and Ismaeel Ahmed Samani (from Samani dynasty) had several qanats constructed in Neyshaboor. Later in the 11th century a writer named as Nasir Khosrow acknowledged all those qanats by the following words: "Neyshaboor is located in a vast plain at a distance of 40 Farsang (~240 km) from Serakhs and 70 Farsang (~420 km) from Mary … all the qanats of this city run underground, and it is said that an Arab who was offended by the people of Neyshaboor has complained that; what a beautiful city Neyshaboor could become if its qanats would flow on the ground surface and instead its people would be underground".

1- Water solution in Fars history, Vol. 1, Page. 91

These documents all certify the importance of qanats during the Islamic history within the cultural territories of Iran.

In 13th century, the invasion of Mongolian tribes to Iran fell many qanats and irrigational systems into ruin, and many qanats were deserted and dried up. Later in the era of Ilkhanid dynasty especially at the time of Ghazan Khan and his Persian minister Rashid Fazl-Allah, some measures were taken to revive the qanats and irrigational systems.

His notes in "the arrangement of the nourishing of the deserted lands", the 37th chapter of his book entitled "Jame ol Tavarikh" which means "comprehensive history" represents the concern about the subject of water and prosperity at that time. The examples of the most important hydraulic structures built at that era are Saveh dam and Kabar dam.

There is another book entitled Al-Vaghfiya Al-Rashidiya (Rashid's Deeds of Endowment) that names all the properties located in Yazd, Shiraz, Maraghe, Tabriz, Isfahan and Mowsel, Rashid Fazl-Allah has donated to the public or religious places. This book mentions many qanats running at that time and irrigating a considerable area of farmlands. At the same time (14th century) another book entitled Jame' al-Kheyrat was written by Seyyed Rokn al-Din on the same subject of that of Rashid's book. In this book Seyyed Rokn al-Din names his properties in the region of Yazd donated. These deeds of endowment indicate that a lot of attention was given to the qanats during the reign of Ilkhanids, but it is attributable to their Persian ministers who had influence on them.

In the Safavid era (15th and 16th century) the problem of the shortage of water intensified and led to constructing many bridges, dams, water reservoirs and qanats.

Many hydraulic structures have remained from that time. For example, the most important bridges and dams in Isfahan, many hydraulic structures in Kerman and many water reservoirs in Yazd belong to safavid era.

Two of the most important hydraulic structures of Safavid, mentioned in many history books and travel accounts, are Allah-verdi-khan Bridge (Sio-se-pol) and Khajoo Bridge and dam, located in the ancient city of Isfahan, across the Zayande-rud river. Sharden the French explorer, who came to Iran at Safavid era, has explained these two structures in details, in his travel account.

Also, at that time, there were many hydraulic structures like water reservoirs and ice-houses in some dry cities like Yazd and Kerman.

Most of the water reservoirs in Yazd have an inscription reading the name of their founders and the date of their construction. These inscriptions show that some of the reservoirs date back to the Safavid era.

Meanwhile, one should mention some structures in Kerman like Moayedi ice-house and hoz-panj water reservoir, left from Ganj-Ali-Khan, the governor of Kerman at Safavid time, and Ali-mardan-khan water reservoir, left from his son named as Ali-mardan-khan.

Sharden the French explorer who made two long journeys to Iran at the time of Safavid reports that: “the Iranians rip the foothills in search of water, and when they find any, by means of qanats they transfer this water to a distance of 50 or 60 kilometers or sometimes further downstream. No nation in the world can compete with the Iranians in recovering and transferring groundwater. They make use of groundwater in irrigating their farmlands, and they construct qanats almost everywhere and always succeed in extracting groundwater.”

The dynasty of Qajar ruled Iran from the 16th century to the early 18th century. According to Goblot, the time of Qajar can be considered as the heyday of qanats, for the qanats could flourish. Agha Mohammad Khan the founder of Qajar dynasty chose Tehran as his capital city, the city where there was no access to a reliable stream of surface water and it had to rely on the groundwater. The rich supply of groundwater and suitable geological-topographical conditions of Tehran allowed this city to house many qanats whose total discharge amounted to 2000 liters per second. Haj Mirza Aghasi (ruling between 1834 and 1848) the prime minister of the third king of Qajar dynasty encouraged and supported qanat construction throughout the country[1]. Jaubert de Passa who has surveyed the situation of irrigation in Iran reports a population of 50000 in Hamedan, 200000 in Isfahan and 130000 in Tehran in the year 1840. Then he claims that in these cities life is indebted to the qanats which are being constructed in a simple but powerful manner. In a nutshell the period of Qajar that lasted about 1.5 century has witnessed lots of endeavors to revive the qanats. At that time there was also a high attention to hydraulic structures. One can refer to Emad-Abad dam in Fars province, water reservoir of Haji-Yadgar in Firooz-Abad Meybod, water reservoir of Do-rah in Rahmat-Abad Yazd and water reservoirs of Takht-Ostad and Jo-horhor in Yazd, as some examples of the hydraulic structures built at the time of Qajar.

THE PERIOD OF PAHLAVI

During the period of Pahlavi, the process of qanat construction and maintenance continued. A county that was responsible for the qanats was set up by the government. At that time most of the qanats of the country belonged to the land lords. In fact feudalism was the prevailing system in the rural regions. The peasants were not entitled to the lands they worked on, but they were considered just as the users of the lands. They had to pay the rent of the land and water to the feudals. The feudals could afford to finance all the proceedings required to maintain the qanats, for they were at a high financial level. According to the report of Safi Asfiya who was in charge of supervising the qanats of Iran in the former regime, in the year 1942 Iran enjoyed 40000 qanats with a total recharge of 600000 liters per second or 18.2 billion cubic meters per year. In the year 1961 another report was published revealing that in Iran there were 30000 qanats out of which just 20000 qanats were still in use with a total output of 560000 lit/se or 17.3 billion cubic meters per year. In 1959 a reformative program named as White

1- According to a famous story, one day Haj Mirza Aghasi paid a visit to a qanat to find out how they are getting on their work. He asked the worker who was at the bottom of a well if the qanat has gotten to the water or not. The worker who did not recognize the prime minister complained that Haj Mirza Aghasi is wasting the country’s budget on the qanats that will never have water. The minister replied: “don’t worry! if the qanat will not get us water, but will get you a living”. The minister’s word has turned into a popular proverb in Iran.

Revolution was declared by the former Shah. One of the articles of this program addressed the land reform that let the peasants take ownership of a part of the feudals' lands. In fact the land reform dashed the lords' hope. They lost their motivation for investing more money in constructing or repairing the qanats which were subject to the land reform law. On the other hand, the peasants could not come up with the money to maintain the qanats, so a lot of qanats gradually got deserted. The introduction of the modern devices that made it possible to drill many deep wells and extract the groundwater much more quickly and easily aggravated the qanats' annihilation. The pumped wells had a negative impact on the qanats due to their overexploitation of the groundwater. These changes that occurred in Mohammad Reza Shah's reign inflicted a great damage on the qanats of the country so that many qanats vanished forever. The statistics related to 14778 qanats estimates the overall discharge of these qanats as 6.2 billion cubic meters per year between the years 1972 and 1973. This figure shows a great decrease in flow rate of qanats.

In the year 1963 the Ministry of Water and Electricity was established in order to build dams and provide the rural and urban areas of the country with the sufficient water and electricity. Later this ministry was renamed as the Ministry of Energy.

At this period, the executive procedures of 19 dams began out of which 13 came into action. The Regulated annual water of these active dams amounts to 13.228 million m3. Most of these dams were designed and constructed by foreigner consulting engineers and contractors. At this time, 553000 Hectares irrigational and drainage networks were constructed.[1]

In the year 1966 the parliament passed a law protecting the groundwater resources. According to this law the Ministry of Water and Electricity was allowed to ban drilling any deep and semi-deep wells wherever the surveys show that the water table is dropping because of overpumping. In fact this law was passed when the growing number of the pumped wells sounded the alarm about the overpumping and depletion of groundwater leading to the decline in the qanats' flow in all over the country. This law as well as the law of water nationalization that was approved in 1968 and eventually the law of fair distribution of water passed (in 1981) after the Islamic revolution emphasized the definition of the restricted and free areas for drilling. In the restricted areas drilling any wells (except for drinking and industry) were prohibited in order to prevent the continuous depletion of groundwater. So the rest of the qanats had a better chance to survive.

THE TIME OF THE ISLAMIC REPUBLIC

The Islamic Republic of Iran, focused on the subject of the management of the surface and ground water since its beginning. In this era, not only, many dams have been constructed, but also, the knowledge of designing and constructing dams has been localized.

According to the statistics published by the Ministry of Energy, since the beginning of Islamic Republic of Iran (1979) the executive projects of 152 dams has lunched, out of which 72 dams came into action by 2005.

1- Water Resources Management Organization's report on present situation of Iranian dams

The Regulated annual water of these active dams amounts to 11.623 million m3. At this time, the irrigational and drainage networks developed and 1115000 Hectares of the main irrigational and drainage networks were added to the existing networks in Iran.[1]

After the Islamic revolution, a special attention was given to the qanats. For the first time in 1981 a conference on qanat was held in Mashhad during which the different options to mitigate the problem were explored. The organization of Jihad Sazandegi took responsibility for the qanats and provided the users of qanats with some funds. Now the same organization which was renamed as Jihad Agriculture is responsible for the qanats and continues to grant some funds to the stakeholders to maintain their qanats. During the last years, the parliament has allowed an annual budget of 13 million USD to go to the construction and maintenance of the qanats. Many other qanats may dry up without this budget, because the owners of the qanats do not afford to pay the whole expenses.

In the years 1984-1985 the ministry of energy took census of 28038 qanats whose total discharge was 9 billion cubic meters. In the years 1992-1993 the census of 28054 qanats showed a total discharge of 10 billion cubic meters. 10 years later in 2002-2003 the number of the qanats was reported as 33691 with a total discharge of 8 billion cubic meters.

In the year 2000, holding the International conference on qanat in Yazd could draw a lot of attention to the qanats.

Creating the International Center on Qanats and Historic Hydraulic Structures in Yazd and establishment of Qanat collage in Taft are two examples of governments support in this regard.

CONCLUSION

Taking into account that this paper examines the qanats on one hand and the hydraulic structures like dams, bridges, water reservoirs, water mills and ice-houses on the other hand, in the various historical periods, so, at conclusion, we try to analyze these two subjects (Qanats – hydraulic structures) separately:

Qanats: In the course of the Iranian history, qanat has had many ups and downs. Sometimes the qanats as well as the qanat constructers were supported and encouraged by the governments, and sometimes were deserted. Even when the qanats were destroyed for some military purposes, the qanat would start flourishing as soon as the political situation got stable. The risks that are threatening the qanats today differ from those in the past. In other words, in the past the political and military crisis had a negative impact on the qanats, however the qanats could recover as soon as the crisis was over. But the present risks are quit something else, and more destructive. The present risks are acting environmentally so it is not that easy to handle them. Therefore it is a must for the governments and nations throughout the world to more think of the new legislations about the protection of groundwater resources against any kind of over exploitation.

1- Water Resources Management Organization's report on present situation of Iranian dams

Qanat civilization is rooted in this ancient hydraulic structure. Over the past 3000 years, the system of qanat has underlain many technological, social, moral, economical and legal principles that have formed an important part of our culture. These principles evolved into the present state by being passed from generation to generation. The present generation is supposed to build on these principles behind which there are three thousand years of history, not to forget about them.

Hydraulic structures: people's needs in the course of history resulted in constructing different buildings such as hydraulic structures that provided safe water for drinking, sanitation and agriculture. These needs resulted in constructing dams, water supplying networks, sewage system, irrigational and drainage networks and water treatment systems, out of which some are still remaining.

Our forefathers constructed the dams in order to use efficiently the surface waters and created many canals in order to transfer water to the consumers. These structures are manifest in the skill of our ancestors in the field of hydraulic, hydrology, architecture, civil, etc, which evolved through tens of thousands of years.

Also, sometimes people's need for overcoming the nature especially in dry regions, led them to construct some structures for keeping water cold or producing ice such as water reservoirs or ice-houses. The engineering and architectural aspects of these structures are very interesting and considerable.

According to the historical records, in some periods, there was more concern about the hydraulic structures and in some other periods, these structures were left deserted. In fact, the more stable the governments and political systems, the more attention was paid to the prosperity of the country and construction of the dams, Qanats, canals, etc, which brought profit to the public. Whenever the governments were in the grip of a war, the hydraulic structures were neglected.

The results of this study show that the dynasties of Sasanid and Safavid were more concerned about the prosperity of the country, agriculture and hydraulic structures. The documents dating back to those times, which took up the subject of the hydraulic structures in details, prove this fact. Whereas the historical records related to some other dynasties mentioned nothing about the hydraulic structures, but they explain the story of the invasion and occupation of other territories in detail. As a result we realize that in the course of history the hydraulic structures have had many ups and downs along with the system of qanats, but in general the knowledge of their construction kept evolving. In fact, the science of the water related modern facilities such as dams, water supplying networks and sewage systems being used by human, today, have historical roots in our ancestors' wisdom.

From this approach, we see some structures such as water reservoirs, ice-houses and water mills have developed just for a while and then stopped due to the development of technology and the advent of the more proper substitutes. For this reason, lots of them are out of action and left useless. Needless to say it is a must to maintain and safeguard these structures as a symbol of our ancestors' elaboration and invention, for these structures are very valuable from different perspectives such as architecture, tourism, etc....

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USE OF QANAT WATER FOR IRRIGATION OF INSIDE HOME LANDSCAPE IN KOUHPAYEH REGION IN CENTRAL IRAN

Dr. Jahangir Abedi-Koupai[1] and Saeid Abedi-Koupai[2]

ABSTRACT

Qanat is an ancient water provision technology that can be described as the greatest contribution made by Iranians to hydraulics and has been globally distributed over 34 countries. Qanat is an environmentally friendly and proper system of water conveyance with gravitational force and without consuming energy. Irrigation water allocation and irrigation method of landscape inside homes are the most interesting tasks in central desert of Iran such as Kohpayeh region, near Isfahan city. The home yards in the region consist of two parts. The first part situated at the same level of natural surface land and the second part situated at the same level of qanat bed for irrigation of landscape. In this study the land use of region which was fully adapted with qanat system, traditional irrigation water allocation and the optimum water use for irrigation of landscape inside homes are described.

1. INTRODUCTION

Qanats have been found throughout the regions that came within the cultural sphere of ancient Persia: in Pakistan, in Chinese, oasis settlements of Turkistan, in southern areas of the U.S.S.R., in Iraq, Syria, Arabia and Yemen. During the periods of Roman and then Arabian domination the system spread westward to North Africa, Spain and Sicily. In the Sahara region a number of oasis settlements are irrigated by the qanat method, and some of the peoples still call the underground conduits "Persian works". Iran (known as Persia until 1935), is part of the arid and semi-arid zone of the earth, and so water is an important factor for the Iranian people, especially for agriculture. Iran has a continental type of climate, with cold winters and hot summers prevalent across the plateau. On the plateau, the annual rainfall does not exceed 300 mm, with the deserts and the Persian Gulf littoral receiving less than 130 mm. In most semi-arid and arid regions of Iran which is called Karizi Civilization (Papoli Yazdi and Labbaf Khaniki, 2000), the annual rainfall does not exceed 250 mm, with the deserts receiving less than 60 mm. Therefore, since antiquity supplying and restoring water for drinking, irrigation,

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washing, etc have been the essential issue for survival. That is why all those qanat (kariz) systems, water reservoirs, icehouses, water mills, water dams, bridges and diversion dams have been built.

This system must have been started at least 5000 years ago in Iran. Qanat system is usually found in central Iran toward the east and southeast of Iran. An existing ancient example of water provision in Iran is old Zavareh qanat dating back to 5000 years ago. Iran's qanat system stands out today as an impressive example of a determined and hardworking people's achievement. The qanat system consists of underground channels that convey water from aquifers in highlands to the surface at lower levels by gravity. This is done by means of a gently sloping tunnel. There are about 22,000 qanat units in Iran, comprising more than 272,000 km of underground channels. The system supplies more than 70 percent of all the water used in the Karizi Civilization (Papoli Yazdi and Labbaf Khaniki, 2000), providing water not only for irrigation but also for house-hold consumption. Commonly the length of qanat is between 10 and 16 km. The water discharge obtainable from individual qanats also varies widely. For example, of some 200 qanats in the Varamin plain southeast of Tehran the largest yields 0.280 (m^3/s) or 280 (lit/s) and the smallest only a few liter per second.

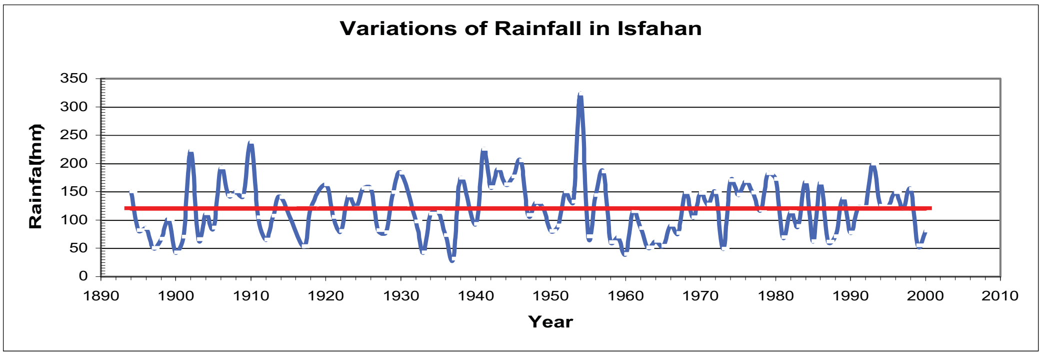

Figure 1. Annual precipitation average at the Isfahan city is about 120 mm.

Isfahan city located in the arid and semi-arid zone, in central Iran, so water is an important factor for the people. Annual precipitation average at the Isfahan city is about 120 mm (Figure 1).

1.1. KOUHPAYEH

Kouhpayeh is located 70 km away from the east of Isfahan city in central Iran, with Longitude 51º, 26´, 45" E and Latitude 32º, 42´, 35" N (Figure 2). Kohpayeh qanat system has been dug in the slope of Mareshnan Mountain where material washed down the slope has been deposited in alluvial fans. At the present, there are two active qanats with the length of about 3 km in Kouhpayeh. The stream of qanat water first flows through the town and then is diverted into farm irrigation channels.

The excavated soil, piled around the mouth of the shafts are seen the Figure 3. Row of craters, each one marking the mouth of a qanat shaft. The shafts provide ventilation and give access for cleaning and repair of the conduit tunnel below. The walls of the craters protect the shafts and the tunnel below from erosion damage from the inflow of water during a heavy desert rainstorm.

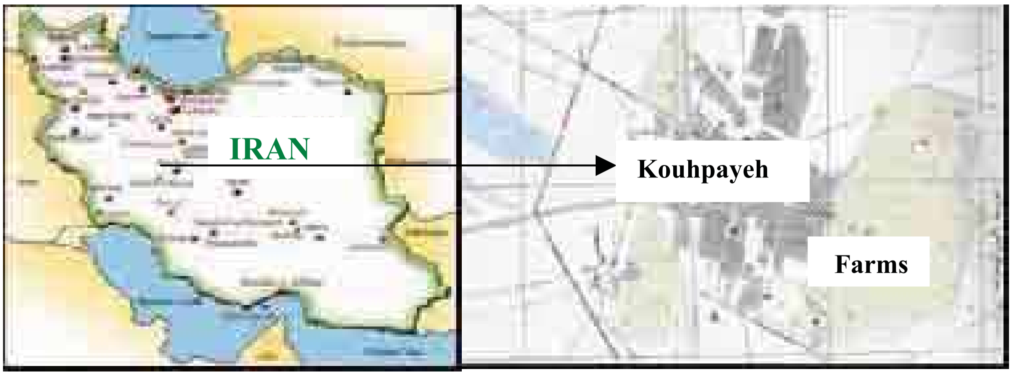

Figure 2. Kouhpayeh is located 70 km away from the east of Isfahan city in central Iran.

(a) (b)

Figure 3. (a) Row of craters (b) The excavated soil, piled around the mouth of the Kohpayeh qanat shafts.

Tunnel cross sections indicate some of the variations possible in qanat conduits. The tunnel walls may be strengthened with tile hoops (Figure 4) or where the tunnel passes through clay or well-compacted soil the walls may be left unlined. If the head well should go dry and therefore need to he dug deeper, the conduit would also need to be deepened.

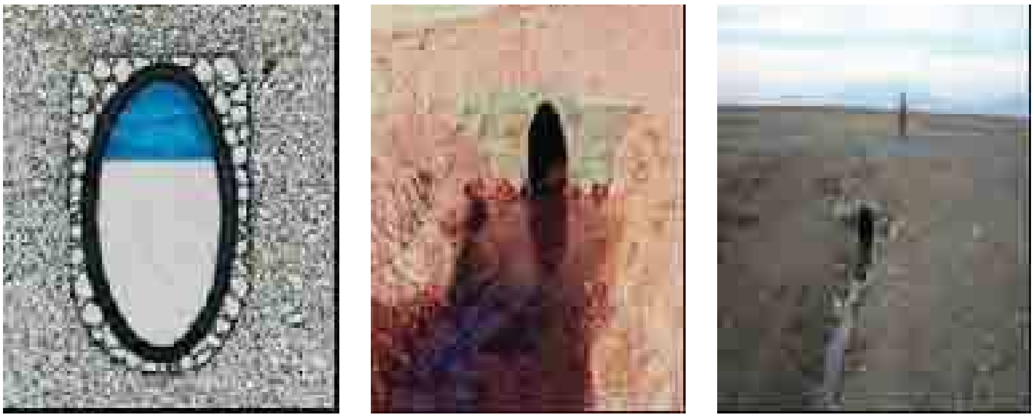

Figure 4. Kouhpayeh tunnel walls have been strengthened with tile hoops in downhill end.

1.2. INSIDE- HOME GARDEN OR LANDSCAPE

An underground conduit through which the water can flow from the head well or group of wells to the ground surface at some point farther down the slope. The downward pitch of the conduit has a slight gradient so that the water flows slowly.

Garden or landscape inside home has been made in home yard. As the qanat advances towards down the slope, the depth of excavation is reduced (Figure 5).

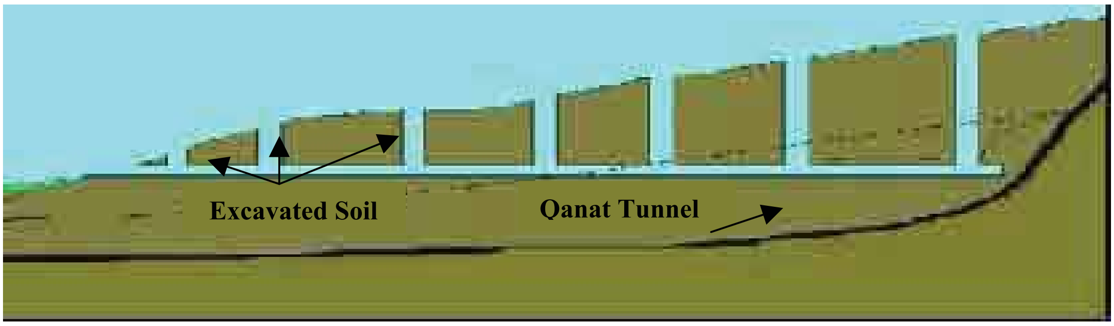

Figure 5. To form inside home garden, excavation of surface land to reach qanat tunnel begins at the downhill end (left). Where the gradually sloping surface land to go far from downhill end, the depth of excavation is increased.

As shown in Figure 6, depending on the depth of the qanat and the slope of the ground, the depth of garden or landscape varies greatly from the upper part (about 4m) to the lower part (about 1m).

Figure 6. An inside home garden having the depth of 3m from the land surface.

Where a qanat passes through inside house garden, it was equipped with a slump that allows for house-hold consumption (Figure 7).

Figure 7. (a) The stream of qanat flows through inside home landscape and then is diverted into farm irrigation channels. (b) Masonry mouth of a qanat in Kohpayeh.

1.3 WATER ALLOCATION SYSTEM

There were traditional systems for the fair allocation of water from a qanat to the users. People appointed a water bailiff, called Mirab, who supervises the allotment of water to each tenant in accordance with the size of the tenant's farm and the nature of the crop he is growing. Water bailiff who saw that each farmer receives his just share of the water at the proper time. The bailiff is guided by an allocation system that has been fixed for hundred of years. Allocation system consisted of a bowl (termed Roneh) having seven small holes (orifices) in the bottom and perimeter. It was placed inside a bigger bowl (termed Qadah) and put on the water in the basin made at the outlet of qanat (Abedi-Koupai, 1999). The time passed to fill bowl with water took about 3-4 minutes and was set to 1 Serejeh which is equal to irrigate a basin (a strip of farmland) with the area of approximately 12 m^2 and 50 mm irrigation water depth (Figure 8).

Figure 8: Water allocation system using a bowl with orifice to distribute water between farmers.

1.4 TAIL WATER

Tail water is downward steps to reach underground qanat tunnel for water consumption (Figure 9). This structure is called "Sarbetagh" in Dezful (Zighami, 1989), "Virab" in Arak and Farahan (Zighami, 1989), "Sipak" in Kashan (Kalantar-Zarrabi, 1962),"Pakaneh" in Yazd (Honari, 1974), "Piu" in khour and Biabanak (Honari, 1974)," Mirabak" in Rey and Varamin (Garrosi, 2000), "Viro" in Ardestan (Zighami, 1989) and "Nilab" in Kouhpayeh.

Figure 9. Public tail water is used for water consumption and as a chatting room.

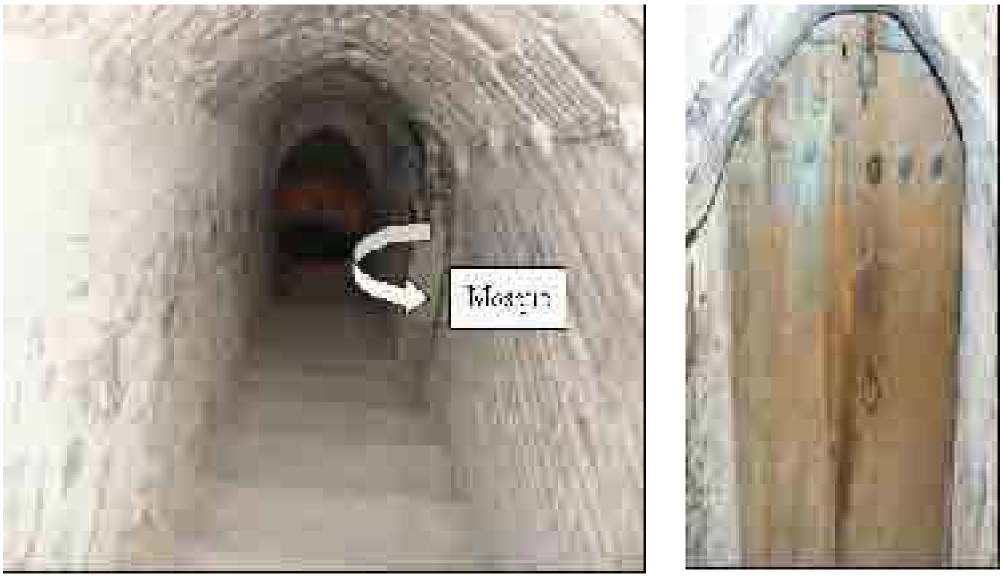

Figure10. (a) A public Nilab in Kouhpayeh to reach underground qanat tunnel for water consumption. A mosque has been located in the middle of steps. (b). Mosque door inside Nilab.

There are two kinds of tail water (Nilab) in Kouhpayeh: private and public. The first one has been located inside home and is used by members of a family and some neighbors around the home and the second one has been located in pubic areas and used by all people. Tail water has different applications consisting water consumption, house-hold consumption, washing, chatting room, resting room etc. There are 2 Nilabs in Kouhpayeh which included small mosque for doing prayer and small public meeting. The small mosque has been located in the middle of steps in Nilab (Figure10).

3. CONCLUSION

As an essential and integral part of ancient Iranian, qanat has played a key role in forming many aspects of culture within community. Kouhpayeh qanat water still used as the main water provision sources for farming. Some features of Kouhpayeh qanat are common in the qanat features of central Iran; however there are some ancient structures which seem to be a unique structures in the region (e.g. mosque inside Nilabs and lowland landscape inside home yards). They need further considerations by Cultural Heritage Organization's authorities.

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WATER MILLS AND ASSEMBLAGE OF MILLS OF MAYMAND IN KERMAN

Sharareh Poormojdehi[1]

ABSTRACT

The vital role of watermills in the past, have had so wealthy value for the rural society which any possibility were used for constructing this kind of structure, although they are rarely in use, now a days those machines are replaced with new electronic systems, it could be seen that these new systems are functionally derived some how from those simple and small but efficient, scientific carefully designed and well performed plants.

Watermills are the best evidences that illustrate how the man utilizes the natural energies for their needs.

According to the climate, availability and existence of water, in Iran the fact is that watermills have been used in different geographical areas, but their importances and values, have not been considered, examined and studied worthily.

The main and most important reasons for this research is to introduce some part of our national heritage, ways for rehabilitation, conservation, innovation these efficient systems using to produce flour as an indigenous significant technical structure even more scientific base systems. You could see our ancestors, as an example, standpoint for the next generations a sample to study the revolution of machines and for them to know how the primitive and supposedly simple but efficient Mechanical systems were. Evolved from the modern and ever sophisticated today plants and also to remember this fact that despite their undeniable role they have played in emergence of more complicated machines, how gradually they are going to be for gotten and declined.

For a better understanding and appreciation of watermills functions, it has been applied a close local survey or site examination in different geographical areas systems to prepare plans of mechanical and hydraulic components, structural details, materials, water discharges, energy dissipating etc.

After studying various kind of watermill, founded that they utilize the energy of water and it ways, functions, mechanisms and know how they are built.

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All studies and investigation on watermills have been done over one of the existing in Meymand region in Kerman province to understand plan, remediation procedure, necessary actions for rehabilitation of this kind ground pressurized hydraulic systems.

INTRODUCTION

Engineering and technique are forms which have knowledge and art in themselves and show their characteristics in the form of it.

Many tools that human create for he is representative of its maker's art, tought and mind.

The composing of technique and engineering with art are visible in historical works of Iran.

The short history of making mills is an example in which this harmony of technique and art is completely obvious, that human knew at the beginning of evolution that how use the energies and materials of surrounding world for improving his life and little by little increase his technique and art.

This paper introduces the types of water mills and humans exploitation of potential energy, with attention to this point that mills had an important role in humans life in past and were the economic safety in each region and destruction of mills in wars was the death.

Today these mills decrease and its technique and engineering have been decreasing.

The mills that work with water called water mill we can divide mills according to usage of water power into kinematics and potential.

We can divide mills according to system and making technique into 2 groups:

1. vertical axis watermill
2. lateral axis watermill:

   A: under spinning axis

   B: over spinning axis

This paper after introduction of mills and state of systems of mills describes the assemblage of mills in Maymand (kerman) which are in the margin of a seasonal river of region that because of being seasonal some parts were added to these vertical axis mills.

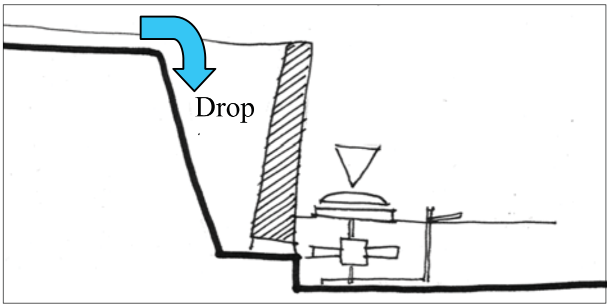
WATER MILLS AND ASSEMBLAGE OF MILLS OF MAYMAND IN KERMAN

Water mills are the best tools for showing the humans usage of natural and strong power of water that works without pollution and with spoke natural energy. Although these small and simple factories had an important role in past, today they decreased and new systems with using other energies took their places.

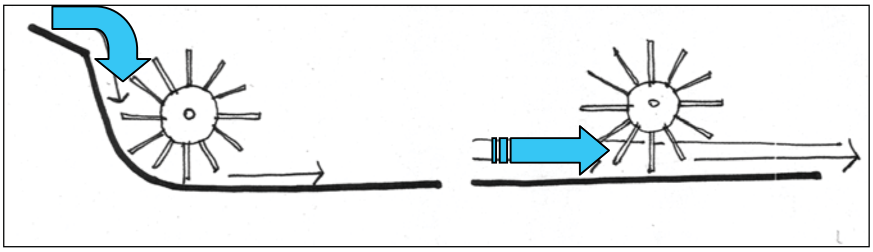
The aim of this paper is introduction and consideration and dividing of mills according to engineering and technique of its making in using the powerful energy of water and deep look in such mechanical engineering tools that they and their makers are forgotten.

At first we consider the root meaning of "Asiab" (mill), mill is a combination of "As" and water with the meaning of water mill. "Asia" was "As Ab" that in phonetic changing changed to "Asiab"(mill) and with elimination of consonant "B" of its end it changed to "Asia", Arabic word "Tahoon" and "Tahoone" use for this.

In general use can divide watermills to kinematics and potential according to their usage of water energy. Both of these types, use the potential energy of water in this way that by making difference between the height of entrance channel and existence channel, potential energy changes to kinematics energy and make the wheel of the mill (vertical axis) moving or at first use the kinematics energy of water and make the wheel of ill (lateral axis) moving. In both group of watermills comes from a channel that cover with lime and cement and has needed gradient for moving water calmly toward water wheel that in different stages saved energy change to kinematics energy and cause moving the water wheel and then the mill stone that flour is the production of it.



Potential mill



Kinematics mill

We can divide the mills in 2 groups according the technique of making and it water wheel:

1- vertical axis mills
2- lateral axis mills

1- VERTICAL AXIS MILLS:

This mill that is known as drop tower mill most seen in dry regions with much obtainable, Supporting water in these mills can be from the water of subterranean canal, river and spring. When the supporting water of mill is the subterranean canal, mill is in subterranean canal system, in this way that in place which water come to ground the mill was made or under ground in the way of water. Like mills in Meybod in Yazd and Ardestan and….

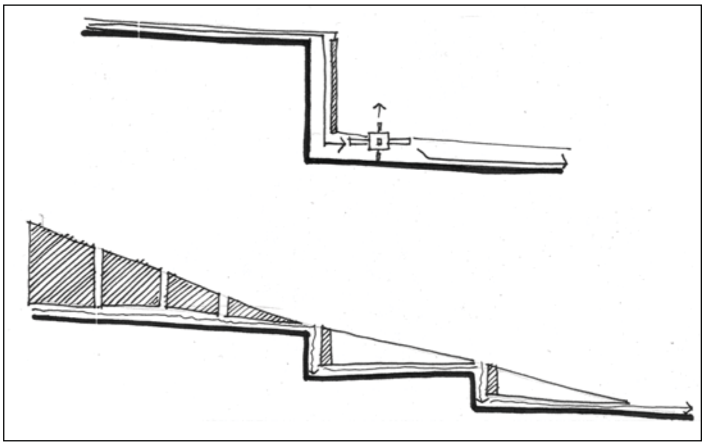
In some regions that the source of supporting water is seasonal river, before the flue of mill there is a big pool to gather the needed water for moving the water wheel: like mills in Fars and Kerman.

In some regions, the supporting source of mill is a brook or small river that water gathers in flue from it: like mills in Kashan and Abyane.

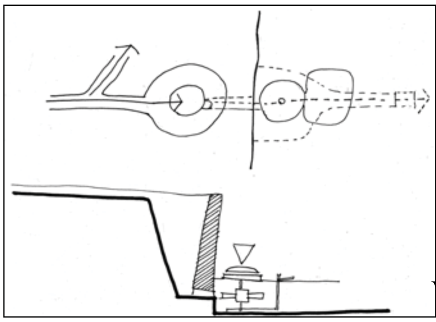
In some places use the gradient of region or natural water fall for guiding water to flue: like mills in Shoshtar.

The main parts of this vertical axis mills are: The canal of water, by pass stream, drop tower, water wheel, under and over stones, corn hopper, flour collect, tail race.

This mill has a waterwheel that its spokes are connected to a vertical axis, saving water of drop tower come to the wings of water wheel and cause the water wheel to spin and so the vertical axis which connected to water wheel – which pan from the under stone of mill and take place in stone by an iron blade like butterfly – that cause the movement of over stone on under stone and pouring cereals between two stones change to flour.

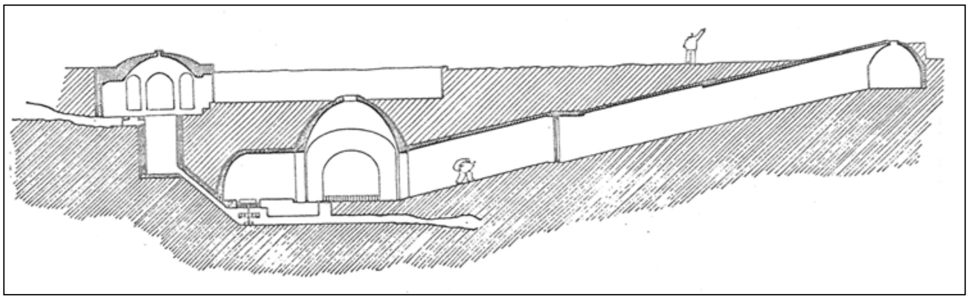


Vertical axis mills

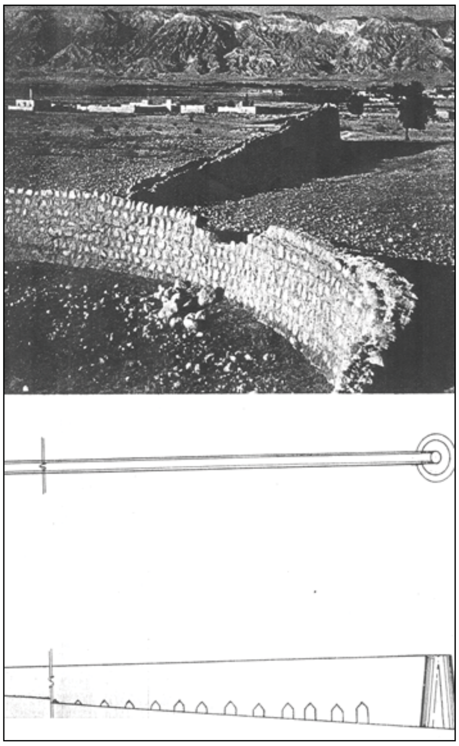


Vertical axis mills

Bande Amir (Fars)

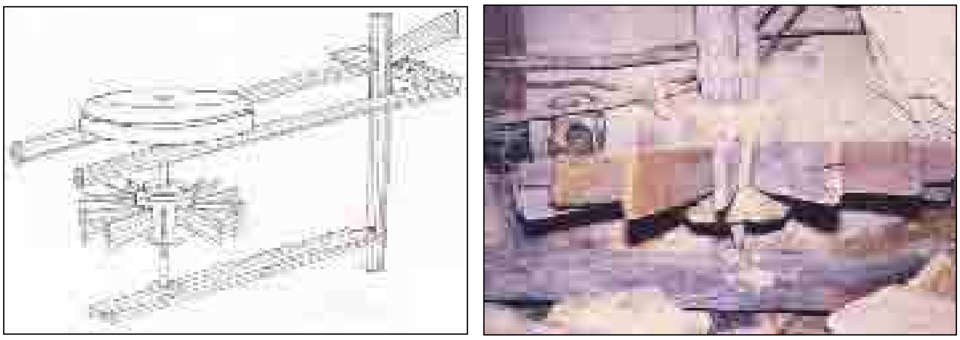


Subterranean drop tower mills
(Yazd nosratabad)



Pool of mill (Shiraz,Tarmoon)

Shooshtar mills



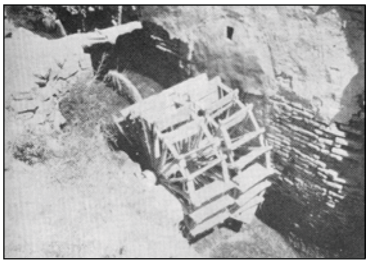
Ingredients of Vertical axis mills

2- LATERAL AXIS MILL

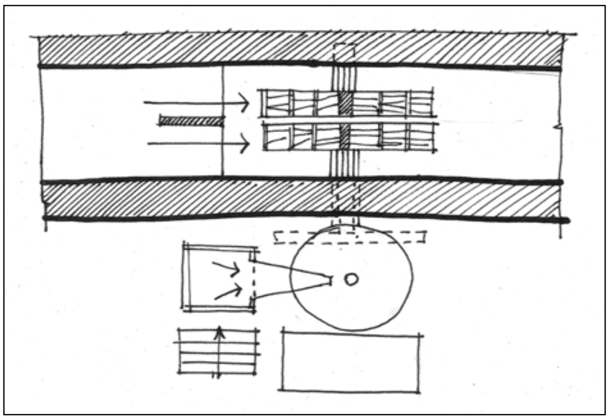
This mill most seen in watery region with low gradient. It has a water wheel that its spokes are connected to a lateral axis. Parts of this mill are more complex than vertical axis mills, because it has gears that transfer the movement of water wheel of lateral axis to stone. Other parts almost are like vertical axis mill with this difference that there isn’t any drop tower in this mill. This mill can be divided in to 2 groups: A: over spinning lateral axis B: under spinning lateral axis

A: over spinning lateral axis

This mill known as Vitruian, in this mill, a branch separates from river or small river and water like a water fall pour from a declivitous canal with height about 1 meter on the spoke of water wheel and move it and cause the movement of gears and so connected axis to over stone of mill move and produce flour. The mills of Isfahan are of this type.

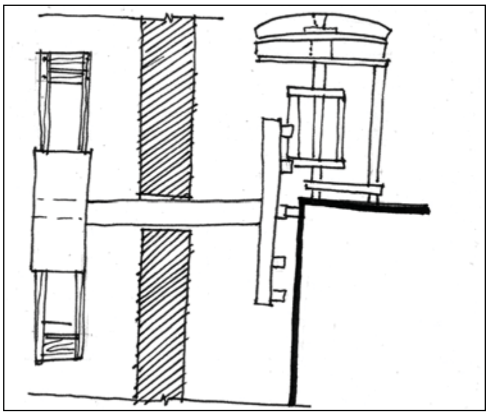


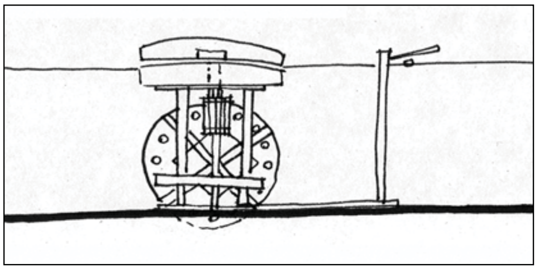
Over spinning lateral axis (Isfahan)



Over spinning lateral axis (plan)

Spoke of water wheel





Section of over spinning lateral axis

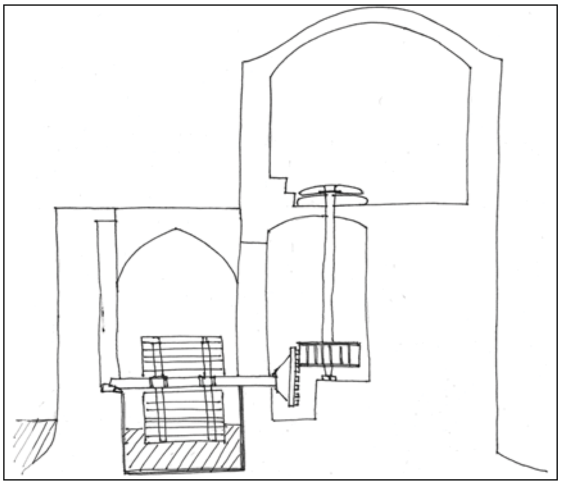
Over spinning lateral axis (Isfahan)

Gears of water wheel

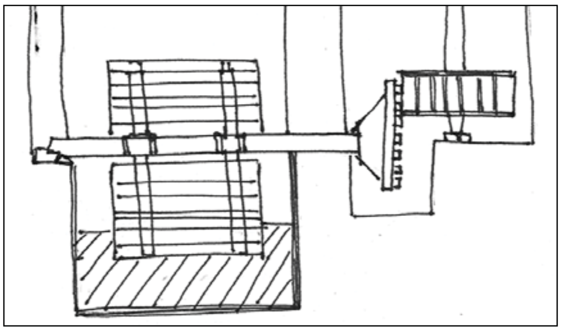
B: UNDER SPINNING LATERAL AXIS

This mill known as supernatant wheel, this mill with wings that are connected to lateral axis, are in rivers, the water impact to the wings of water wheel with pressure and spin it and this system transfer movement by gears to a vertical axis that is connected to over stone and spin it. The stones in this mill are consist of several parts and aren't unit and they are connected together with metal braces or belt.

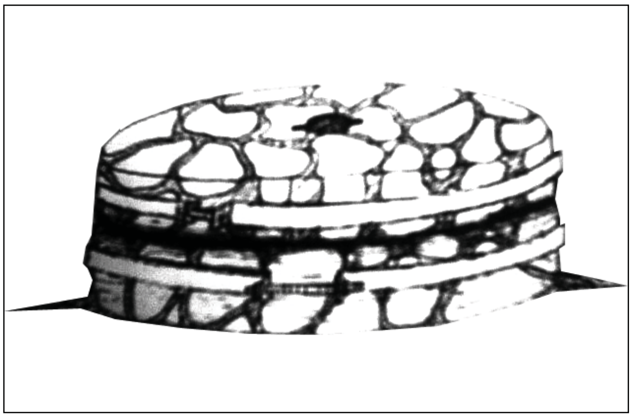
This kind of mill is seen in the south of Iran in cities like Dezful and Shahjerd in Ahvaz. In general in all the systems of water mill use the powerful energy of water for spinning of wings of the wheel and resulting movement of stone and production of flour.



Dezfool (under spinning lateral axis)



Dezfool(gale geh mill)



Mill stones (Dezfool)

Over and under stones mills

THE MILLS OF MAYMAND

Meymand the center of Maymand, central part, the town of Sharebabak is in Kerman province. The main activity of people of Maymand village is animal husbandry. Because of droughty, low range of utilized land, not using machines in these lands and animals like swine agriculture is low in this region.

In past the cultivation of needed wheat and grain did in flat lands (called Keshmoon) around the river and its deficit come from Istahban of Fars and around yazd. For producing little flour or when there isn't water mill they use handy mill.

Mills in Maymand village were drop tower mill in which the drop tower have 4 meter to 8 meter height and by topography recognized that apart of mountain is dinged and a part of it is covered by stone and lime and cement.

The water of drop tower from a hole that called "Na" goes toward the wings of wheel, The "Na" is made of wood and its diameter is 15cm and its length is 30cm, there is a hole at the center of it that its diameter is 6cm and made of darnel of weeping willow.

The place that "Na" is in is a stone that called "Shahna" that its thick part is inside and thin part is outside and Shahna is 50-60cm above it.

For making height difference, across the river make fence of stones and called "Benoodan".

On the way of it make a window and called it "Kote pole" that can open it and close it easily and see the Benoodan and drop tower of mill for pool to gather water when droughty and have needed pressure for spinning the spokes of water wheel. On day close the way of water of pool that called "Glang" to gather water.

For filling the drop tower, they close the window at the end of it, after filling the open the window and water impact the spokes of water wheel has a woody cylindrical part that its height is 40cm and its diameter is 30cm and its made of berry wood and has wings that are made of darnel of weeping willow the become voluminous by water. spokes have thicker about 2.5cm and has dimensions about 13 ×40 cm and is in the woody part. Wings wheel spin around an axis of iron that has a length about 1 to 1.2 meters and has a diameter about 5cm.

The end of axle is on a stone that called emery that is like a triangle that its base is 5cm and its mane is 10cm and in a flat with the thickener about 7cm, width about 3cm and length about 2meters.

The up part of axel is like a can with a height about 3cm and called "chahar rokh" that is inside "Tabareh". There is a marble under "Tabareh" that doesn't allow it to move. "Tabareh" is like butterfly and it made of iron that its width is 10cm and its length is 25cm and the top of axel is at the center of it, over stone put under it and spins it.

The diameter of over stones in these mills is about 1meter and thickener of them is about 105cm. The haven of these stones is on a wood of "Tai" or "Bane" tree that is resistant against wet and pressure.

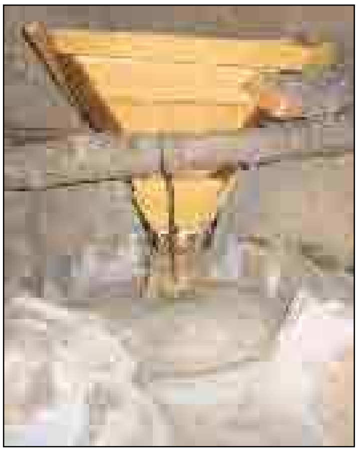
The stone put on gradient toward the place of falling flour that is called "Akhore" that is dinged on the floor.

At the end of wood that the emery stone is, there is a wood called "Pa" and is vertical and install by connection of mortise and tenor. The diameter of wood is 15cm; its length is 2 meter and is made of weeping willow. At the top of it there are 2 splits that are vertical for putting a lever and wedge. The wood takes the wheel up and down by this and in crease or decrease the attaching of the wheel with water. This activity changes the speed of stone movement and can control the middling and soften of flour.

At the top of the 2 stones there is a reservoir of cereals that called "Doul" that is like a square by dimensions 100×100 and height about 80cm, at the top of it there is a hole and in front of it there is wood that called "Makoo" by dimensions about 20×20 that its center is a little deep and a rope connect to it, The range of falling wheat control by "Makoo" and rope.

By pass stream

Canal of water& drop tower

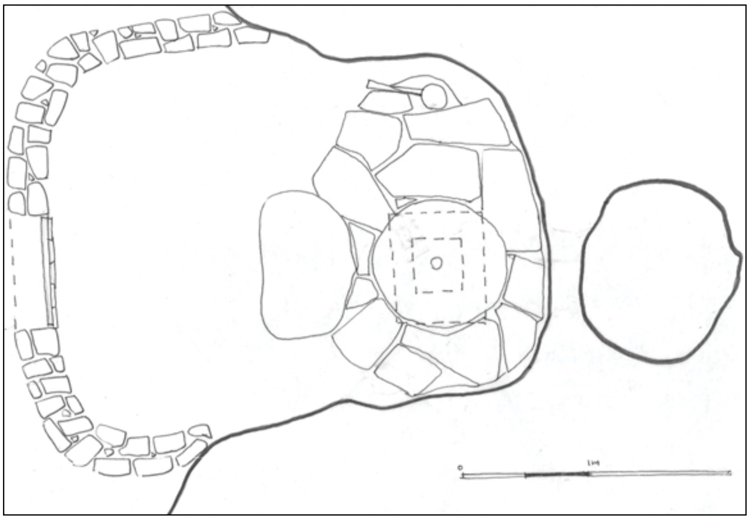


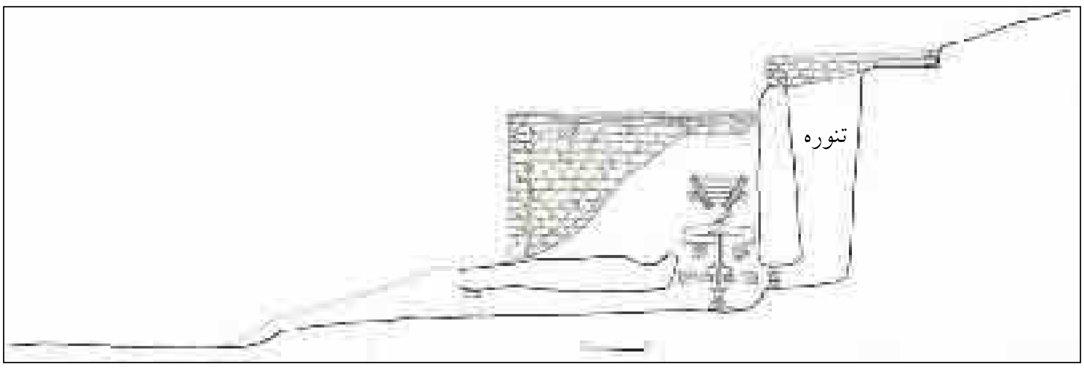
Ston,Dool,Akhore


Pool


Benoodan


Kote pele,Benoodan

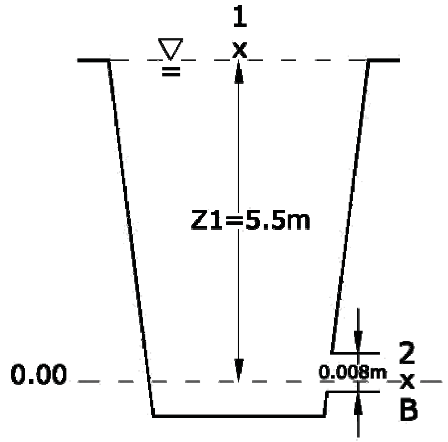




Plan & section of maymand mills

THE DYNAMIC AND HYDRAULIC CONSIDERATION OF MILLS OF MAYMAND

At first by having the data like height of drop tower Z1= 5.5m and the
Window at the end of the drop tower 0.008m, we can calculate the speed of water when it exits from window (V2).



$$\text{m/s } 10.4 = V2 \Rightarrow 5.5\times 9.81\times 2 = \sqrt{\ } V2 \Rightarrow 1\ Z\ 2g = \sqrt{\ } V2$$

With attention to roughen of drop tower body and salts in water and viscous currents, as said some energy lost between places 1 and 2 so real speed of water exit is Cv= 0.96

$$V = Cv \sqrt{2g Z 1} \Rightarrow V = ./96 \sqrt{2\times 9.81\times 5.5} \Rightarrow V = 9.98 \text{ m/s}$$

The speed of exit of window (Q) calculate like this, the level of window $A=0.008m^2$

$$Q = Cv\ Cc\ A \sqrt{2g Z} \Rightarrow Q = 0.96\times 1\times 0.008 \sqrt{2\times 9.81\times 5.5}$$
$$\Rightarrow Q = 0.079 \text{ m}^3/\text{s}$$

By

$= \rho\ 1000\text{kg/m}^3$ و $\theta = 95$ و $V=0$ و $VA = 9.98$ m/s و $A= 0.008\ m^2$

The force on water wheel calculates.

$$F x= A \rho VA(VA- V)(1 -\cos \theta) \Rightarrow$$
$$Fx = 0.008\times 1000\times 9.98(9.98 - 0)(1- \text{Cos}95)$$
$$\Rightarrow Fx = 866.2 \text{ kg}$$

The beam of water wheel is 0.5m and by earned force we calculate the entropy.

$$M = F\times R \Rightarrow M= 866.2\times 0.5 \Rightarrow M = 433.1 \text{ Kg/m}$$

The entrance power of impact the water by wing calculates by this.

$$\text{entrance power} = M\omega$$
$$M\omega = \tfrac{1}{2}\rho\ A\ VA^3 \Rightarrow \tfrac{1}{2}\times 1000\times 0.008\times 9.98^3 = 3976$$
$$\Rightarrow M\omega = \tfrac{1}{2}\rho\ A\ VA^3$$
$$\omega = \rho\ A\ VA^3 / 2M \Rightarrow \omega = 3976/ 433.1 \Rightarrow \omega = 9.18 \text{ rad/s}$$
$$V = R\ \omega \rightarrow V = 0.5\times 9.18 \Rightarrow V = 4.59 \text{ m/s}$$

. Then we change the efficiency to a theory

$$\eta = 2V/ VA [1 - V/ VA] (1 -\cos \theta)$$

$$\Rightarrow \eta = 2\times 4.59/ 9.98 [1 – 4.59 / 9.98](1- \cos 95)$$
$$\Rightarrow \eta = 0.54\times 100 = 54\%$$

. The power of water when the wheel spins by the liner speed about4.59 m/s can calculate.

$$Fx = 0.008\times 1000\times 9.98\times(9.98- 4.59)(1- \cos 95)$$
$$Fx = 467.8 \text{ kg}$$

OBSERVING THE EFFICIENCY OF THEORY BY ACTIVITY:

According to calculations in Mr. Halverson's essay in a mill that has a height of drop tower about 5m and the diameter of window is 3 Inch, theory efficiency in the mill of Maymand comprised with the practical efficiency of this mill.

$\omega = 121$ R.P.M
$\omega = 121/60 = 2.02$ R.P.Sec(دور بر ثانیه)
$\omega = 2.02\times 3.14 = 6.34$ rad/s
$V = R\omega \Rightarrow V = 0.5\times 6.34 \Rightarrow V = 3.17$ m/s
$\eta = 2V/ VA [1 – V/ VA] (1 -\cos \theta)$
$\eta = 2\times 3.17/9.98 [1 – 3.17/ 9.98](1 – \cos 95) \Rightarrow \eta = 0.47\times 100 = 47\%$

Earned efficiency in theory is 54٪ and in practice is 47٪ , and this difference is because of the friction of mill's parts and also the large friction that is between two stones of mill, of course some of this friction is important that cause the changing of wheat to flour.

STATUS OF IRRIGATION IN LIGHT OF RECENT HISTORY OF THREE CENTRAL EUROPEAN COUNTRIES: CZECH REPUBLIC, AUSTRIA AND SLOVENIA

Milada Šťastná[1], Pintar Marina[2], Cepuder Peter[3] and Zupanc Vesna[2]

ABSTRACT

The three central European countries, Czech Republic, Austria and Slovenia not only have common culture and share much of the history, they also share experiences with growing more or less the same kind of crops. This paper gives overview for each country individually in pre and post Second World War. It is evident that events of the 20th century, especially second half, greatly influenced the state of irrigation as well as challenges and issues each of the countries are facing. The Czech Republic is facing the need for rehabilitation and modernization of irrigation systems and for that new, economic tools are needed. The process of the building of new, modern irrigation systems is already happening on a small scale and suggests that the future irrigations systems will be small and flexible. For Austria it is expected that the irrigation amount will remain on the same level. Only in the Eastern part of Austria, especially in the Marchfeld Hochterasse and the Wachau region, an increase is expected. The need for irrigation in Slovenia is growing, irrigation becoming a necessary measure to meet the demands of intensifying agricultural production and to ensure quality and yield. In spite of short tradition, the use of water efficient technologies is strongly presented on the market and applied in practice, as well as favored by governmental financial support programs.

INTRODUCTION

As agriculture is the biggest consumer of fresh water, and with impending climate change bringing severe weather conditions, such as prolong droughts, flexible and reliable policy for irrigation regulation will be prerequisite to maintain sustainable water use as well as to provide water consumption control. Improving the recent irrigation technologies and consequently water use efficiency as well as fertilizer input levels on

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farm level are the major contributors to increase crop production, reverse the degradation of the environment or avoid irreversible environmental damage and allow a sustainable irrigated agriculture. The three central European countries, Czech Republic, Austria and Slovenia (Figure 1) not only have common culture and share much of the history, they also share experiences with growing more or less the same kind of crops. All that, as well as their geographical position, provides good conditions for technology exchange. Before the scientific development of the new sustainable and environmentally friendly technology can be initiated, it is necessary to establish the current status of existing irrigation systems and practices. In addition to that the needs of the end users, technicians and farmers, the benefits and shortcomings of existing systems should be defined and described, to ensure successful improvement (Šť'astna et al., 2005).

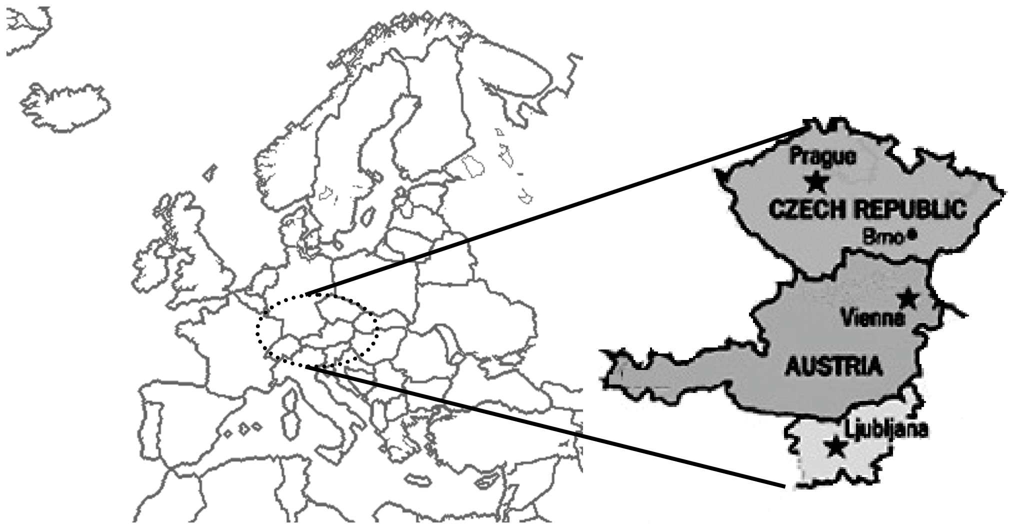

Figure 1: The three central European countries, Czech Republic, Austria and Slovenia

Historically both Czech republic and Austria have had early experience with irrigation systems. The oldest irrigation canal of Lower Austria is first mentioned in a mid- 12th century document, whereas in Czech Republic the first reports of irrigation systems are from the early 16th century in north Bohemia (Dvořak et al., 2002). Irrigation engineering came to full expansion under the Empress Maria Theresa at the end of 18th century (Cate et al., 2002). Slovenia is relatively young in implementation of irrigation systems, first designed irrigation system being in first half of 20th century (Jamnik, 1938).

The paper gives overview for each country individually in pre and post Second World War. After the Second World War the political situation in the three countries was greatly different. Austria has democracy, Slovenia was part of Socialist Federal Republic of Yugoslavia and Czech Republic was part of Czechoslovakia. For Czech Republic and Slovenia the most obvious mark was the downfall of the communist regime in the year of 1991. The political situation influenced the legislation, administrative mechanisms and as well as socio-economic perception of irrigation.

CZECH REPUBLIC

Historical sources indicate that first more extensive irrigation structures on Czech Republic territory were built by the end of 19th century. For example, a cross-contour-furrow irrigation system was built in 1875 for the irrigation of meadows and pastures in the Upa river valley. A similar project was operational in the Metuje river valley between 1905 and 1912. Before 1940, when the total irrigated area amounted to almost 18 000 ha, further irrigation systems had been built in the Labe lowland, in the Cidlina valley, in the northern part of the so-called Little Hana (along the Trebuvka and the Jevicka rivers) and, in particular, in the Morava lowland between Otrokovice and Hodonin. Further expansion of irrigation systems took place after the Second World War. The statistics tell that, in 1950, the total irrigated area on the territory of the Czechoslovak Republic was 28 400 ha. This area grew up to 39 000 ha ten years later. It also included fertiliser application systems supplying crops with both inorganic and organic fertilisers and special-purpose irrigation systems. The latter made their way into the practice of fruit, wine and hop growing and were also used for protection against frost and other harmful factors.

The year 1970 brought further dynamic expansion of irrigation systems. In that year, the Federal Assembly adopted the Act on the State Land Improvement Fund. The Ministry of Agriculture, its guarantor, founded within its competence a new organisation, the State Administration of Land Reclamation and Improvement, today's Agricultural Water Management Administration. This institution, supported by the State Land Improvement Fund, took over administration of both the existing and the newly built land reclamation structures, small water courses (called "agricultural streams") and the reservoirs built on them (Jancak and Goetz, 1997). The construction of main irrigation structures, starting from the intake structures up to water supply hydrants, was fully financed by the state. The State Administration of Land Reclamation and Improvement took care of maintenance, repairs and operation of these structures. The exploiters of these irrigation systems used to receive, up to 1991, subventions from the State Land Improvement Fund. The subventions enabled them to procure the so-called irrigation detail (i.e., the equipment for distribution of water over individual field). The subventions amounted between 30 and 80 % of the total investment costs. The electricity and water for irrigation were available to the users under very favourable conditions (details are given below); water, in particular, was provided free of charge until 1997.

All the above-quoted factors caused immense expansion of irrigation systems over our territory. The systems were built in order to assist in intensification and stabilisation of agricultural production. The development was planned on three conceptual levels: the long-term (20 years), the middle-term (5 years) and the short-term (1 year) ones. In this way, the state succeeded in building and subsequently administering the property worth about 3.5 billion CZK. The total irrigable area in 1969 was 30 100 ha. It grew up to 82 600 ha in 1979, up to 137 100 ha in 1989 and up to 154 900 ha right before the privatisation in 1997 (Šťastna et al., 2005).

The irrigation is rarely appreciated as an indispensable part of agricultural production and its economic, socio-demographic and environmental sustainability in the Czech Republic. Economical analyses show that the operation cost of irrigations is high and the irrigation is not always profitable. An overall decrease in agricultural production took place after 1989 and the intensity and efficiency of the production is not yet as high as in most old EU countries. The crop yields represent on average 60 to 80 % of those in old EU, the use of fertilisers is lower and also the productivity of labour is lower. There are, of course, large differences between particular enterprises.

The circumstances described above lead to establishment of the Czech Irrigation Association (CIRA) in December 1997, which brought together owners and operators of irrigation systems, farmers, researchers, and designers, manufacturers and distributors of irrigation equipment. CIRA's main role was up to now to negotiate subsidies for the water abstracted for irrigation, adjustments of prices of electric power, procedures how to specify quotas of water freely provided for irrigation, etc.

A limiting factor of the development of irrigation in the Czech Republic may be seen in the implementation of the Act on Agriculture (252/1997 Coll.), which resulted in classifying the regions with high precipitation deficits as less favourable areas (LFA), in compliance with EC regulations. The operation of irrigation may be also affected by implementation of the EC nitrate directive.

In future, the fundamental driving force of the expected renaissance of irrigation can be the demand of market for stable and high quality production. The target is not the maximisation of food production but the stabilisation of yields and quality by irrigation. This is the way, how to ensure a long-term profitability of husbandry and, at the same time, to protect the environment. The stability of yields will increase commercial credibility of Czech farmers, strengthen their competitiveness at local markets and on the common European market. It will also render them a better position for negotiations with business chains and other partners.

Another important instigation for future expansion of irrigation may be the oncoming climate change. The droughts in 2000 and 2003 clearly demonstrated what impact a shortage of water can have on the growth of crops. In 2000, the Ministry of Agriculture estimated the loss due to drought at app. 10 billion CZK. Apart from that, the need to irrigate „energy“ crops, newly planted windbreaks or shelterbelts etc. is also expected (Šťastna et al., 2005).

Unfortunately, the operators of irrigation systems suffer from the lack of financial resources for modernization and reconstruction. Thus the state endowment is important. Governmental subsidies in agriculture for 2005 are provided in accordance with the Act on Agriculture (252/1997 Coll.), the Horizontal Plan of Rural Development, the system of direct payments related to the land area, the Operational Plan of the Ministry of Agriculture and other subsidy programmes. Only few subsidies are focused on the support of irrigation. It is recommended that new economic tools will sought, which would motivate the owners and users of irrigation systems to finance the maintenance and modernisation of the systems. A separate question is the building of new, modern irrigation systems. It is already going on a small scale and suggests that the future irrigations systems will be small and flexible. Strategy for decision support system would be new and practical solution for all users dealing with irrigation and it may bring them even higher profit by saving water and energy.

AUSTRIA

The oldest irrigation system was mentioned in the 12th century, where a channel between two rivers in Lower Austria should supply the area along the channel with additional water. During the 17th century an irrigation system, which distributes the water by side channels, was built by military engineers (Cate et al., 2002). Tyroleans had a great familiarity with irrigation technique therefore they were consulted. It was an early example of domestic colonisation. At the beginning of last century, wastewater from Vienna was used for irrigation of the near Marchfeld area. Between the two world wars, sprinkler irrigation systems were introduced in the Marchfeld plain, which was a great progress for plant production.

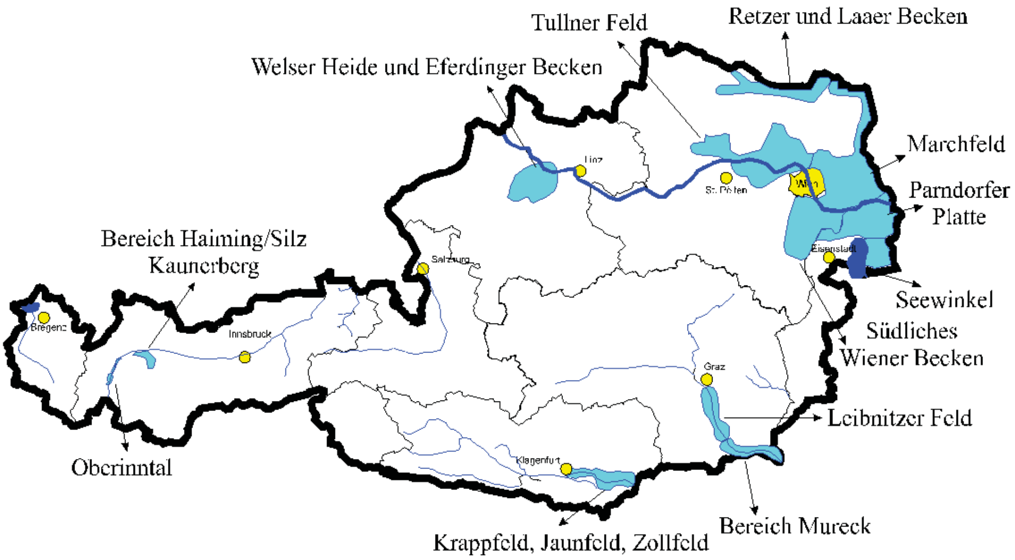

Figure 2: Irrigation areas in Austria

Nowadays, in average 4 % of whole water consumption are used for irrigation purposes. In the dry eastern areas this portion is up to 50 % and more (Figure 2). In most parts of Austria natural rainfall per se allows productive agriculture, but in order to optimise yields (especially maize, sugar beet, vegetables and industrial crops) and to minimize risk of crop loss in case of rainfall deficits during the vegetation period many farmers have irrigation equipments. However, in the Pannonian region of eastern Austria semi-arid conditions make irrigated agriculture significantly more productive than dry-land agriculture (Baldock et al., 2000).

The annual Austrian water balance with an average precipitation of 1 170 mm and 340 mm of surface and subsurface input of water shows a total water amount of 1 510 mm per annum. The output by surface and subsurface waters is nearly 1 000 mm. The rest of 510 mm is annual evapotranspiration.

Austria's potential irrigation area comprises almost 100 000 ha, but in fact only almost 50 % are irrigated because of crop rotation factors and climatic conditions (Table 1). From this more then 90 percent are irrigated root crops and vegetables. The rest is split in vineyards, orchards and grasslands.

Table 1: Irrigation areas in Austria (Statistik Austria, 2002)

	Arable area (1999)	Potential irrigation area (1995)		Irrigated area (1995)	
	[ha]	[ha]	[%]	[ha]	[%]
Burgenland	198 200	23 400	12	10 670	46
Carinthia	354 000	290	0.1	350	36
Lower Austria	96 900	64 600	7	30 210	47
Upper Austria	585 800	1 280	0.2	940	
Salzburg	316,600	100	0.03	40	
Styria	530 100	920	0.2	750	
Tirol	451 500	1 900	0.4	1 420	75
Vorarlberg	122 400	240	0.2	30	
Vienna	9 800	2 710	27	1 330	49
total	3537 900	95 440	3	45 740	48

The legal framework for irrigation is set by Austrian Water Act, which regulates on the one hand withdrawals from ground or surface water and on the other hand water quality. It was passed in 1959. In 1990 an amendment entered into force, which limits for example the duration of a permission for an irrigation system to 10 years.

During the second half of last century different kinds of irrigation systems have been developed. The most common devices in Austria are sprinklers in different sizes. For most crops movable sprinkler facilities are utilized. In orchards usually solid state sprinkler systems are installed which are used for frost protection but also for compensating precipitation deficits. In the 1990s first more efficient drip irrigation systems started up (especially for perennial crops, e. g. vineyards).

The aim of irrigation is obtaining an optimal plant available soil water content. Therefore time and water amount have to be chosen very carefully. Experienced farmers decide this according to actual precipitation and plant growth.

In future general irrigation amount will remain on the same level. Only in the Eastern part of Austria, especially in the Marchfeld Hochterasse and the Wachau region, an increase is expected. For example in Marchfeld area there are different projects where water cooperatives irrigate fields with areas from 2 000 to 4 000 ha. In Wachau region projects about drip irrigation in vineyards are previewed for ensuring socio-economic standard of people living there.

One important aspect in future irrigation is to optimize irrigation water amounts. Therefore automatic irrigation control systems based on measurements of soil water content and GIS supported systems will be developed or improved and used in large scale.

SLOVENIA

Agricultural production in Slovenia in the past was extensive, big farm entities consisted of mainly forest and not arable areas (Maček, 1995). The unfavorable land structure of small parcels (Jamnik, 1938) prevented bigger technological development (Maček, 1995) thus contributing to extensive nature of Slovenian farms. Due to the high annual precipitation amount, agricultural land melioration on Slovenian territory mostly comprised of drainage systems and flood control, irrigation was and is a supplementary measure to ensure an reliable plant production with steady quantity and quality.

Before the First World War, implementation of melioration on arable areas was financed by Melioration Fund of Drava ban's county, which granted subsidies for hydro technical work, established by Melioration act (1884). The fund provided financing of wild stream regulations and drainage systems, but due to poor land structure Slovenian territory was rarely the beneficiary of the fund (Jamnik, 1938). If implementation of the irrigation system was considered, then it was in combination with simultaneous installation of drainage system (Jamnik, 1938). The first record of organized installation of irrigation systems is documented for channel system for flood irrigation on 25 ha of meadows in Prekmurje in 20th century's early thirties (Jamnik, 1938). River Ledava was routed into irrigation channels.

After the Second World War water management responsibilities were transferred to Ministry of Construction, then in 1960 to the organization of Water Communities. In 1974 a new Water Act transferred water management activities on water management enterprises. The amendment in 1989 dismissed the binding transfer of water management obligations on Water Management Enterprises. In 1990 the Republic Water Administration Board was founded, with branch offices for water counties.

The focus on implementation of drainage system as a melioration measure on arable land continued. In the 1970ies there was attempt to construct peach orchard with irrigation system in maritime Slovenia, but the plans were never completed (Adamič, 1986). First reports of modern irrigation systems being installed are dated back to 1978 (Juvan and Edelbaher, 2000) in east Slovenia.

From 1986 to 1989 storage lake Vogršček was constructed to boost intensive agricultural production in Vipava Valley, West Slovenia by ensuring water for 3 500 ha of arable land. The construction of large storage lake in West Slovenia was outset for more systematic approach to irrigation, evolving from program developed on the national level with general review of the state's needs and conditions for irrigation, to proposal and designs on the smaller scale with detailed plan for specific irrigation needs.

At the beginning of 90ies, a study “National Irrigation Programme” (NIP) has been prepared (Biotechnical Faculty, 1994) for the total area of 193 450 ha. NIP considered use of sprinkler irrigation. Slovenia was divided into five climate zones: Mediterranean climate, panonic climate, submediterranean climate, subpanonic climate and climate of the central Slovenia. Alpine region in the north and part of Karst forest area in the south under Dinara climate were considered as sixth climate zone, where no irrigation is required. Calculated average water net requirements for irrigation range from 300 to 4 000 m^3/ha per year, varying between crops and climate areas. Analyses of water sources availability have shown that there is enough water in surface waters in Slovenia for irrigation of 60 000 ha of arable land, without additional water reservoirs (Biotechnical Faculty, 1994).

The Slovenian government confirmed in 1994 “The Strategy of Irrigation in Slovenia” according to which every year 10 000 – 12 000 ha of new irrigation systems would be constructed in the following five years (Stražar, 2002). The proposal for the implementation of the first phase of the strategy outlined plans for 10 605 ha of arable land in total (Slovenia Irrigation Project, 1999). Country has been divided in eight irrigation regions for the criteria of the water sources (Figure 3). Areas from the first phase of “The Strategy of Irrigation in Slovenia” were verified with spatial plans of Slovenia in 1997. There have been 5 775 ha of irrigation systems in that time in Slovenia (Slovenia Irrigation Project, 1999). Smaller area (3 688 ha) has been defined for preparation of more detailed projects. By the year 2000 approximately 4 000 ha of new irrigation systems have been constructed in Slovenia, additional 300 ha by the year 2005, but none of them on areas, which have been taken into account in “Slovenia Irrigation Project”.

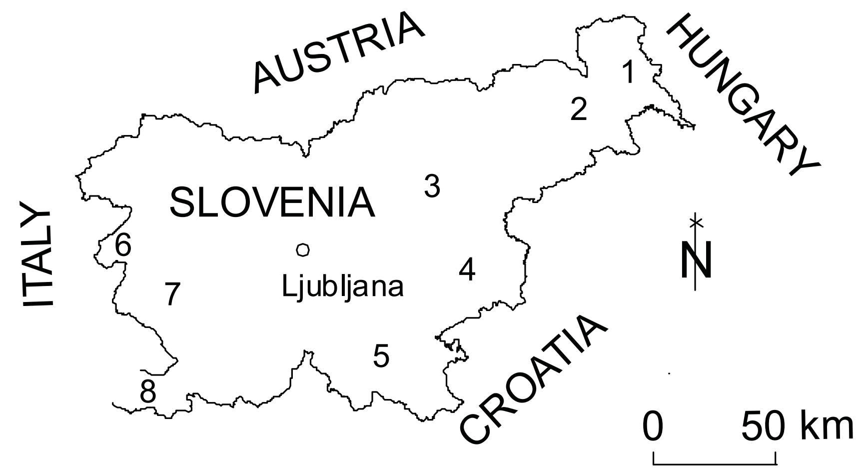

Figure 3: Schematic view of irrigation regions in Slovenia

(1 Pomurje, 2 Podravje, 3 Savinja valley, 4 Lower Sava in Lower Krka, 5 Bela krajina, 6 Goriška brda, 7 Vipava valley, 8 Coastal region).

Seemingly systematic approach to the irrigation planning and construction of irrigation systems did not diminish the farmer's increasing demand for subsidies for the drought damages in dry years. To gain control over the situation, Ministry for Agriculture, Forestry and Food systematically surveyed all existing irrigation (and drainage) systems in the country. Register inclusion criteria was prepared minimal project documentation for irrigation system and formal construction process in progress. According to this criteria there are 10 000 ha of irrigation systems in Slovenia. The register has been established with the purpose to charge farmers with a reclamation fee for the maintenance of the system (drainage or irrigation). There is no information about the functioning of the irrigation systems, which have been poorly maintained and are consequently in very bad condition in general. The situation is worse with drainage systems and some irrigation systems as well (Stražar, 2002).

In 2004, 2 329 ha of agricultural land were irrigated, which is 15 % less than in 2003. According official state statistics (Statistical office of RS, 2005), majority (90 %) of the area was irrigated by sprinklers, and 10 % (i.e. 233 ha) by drip irrigation. On the other hand, the ministry for agriculture, food and forestry has a register about irrigation technologies in orchards. According to this data 45.1% of orchards are irrigated by drip irrigation (i.e. 337 ha) and 47.3% are irrigated by sprinkler irrigation (i.e. 353 ha). The average yearly water consumption is approximately 2 000 m^3/ha. In total 4.5 million m^3 of water were used for irrigation, the majority, i.e. 84.7 % from water reservoirs, 12.1 % from water streams directly, 2.6 % from ground water, and 0.6 % from other sources (Statistical Office of the Republic of Slovenia, 2005).

Legislation that manages the irrigation is complex and comprises of several acts and decrees (Čuden-Osredkar and Pintar 2003), pertaining both agricultural as well as sector for environment and spatial planning. The Agricultural Land Act, accepted in 1996, with several acts amending the Agricultural Land Act, the latest in 2003, defines irrigation as a melioration measure. The Agricultural Land Act differentiates between big irrigation systems, meant for common use under irrigation schedule and small irrigation systems, which use irrigation independently. Water act accepted in 2002 regulates water management with the goal of water protection and the water rights acquisition. Decree on the Water Fee (2002) establishes a method to determine the amount of water fee and method for the calculation, allotment and payment of the water fee as well as criterion for decrease or pardoning of the water fee payment.

To promote water efficient irrigation technologies, government gives priority for financial support to the irrigation project petitions that consider use of water efficient technologies (drip irrigation). High share of drip irrigation system applied in fruit orchard suggest good organization on the part of fruit growers who apply for financial support from the Ministry for Agriculture, Forestry and Food.

CONCLUSIONS

It is evident that events of the 20th century, especially second half, greatly influenced the state of irrigation as well as challenges and issues each of the countries are facing. The Czech Republic is facing the need for rehabilitation and modernization of irrigation systems. For that new economic tools, which would motivate the owners and users of irrigation systems to finance the maintenance and modernization of the systems, are needed. A separate idea is the building of new, modern irrigation systems. The process is already happening on a small scale and suggests that the future irrigations systems will be small and flexible.

For Austria it is expected that the irrigation amount will remain on the same level. Only in the Eastern part of Austria, especially in the Marchfeld area and the Wachau region, an increase is expected.

The need for irrigation in Slovenia is growing, irrigation becoming a necessary measure to meet the demands of intensifying agricultural production and to ensure quality and yield. In spite of short tradition, the use of water efficient technologies is strongly presented on the market and applied in practice, as well as favored by governmental financial support programs. To further implement and solidify the perception of irrigation as helpful and valuable measure raising of public awareness would be necessary. In addition to promotion of irrigation, education about proper and correct irrigation methodology would be necessary, to diminish environmental risks, such as overexploitation of water sources and nutrient leaching from irrigated areas.

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INTRODUCTION OF HISTORICAL HYDRAULIC STRUCTURES OF KAROON RIVER IN SHUSHTAR DISTRICTS

Kazem torfi[1], Arash mahjoobi[2], Hassan kiamanesh[3]and Mohamad hossein sheikgarga[4]

ABSTRACT:

Because of good condition of life and situation in Shushtar city and also good climatology, various tribes were abstracted water availability and proper quality of Karun river, beside of fertilization of land are the reasons of different hydraulic structures. These expensive structures are Barrier Bridge and intakes that are related to Haknamaneshian & Sasanian of historical structures on the world. Although some of these structures are destroyed by floods and wars during the times but some of them still are working or repaired to work (Daryoon canal & intake).

In this article not only we introduce the structures but also we discuss about structure goals material operation relation and access of them.

Keywords: historical structures barrier– bridge intake

INTRODUCTION:

Before of farming human used water as drinking and hungering after that human con concentration was happened.

Existence of Karun. Kharkheh, Garahi, Zohreh and flat fertilize land , Khnzestan province was the last place of living for new rock time and later. Because of little rain store and conveyance of water was of first thought by this way differet hydraulic structures are built. The first irrigation of Choghamish hill (Between dezfull & shushtar) are related to six thousand years B.C. destroyed , the oldest one is Choghazabil water refinery about 3250 years ago in time of Onatash imperial of Ilam. Until now mare than 260 hydraulic structures were introduced that are the most number in the world.

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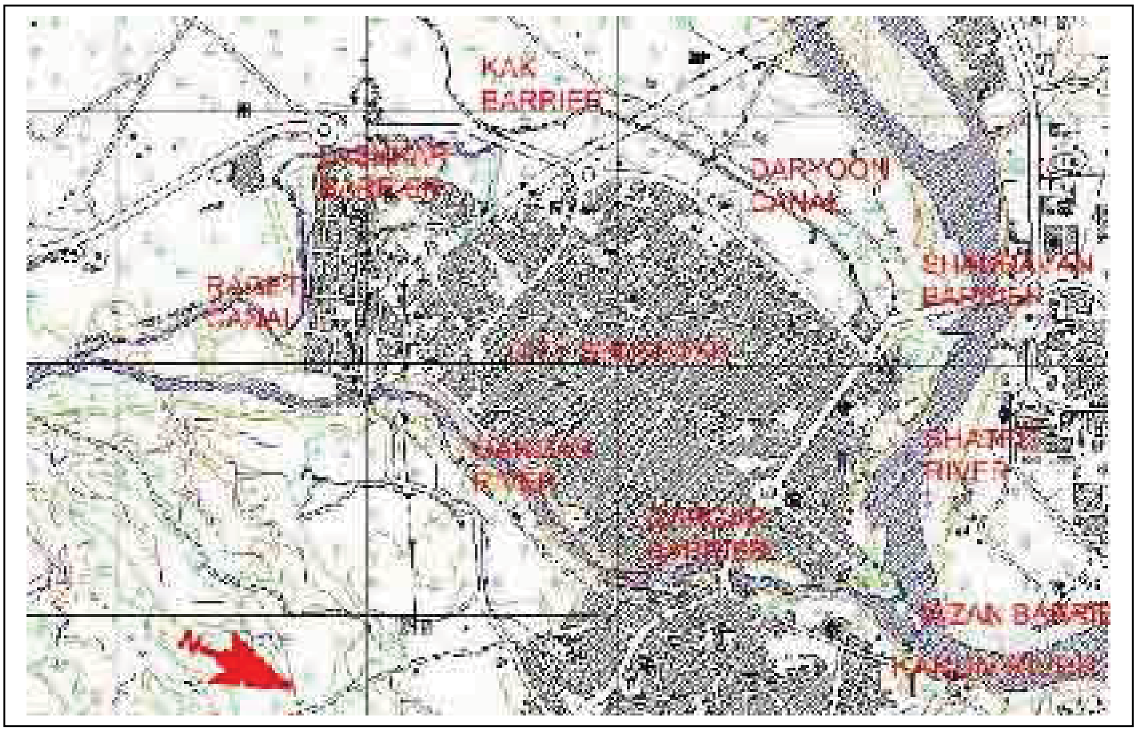
Shushtar hydraulic structures in totally are the oldest one in country without debt they are the biggest centre of hydropower in the world. These structure are 2000 years old and were located cross Karun river between Gotvand to Ahwaz city and some of barrier – bridge canals, underground conduit in this distance are seem.

Shushar city in north 5th of Khuzestan province is the oldest city of Iran.

Karun River at the point of entrain from north of shushtar at the place of Ghasar Takht by historical barrier as mizan is divided to branches as Dodangheh (Gar gar) Four dongheh (Shotat). Near 300 meters of Mizan barrier on Shoshtat another barriers as barrier briage Shadravan was located and near 1000 meters south of mizan over Gargar branch Gar gar barrier- bridge over Gargar branch Gargar barrier- bridge underground tunnels are located.

In this article in attention to numbers historical hydraulic structures because of limitation only a few number are presented.



Map (1) – situation of historical hydraulic structures on Karun river around Shushtar city.

RESEARCH REVIEWING:

Najmolmolk itinerary says that Shushtar wide barrier , Mohammad Alimirza on Gargar river is located dam wide is about 25 zar (zar= 41 in) and hieght is less than 5 zar and 200 zar length that is not straight total cost of dam is about 120.000 tomans. Few times it was destroyed by digging of masraghan stream in soft texture of Khuzestan soil this stream became bigger to flow more water. In other hand in shotat branch water flowing Lester and damage to agriculture.

Because of that, they built a burrier on Mosrghan intake in this place one branch as Four dongeh.

And other one is two Dongeh. From this book in downstream of Mizan barrier beside of city there was Magham barrier could lift water few Zar (zar= 41 in) for people conveyance that by water wheels to city. Two dongh more than 20 Zar (zar= 41 in) is deeper than city, this is the why they use water wheels.

About 300 meters upstream barrier- bridge of Shushtar under Salacel fort there is two tunnels. These tunnels after one hundred are joined to each other , and create Daryoon canal. Another name of this canal is Minoab or Darabian that built by great Daryosh imperial of Iran. Also about 500 meters downstream of Mizan barrier there is another barriers that were built of bricks and in the front of this dam there is a earth dam because of simplify is a temporary dam.

In Shushter city there is barrier as name of Shapur imperial of Iran it has 1 mile Length and was built by bricks to left water for Shushtar.

Historical investigation of irrigation networks is showing that this networks 300 yeas before Shadrawan brier- bridge it supply water it means that barrier bridge of Shadrawan was built to complete Daryoon stream operation.

HISTORICAL AND HYDRAULIC STRUCTURES :

1- BARRIERS AND BARRIER- BRIDGE

1-1 Mizan barrier :

1-1-1- Barrier introducery and it history:

this barrier is one of the important hydraulic structures in Shushtar evidence shows that it is related to Sasanian times. Migan barriers is loc teal in east west of Shushtar north and near to Seyed Mohamad Mausoleum. In this location, Karun river in direction of east- west divided to east& west branches (map l). This barrier is divided karun river 4 to 6 and 2 to 4. four sections of water cross of Shushat river are famous as four Dongeh and 2 another sections in east direction are famous as Dongeh or Gargar or Masarghan. We have no historical evidence about construction time of this barrier. But it should in same time of Shadravan, Daryoon, Gar gar canal. There is a thought that this barrier has a time duration as Masarghan in Sasanian time. Because of problem regarding to flowing wafer on lands they built Masarghan barrier on Daryoon river barrier divided the river to Shoshat& Gar gar branches.

1-1-1-2 cause of denomination :

Shapour dam , Shapoury barrier, Khaghan barriers , Trazo barrier , Fata Ali Shah Mizan barrier are another names for this barrier.

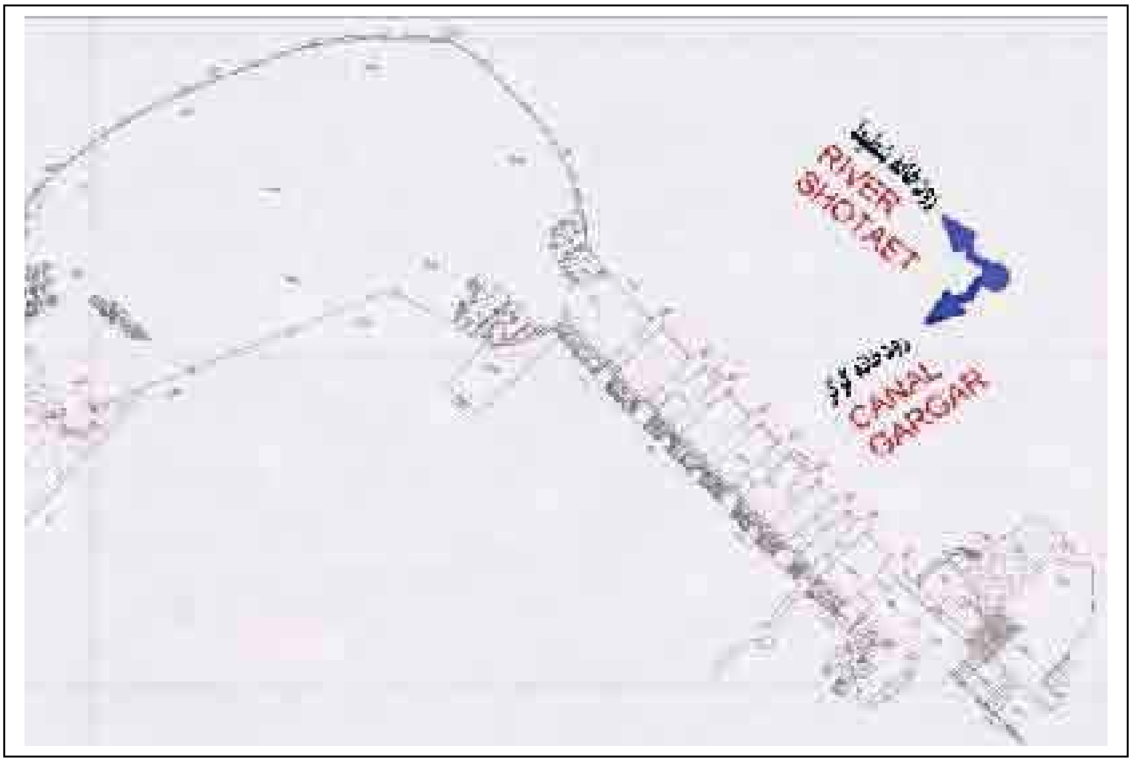
Fig (1) – Arial map of Mizan barrier

1-1-3 Barrier architect:

Mian barrier has 6 conduit 9 open channel, pressure relif & broad weir conduit wide are different, but foundation wide of nine conduit are the same. 4/9& 7 intakes are now exist. Barrier length is 523 meters crest length 323.32 meters, and different elevations of upstream and down stream in 0.45 m, height of buries is 6.5 meters. Mizan barrier materials are sandstone in regular & irregular shape, grove, and primary materials are sandstone in regular& irregular shape, grovel , and primary material of cement.

Table (1) – technical specification of Mizan Open conduit.

X	IX	VIII	VII	VI	V	IV	III	II	I	Gates Number
5.90	2.55	3.10	2.40	2.60	3.20	2.80	3.60	2.90	3.20	Gates width (m)



Map (2) – Mizan barrier plan.

1-1-4- Geometry situation investigation & reparation.

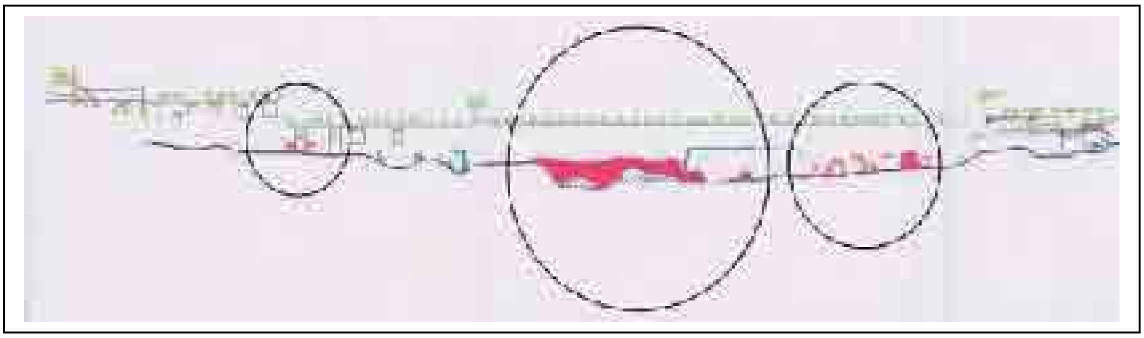
There is no information about foundation & plan of Mizan barrier. But some investigation such as incuvation is done. There is none. There is some possibility that foundation is settlement and felt down in river. For stability consulting engineers has presented the following ways:

- repairing the 1, 2 and 8 conduits

- repairing the pressure relief of conduit 9.

- Wall & foundation reconstruction.

- Re construction of equilibrium canal



Map (3) - situation of scouring in Mizan barrier piers

1-2 - Lashkar barrier- bridge

1-2-1- Historical specification.

Lashkar barrier brig is located in south- west of Shushtar in 2300 wetter far away from Daryoon river intake. It is one of historical set of hydraulic structures.

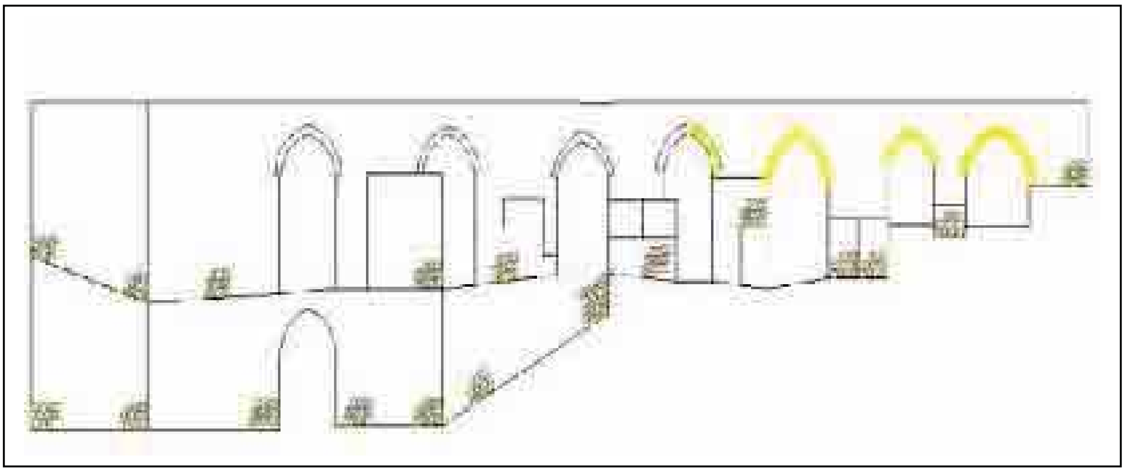
1-2-2- Cause of denomination:

As Lashkar barrier, Askar is famous.

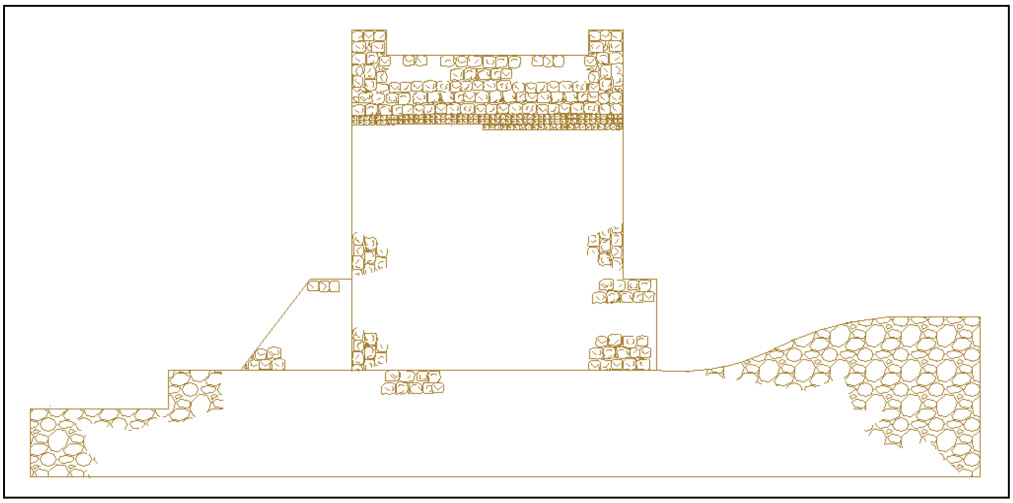
Fig (2) – Lashkar barrier

1-2-3- Barrier architect:

This barrier has 12 intakes bridge length is 124 meters, average height 10 meters, top wide is 4 meters. Wide of each intake is 3.2 meters. Height of intakes from bottom is 4.9 meters.



Map (4) - longitudinal profile of lascar barrier brig.



Map (5) - width profile of lascar barrier brig

1-3- Shadravan barrier- bridge :

1-3-1 - Historical specification:

It is located in east of Shushtar bridge on Shutat river. The construction time is at the time of Shapour 1 and was built by Rom imperator. It is one of original part of old irrigation of Shushtar.

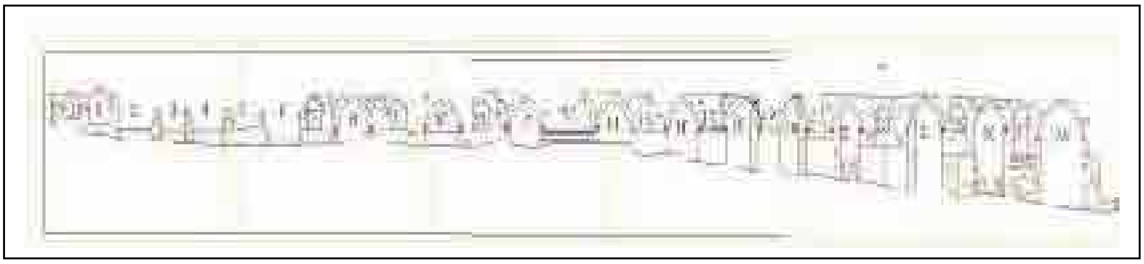
1-3-2- Cause of denomination.

Shadravan bridge , Shapour brig, barrier- brig of Gysar are others names.

Fig (3) – Shadravan barrier- bridge

1-3-3- Barrier architect:

It has 534 meters length, 44 big intakes & 43 small intakes. At the present time only 28 intakes are remained. Telis barrier- bird has 2 convex at upstream& one concave in downstream



Map (6) – longitudinal of barrier- bridge of Shadravan.

1-4- Gar Gar barrier – bridge:

1-4-1- Historical, specification :

It is located at 300 meters downstream Mizan barrier with 1700 years old.

This barrier with migan barrier controls the water surface up to 9.2 meters.

1-4-2- Barrier architect:

It has 3 underground conduit as 3 Koreh, city intake & Bolyti.

Fig (4) – Arial map of Migan barrier

1-4-2-1- Repairing & risk decreasing historical flood damaged to this barrier.

Some considerations for structural protection are:

- Construction a rash between Migan Gar gar barrier.
- repairing & reconstruction of 3 Koreh and city intake.

1-4-2-2 Gar gar threeple tunnels:

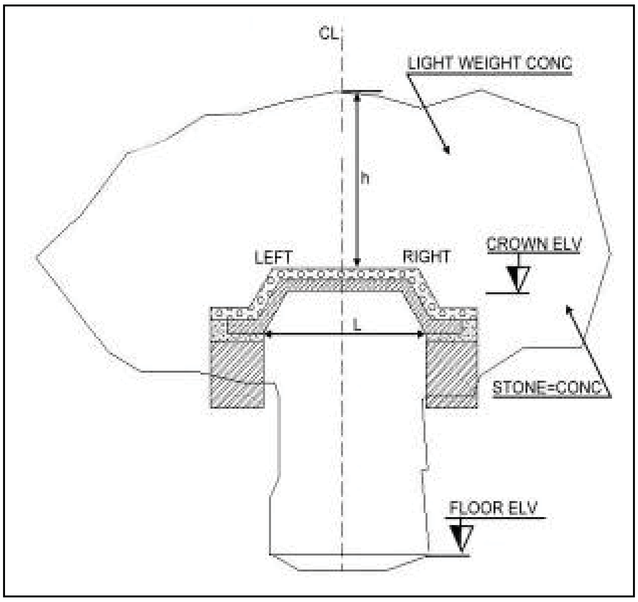
1-4-2-2-1- Bolyti tunnel :

This tunnel has 1700 years old and conveyance the water from upstream of Gar gar barrier to water – mill. Bolyti in miditranian is famous as Mother Goddess.

Table (1) - outlet specification of secondary lateral of Bolyti base on minimum 300 m^3/s

Differential elevation between inlet & outlet of tunnel	Differential elevation River surface with Outlet tunnel	Cross-section (m^2)	Secondary outlet
-0.25	8.45	1.30*2.10	AV1
2.38	8.33	1.05*2.10	AV2
0.95	8.40	0.95*1.90	AV3
-	8.43	0.6*1.90	NIR

Map (7) - situation of Bolyti tunnel with lateral Branches under Shushtar city Bolyti studies.



Map (8) - overflow cross section of Bolyti tunnel in details

Study shows some tension& shear cracks on foundation and walls. There is a large scouring in tunnel invert. KwpA incorporation to cultural heritage organization had done some studies to protect the shape.

1-4-2-2-2- City tunnel intake:

It is one of the tunnels that conveyance water from behind of Gar Gar barrier – bridge to all of water – mill. Because of intake is in front of city they called city tunnel intake. It is located in east- north of gar- gar barrier- Bridge and supply water to city tunnel intake and Haje Handal water mill.

Table 2- city tunnel intake specification

DIFFERENT ELEVATION BETWEEN OUTLET INVERT WITH INLET INVERT	DIFFERENT ELEVATION BETWEEN OUTLET INVERT WITH WATER SURFACE	CROSS-SECTION (M^2)	LENGTH (M)
4.80	4.20	4*4.90	80

1-4-2-2-3 -Three Coreh intake tunnel

In Shushtarian speech for under ground tunnel they used Coreh name. Tunnel has 3 intakes by this means they named three Coreh intake.

Intake of this tunnel in located in east- north of Gar Gar Bridge. in it’s direction has a diversion canal for water- mills as named Bokhbodeh outlet of tunnel is famous as loaf it comes from the word related to wavy and high currently water as name lof. The plural of lof is loaf.

Table (3)- three – Coreh technical specification

DIFFERENT ELEVATION BETWEEN OUTLET INVERT WITH INLET INVERT (IN METER).	DIFFERENT ELEVATION BETWEEN OUTLET INVERT WITH WATER SURFACE (METER)	CROSS-SECTION (M^2)	LENGTH (M)
0.70	4.90	3*(1*3)	100

Map (9) - situation of three Coreh tunnel and city intake of Gar- Gar intake

- DAMAGE CAUSES IN GOR – GOR BARRIER TUNNELS

1- Erosion in stones

2- Scouring by floods

3- Lack of aeration

4- Lack of durational reprimand

Fig (5)- Three – Coreh tunnel inlet.

1-5 - Borjeh Ayar barrier – bridge

The time of this barrier is related to Sasanian time. It is located on gar – gar branch and close to Maugham ale tam pal. It has some canal & chambers that looks like cross.

1-5-3 - Cause of denomination

The other names are: Sabaeikash , borjyeh ayar.

1-5-3 - Barrier architect.

Some parts of this barrier are located beside of river two parts of that has 150 meters long beside the river that use it for water diversion as the east of this barrier there are some residual of structures related to Sabaian prey- site.

This bridge has is netter thickness height of wall is 4.s meter & wide of that is 4.5 meters.

It has 20 meters long.

Fig (6)- residual parts of Borjeh ayar stricture.

1-6 - Khak barrier:

1-6-1- Historical specification:

It is related to Sasanian time. This barrier is located in west - south of Shushtar at 1900 meters Downstream of Daryoon intake & 400 meter upstream of (12) lashkar barrier.

1-6-2- cause of denomination:

Because of two large earth columns in both sides is famous as Khak barrier.

1-6-3 barrier architect:

Spite of small body it has nine gates.

Reservoir area is 1000 m^2. Only 40 cm of this structure is visible, now 3.5 meters of this barrier is getting up of the soil. It has 2 sections. Each section, has 5 gates with columns of 1.33 lengths. Each gate has 1.72 meters wide. In ten steps downstream has diversion gate that was destroyed

Fig (7) - Khak barrier of Shushtar

2- CANALS & RIVERS:

2-1- Historical Daryoon Specification:

Daryoon canal after Gar – Gar river is the second man built canal in Shushtar. It is related to Hakhamaneshian time that about 5 hundred years B.C

Hydraulic structures of Daryoon Are Shadravan barrier, intake & tunnel of daryoon ,Mizan barrier ,Lashkar barrier , water- mills with 2000 years old.

2-2- Caugo of Denomination:

Other names are Daryoon stream, daryoon canal dara stream, minad canal.

2-3- Barrier Architect:

Intake of Daryoon is located under Slacel castle at the highest elevation of north plan.

Watering is supplying directly from river.

It has 2.2 - 4 meters width, 2-8 meters highs invert of this tunnel is rectangular with two pass way in both sides.

2-4- Repairing The Stream& Intake Of Daryoon:

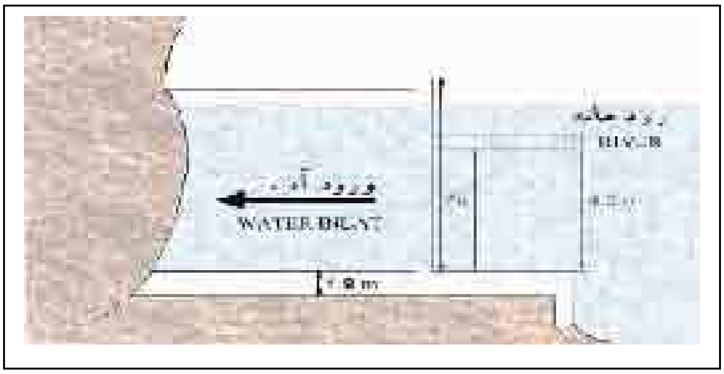
Historical floods were damaged to Shadravan barrier. Minab network with 3600 hectares need to a modern design and intake for this reason it was decided to rebuilt and repairing the intake & tunnel

2-4-1 - Parts specification:

Structure specifications are:

- intake

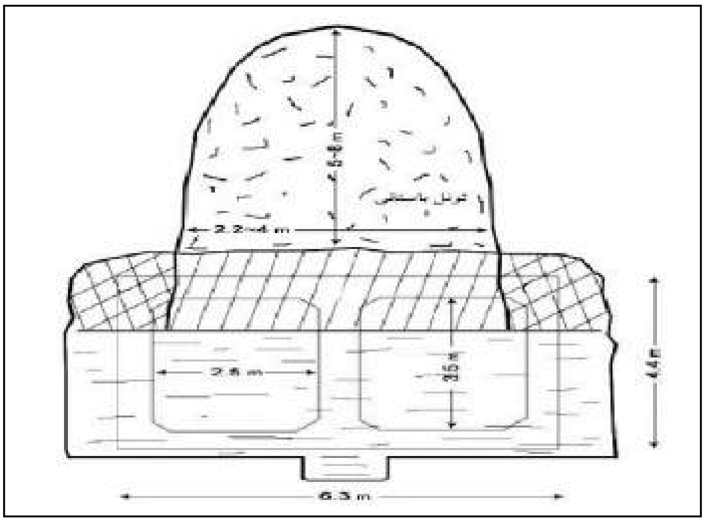
It has 2 intakes with 3.7 * 5.6 meter & another 2 intakes with 2.4 * 3.7 meter that hare trash system it has 40 m per month that is the biggest intake.



Map (10)- longitudinal profile of Daryoon stream

- Tunnel

It convenience water from two box conduit by 3.5 * 2.5 meter. Wide of tunnels 6.3 meter height 4.4 meters and length of that is 169 meters.



Map (11) - cross- section of under pressure tunnel in Bastian tunnel.

ACKNOWLEDGEMEANT:

We should say thanks to manager of irrigation & drainage technical and manager of research and standard of KWPA.

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GHANAT TRANSITIONS, TECHNOLOGY AND CIVILIZATION FROM PAST UP TO NOW

Mohannad Barshan[1]

ABSTRACT

Iranian plateau is a vast desert and annual rainfall in most parts of Iran, except for northwest regions and southern border of Caspian Sea, is about 15 to 25mm. Therefore, Iran is a barren country considering agricultural activities in compare to other parts of the world. Iranians have invented an interesting technique to overcome drought; this technique can transfer water from high lands and mountains to low-altitude areas and deserts. Documents show that Iranians have created Ghanat system and it can be said that lead miners were the first to use this system in northwest of Iran.

In addition to supply the drinking and agricultural water, Ghanat can provide a good atmosphere for good correlation and social cooperation to improve the culture and to establish the society. Two fifth of water used in east of Iran is supplied by Ghanats which are located in this part. Lack of water in these areas and making use of Ghanat has caused maximum utilization of water and traditional collective agriculture. This is why irrigation systems in eastern parts are better than those in western parts and their traditional products are much more than those of western areas. Ghanat is a civilization and a culture; it exists in Iran culture and is integral part of it.

Keywords: irrigation, Ghanat, watering, well, spring, pond, desert

INTRODUCTION

Dry land of Iran has been the cradle of different civilizations and its only problem has been water during 8000 years of compiled history; several civilizations have been disappeared due to drought and lack of water.

In the ancient world, due to lack of tools and little growth of technology, Iranians have brought water from foothills of mountains to the arid areas and deserts by inventing a useful method. Inventing this technology, almost all big cities of Iran located in foothills have been developed and improved.

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Ghanat is the basis of evolution of stable and tolerant civilization and is shunning war and violation according to documents. Ghanat is considered the veins of deserts, providing them life, joy and development. Ghanats which can be found throughout Iran are sometimes as old as 2000 years and are witness of our ancestors' attempts to develop this land.

GHANAT TRANSITIONS, TECHNOLOGY AND CIVILIZATION FROM PAST UP TO NOW.

The term Ghanat or sewer has monotonous and similar meanings in Persian dictionaries; the best and most complete definition of Ghanat can be found in a convincing proof(sewer is a water canal which is excavated under ground to flow water in it). In Ennendrag Dictionary we have: pathway of water in underground which is called ghanat in Arabic.

Sewer is derived from the words "mountain and fall" and it refers to water that arises from mountain and then flows downward; in Iran, this irrigating system is usually called Ghanat but in eastern parts of Iranian plateau and Afghanistan it is derived from words mountain+ fall. Sewer is more common in eastern parts of Iran, Afghanistan, central Asia and Turkistan. Moreover, names of some of the villages in these areas are derived from this word.

In central Europe, Ghanat is called water channel while in south and Central America, it is called "caller or filter". Iranian sewer is the most interesting name referred to this irrigating system and it is used in Hoogar region in foothills of Atlas Mounts because people believe that Barmakian brought this system to this area. There are some contradictions among researchers considering the time of innovation of Ghanat and the way of its evolution because its structure has been changed over time. Here, it can be said that Ghanat is one of the most significant innovations of man, affecting their agricultural activities and irrigation of Iranian plateau over several thousands years. It also has influenced on human societies and communities. Constructing Ghanats encouraged people to stay in semi arid and dry areas and improve agriculture. Unlikely, by destroying these Ghanats, most of these areas are abandoned and destroyed. Simplicity is one of the main advantages of this irrigating system so that its structure hasn't been changed so much during past years and remains simple.

In deed, making use of Ghanat dates back to the time when man found out the necessary knowledge. On the other hand, when people learned how to evaluate ups and downs of the earth, solve problems of sloping of the bottom of sewers and use simple tools like pick, wheel, lantern and spade, they could build wells. It is hard to say when and where they were found and evolution of wells can't be referred to one age but it should be noted that water, as an important factor, is found everywhere man lives.

The main reason why wells are extended to most parts of Iran can be found in some points, the most important of which is ecological conditions of different parts in which Ghanat exists. In fact, this irrigating system has been appeared according to special ecological conditions of Iranian plateau especially in hot and semi arid areas. Then, it was extended to other regions with similar ecological conditions. It is impossible to mention the exact location of the first Ghanats, but according to Fagih, they were first found in Kerman; however, his findings aren't proved scientifically. By the way, Kerman can be considered as at least one of the regions in which Ghanats have evolved and all researchers confirm that Iranian plateau is the origin of Ghanats. Another reason why evolution of Ghanats is referred to Iran is that Ghanats haven't been found in ancient Rome and Greece which are the most developed countries. However, special ecological conditions of these countries caused them not to use Ghanats. In compare to other parts of the world, Iran has the most Ghanats.

Generally, Ghanat system is an easy system which includes a steep tunnel with tens of Ghanats perpendicular to it but Ghanats are divided into three groups considering their shape and structure:

1- simple Ghanats: they are those tunnels with a series of perpendicular wells
2- Two layered Ghanats: in these Ghanats, there are two tunnels, one of which is located on top of the second one. So far, only one two layered Ghanat has been recognized and it is in Ardestan and the water of one layer doesn't penetrate into the second layer.
3- Ghanats branched from river: unlike simple Ghanats, the water in these wells isn't transferred from mountains but it is transferred from rivers to farms. Naser Khosro Ghobadiani has also reported one example of these Ghanats in Tarom. In Shahdad, one of these Ghanats is also found.

In this kind of Ghanat, the water of river was used especially when conditions of the earth didn't allow people to establish an open channel from river to control water to their lands.

In the first place, the most important condition to explore sewers is the existence of permanent and ground water and then slope of the ground. Moreover, if during excavation we encounter bad smelling soil, we should change our way and establishing wells on the way of flood or among valleys is strongly forbidden unless these routes are hard and rough. The best time to excavate wells is on dryness occasions that are Shahrivar and Mehr. The presence of watery lands is the main condition of excavating wells and if it is not considered, digging is completely useless.

Watery land has pores and those lands that have numerous vapor and dew during morning and mountains are always full of water. If desert is cover by laminated rocks, it can be said that there is some hidden water in here. Generally, the best place for excavation is the plains of mountain foothills which have permanent snow and humidity or lands located in vast valleys between these mountains. Therefore, we can talk about channels arising from humid mountains and deserts which are far from mountains but have green plants. Although several centuries have passed from the invention of Ghanats, this method is still usable in Iran and other regions; its structure hasn't been changed a lot and it means that both excavation techniques and tools are those used in thousands years ago. Recently, some new tools are used for excavation but the main tools which are pick, wheel and spade still remain intact.

In digging a new Ghanat, some points should be taken into consideration: presence of watery lands, presence of enough and permanent water and suitability of soil in pathway of Ghanats.

Mother well is in fact the main source of water and is a part of Ghanat, supplying its water throughout the year. They are usually located in watery layers and are considered the deepest wells. In fact, mother well is in foothills and is considered the source of Ghanats. Considering ground water resources, their depth vary from 3 meters to 400 meters. For example, the deepest mother wells are situated around Gonabad.

Ghanat channel is one of three main internal components of an Ghanat, transferring water from mother well to source. Excavating channel is done after determining the borehole.

One of the most important principles which should be taken into consideration in Ghanats structure is the slope of underground channel. In past, well diggers determined this slope and distance from boreholes to place of sources using surveying tools. Karaji states "depth of water should be the same from the beginning to the end". To maintain these channels, water pipes are used to cover bottom and channel of Ghanats and to save water. Karaji believes that in past, bricks were used to cover the internal ceiling of wells and that's why dredge should be done regularly because when the channel of an Ghanat is dried, this channel will be unusable in future.

Source of Ghanat is near the villages and in fact the water passes through the underground ways and opens its way to surface. To determine the place of the source, at first the depth of mother well and then the depth of the first borehole and after that the flat slope of the earth are determined and finally the route of underground channel is determined using scale and compass. One of the most important conditions of choosing the place of sources or openings of wells is that the height of them should be lower than water level in boreholes; that is, necessary slope should be considered so that water can exit the opening of the source easily.

Water of all Ghanats is not usable in the source because sometimes, sources are far from the places in which water is needed so in this case, an open canal or stream is used to transfer water from source to the places; this open canal or stream is called **HARANH**.

There are some reasons why these Ghanats are dried:

- After severe or sometimes mild earthquakes, water level in watery part of Ghanat is lowered and causes shortage of water or dryness of Ghanats.
- Destruction resulted from wars; the first measure conquerors and warriors did to beat cities was to destroy the water resources and this disaster have happened in Iran many times; Sargon the second, was the first to do this method. In the war between Ashk the third and Anitokos, this method was also used.
- Decrease in rainfall, destruction of forests or erosion of soil in foothills that lower the water level and cause dryness of Ghanat. Increase in penetration of rainfall into soil is the only way to prevent this problem.
- Flood is also a factor that causes the destruction of Ghanats so it is better not to build them in these areas. Sometimes, natural fall-down of some parts of Ghanat blocks the flow of water and because water is accumulated in other parts of Ghanat, walls and ceilings will collapse and water is accumulated behind these ruins and finally entire Ghanat is destroyed. It is possible that mud and sly penetrate into Ghanat and inhibit penetration of water and its flow and that's why Ghanats should be dredged regularly.

- Changing the ownership can also be considered a devastating factor. Most Ghanats which are owned by individuals are divided between heirs after death of the owner and thus they are forgotten and their dredge and repairs are delayed and finally are abandoned and destroyed.
- Excavating deep wells is the main factor of destruction. It is apparent since 40s; unfortunately, deep wells have caused the destruction of Ghanats and they can't be a good substitution for them. Equipments of well diggers are so simple and include a wheel, a leather bucket, a pick, a lantern, spade and compass.

To dig an Ghanat, 3 to 5 people are required and if constructor wants to use one wheel, the required workers are:

Pick holder: he is the most experienced excavation worker; in fact, he is responsible for digging, determining the directions and choosing wells' dimensions and underground canals.

Mud collector: his duty is to collect dust and mud accumulated on wells by dibble and to pour it into bucket and give it to collapse puller.

Collapse puller: after mud collector gives the bucket full of dust and mud to him, collapse puller brings it near the bar and changes it with the dust bucket which is fastened to wheel's rope.

Wheel puller: he works on the ground and near the opening of the wells. Turning the wheel and the rope fastened to the wheel, he changes the full and empty buckets.

Bucket receptor: he stands near the wheel and when the full bucket reaches the ground, wheel puller stops the wheel and bucket receptor empties the bucket and then gives the empty bucket to the wheel puller

Different methods of water division in Iran are attributed to different people. For example, in Ardestan, water division was known to be under supervision of Khaje Nasiradin Toosi; in Tabriz and Isfahan, it is attributed to Sheikh Bahaii. In past, to determine the time needed to use water, movement of stars and the sun was done and today it is replaced by clock. To divide water, there is a special unit called arch. In Kangavar Region, water division unit is arch that equals 6 hours of irrigation while in other villages every arch is 12 hours. In fact, owners of wells determine these arches at the beginning of every agricultural year (Mehr) and before cultivation.

The kinds of ownerships are also different so that in some areas, one well has only one owner who sells the water; some have several owners; some are sold as various shares; and finally some of them are endowed.

Ghanat is a traditional phenomenon which is located in some cities of Iran like Kerman but due to new generation that has little knowledge about Ghanats conditions, Ghanats are to be inclined unless a number of them are recognized and kept as some monuments.

Ghanats are essential part of agriculture and encourage people in dry areas to dig lands and plant trees and flowers there. Trying to extract water, these people have made the dead lands of deserts alive.

But new generation wants to experience something new and try to wash old thoughts and pattern away; they don’t like mud houses and want to live in cities because they are told that brick and iron are signs of civilization. Today, technology doesn't know time so deep wells replace sewers. Now, those traditional well diggers who once called their friends from the bottom of the wells are not working and machines and new technologies are replacing them. Dried lands are no longer waiting for water that comes out of wells and in our deserts, we can't see the signs of green nature anymore. People who extracted water from depth and planted green lands and farms are now regretting those green days.

As deep wells are dug and sky refuses its rain to deserts, Ghanats, these significant heritages, are forgotten and abandoned.

According to valid documents, miners in northwest of Iran were the first people who though of inventing wells several thousands years ago. Following discovering cooper in Zagros Mounts, they accidentally discovered this system of irrigation by creating drainage. These Ghanats date back to the first millennium but making use of Ghanats water for agriculture started some years later.

The first report about water supply was written 700 years bc and in an epigraph of Sargon the second, king of Ashour.

At the time of Great Darioush, the best achievements were made considering irrigation and excavating sewers and achaenemian kings announced that everyone who could find a well, dig it, and plant a land using that water, he and his next five generations were exempted from taxes. At this time, excavating sewers were expanded to Egypt and in Hamant village a sewer were dug and irrigated 5 thousand hectares of lands.

According to Hamdolah Mostofi, after Islam the first excavation was to supply the drinking water of Mecca and it was done by Zobeide Khatoon, Haroonareshid's wife. Iranian scientists have written some books about excavating wells, extracting ground water and determining the quality of water. For example, Abobakr Mohamad Ebnel Hassan wrote the book" extracting ground water ". In Mongols attack, irrigating systems and wells were destroyed and most of them were dried and abandoned. In Safavie dynasty, excavating wells were started again due to severe drought. In the Qajar dynasty, Aga Mohammad Khan destroyed the Ghanats and then occupied Kerman. At this time, excavation improved and most Ghanats were dug during 200 past years. Haj Mirza Aghasi was the man who encouraged people to dig Ghanats.

Today, the number of Ghanats is decreasing and sewers are destroying by making use of new technologies. Before land reforms in 1341, there were about 50 thousand series of Ghanats in Iran but after land reforms their development was stopped and their destruction and dryness were started. In less than 25 years, approximately 20 thousand Ghanats were destroyed and it was the ending of sewer civilization in Iran.

Ghanat is a traditional aquatic structure used to extract ground water. Ghanat is in fact an underground channel that transfers ground water to the surface. Although this system was invented in north or northwest of Iran, this method was very useful in dry areas of centre or east of Iran. Although Ghanats can be found all over the world from Japan to Chili, the biggest place in which Ghanats are considered the sources of water supply, is Iran. In dry areas, improving agriculture and building cities or villages is impossible without using water of Ghanats. In fact, in most areas around Iran deserts like Kerman, Yazd, Kashan, SAbzevar, Birjand, Gonabad, Ferdos and…, life would be so difficult without water. The dependency of these people to water of Ghanats is very much and according to experts, without Ghanats, big cities like Kerman, Yazd, Kashan, SAbzevar, Birjand, Gonabad, Ferdos weren't appeared. Therefore, attempts of people in eastern part of Iran caused that over 74% of Ghanats in Iran to be dug in these regions so that there are more than 12600 Ghanats in internal areas like salt deserts. In Iranians plateaus, there are 300 thousand kilometers of Ghanats and according to UNESCO, three fifth of world's Ghanats are in Iran. Among them, the biggest and the longest ones are located in Yazd and Gonabad, showing high techniques of construction. Documents show that there are Ghanats in four continents of Asia, Africa, Europe and America; among them Asia has the most ones. Although they can be found in all cities of Iran, they are more in deserts and dry cities and the most popular ones are located in Kerman, Yazd, Isfahan, Semnan and East Azerbaijan. One of the most significant Ghanats is a two-thousand-year Ghanat in Gonabad; it is 33km long and has 420 wells. Depth of mother well is more than 300 meters and is considered the deepest one in Iran. This Ghanat is a significant phenomenon in the world considering its age, length and amount of watering. Although the first usage of Ghanat was to flow groundwater on the earth, other usages are drainage of water and sweeten the lands. By building wells, the drinking water in tropical islands like Persian Gulf is supplied. Artificial feeding of underground layers, keeping environmental balance and preventing intra-municipal floods are important usages of Ghanats. Not only is Ghanat a valuable memorial of our ancestors, but also it is a huge and important capital for the present generation.

According to report of ministry of agriculture in 1378, annual discharge of Ghanats water for agriculture is more than 10 milliards m3, 70% of which belongs to deserts. Drought and low precipitation in recent years have dried and abandoned the Ghanats. In recent years, water of most Ghanats has been lowered and some of them are completely dried. Irrigation of these Ghanats which once was stable and helped the development of cities is now forgotten. Today, excavating an Ghanat is very costly and utilizing water of deserts or wells cause drop of quality and level of water and decrease the useful life time of wells. Despite modern technologies, value of Ghanats is still kept but to have a better result, old and modern methods should be mixed. According to statistics of ministry of agriculture, number of Ghanats in Iran were more than 44000 in 1367 but bad maintenance, lack of financial and technical support reduces these numbers to 33405 ones with output of 10/7 milliard m3. The irrigating and watering of them in some southern and eastern parts are decreased to 20 to 80% due to recent drought. Watering problems of wells are overcome in areas where reconstruction and controlling operations are done. In most eastern parts of Iran, the wells are destroyed and if this trend continues, in near future there will be no sign of these monuments. In this case, the result of our ancestors' attempts to use groundwater for irrigating will be buried. Destruction of Ghanats is not only decline of one method of irrigation but also is fading of one culture so they shouldn't be allowed to be ruined. Dryness of these wells has caused other strength factors to be destroyed too. Restoring wells can help development of these abandoned places and encourage people to start living there again. Current conditions of Ghanats reveal that if this reduction trend of water level continues, in future we will have more dried wells. In this case, the government must pay more attention to owners and legislators of wells and must try to prevent digging deep wells around Ghanats. To maintain the Ghanats, assigning governmental financial supports to dredge them and to use new technologies in excavating Ghanats are essential.

Ghanat is not an ancient monument but rather it is a good method of extracting water and making use of groundwater resources. Moreover, it is mixed with culture, national and religious traditions of Iranians. Sewers are masterpieces of civilization in Iran and are heritage of our ancestors in deserts. Let's try to keep them from drought and don't let deserts win over villages and destroy our ancestors' attempts.

Iran is the origin of Ghanats and has the oldest and the most historical ones. Ghanats are the basis of evolution of a stable civilization. Ghanats that are ancient symbols of Iran should be known and understood and we must transmit them to the next generations. These masterpieces are mostly built in dry areas like Khorasan, Yazd, Kerman; they bring development with themselves. Unfortunately, most of them that once were veins of live and caused the development of deserts are now dried and destroyed

Ghanat in desert means life. Ghanats are symbols of thought, knowledge, technology, cultural heritage and history of Iran and Iranians. They are valuable capitals hidden under the ground. In fact, Ghanat industry is considered the oldest industry and one of engineering masterpieces of our ancestors as the oldest aquatic structure and water supply. Ghanats was first excavated to extract water and improve rural life and now are dried. Ghanats are reported to be invented before 1780 bc and it is said that since then, well diggers started digging Ghanats in Kerman and Khorasan; gradually it was expanded to all parts of Iran and then to other countries so that they can be found all over the world. However, Iranian plateau has the most wells in the world. According to Hamdilah Mostofi, Ghanats are located in 30 cities of Iran and the most important ones are Gonabad Ghanat with depth of 500 meters and Sanabad Ghanat which is 1220 years old.

Today, those lands that were full of Ghanats and had green landscapes now are so thirsty in dry lands of deserts and those rural Ghanats are to be dried due to unwise measures of unqualified people.

According to authorities, total amount of water extracted is 70 milliard m3, 8 milliards of which is extracted from Ghanats. In fact, according to official statistics, more than 12% of extraction of groundwater is done by Ghanats. Today, there are 33000 active wells in Iran. In Khorasan and Kerman that are the origins of these aquatic structures, more than 4000 Ghanats have been dried during the past years due to continuous drought. Shortage of water which is the worst problem of the third millennium made our ancestors find a solution and they could solve it by digging wells. Today, we can also solve this problem by using our ancestors' experiences and man force.

Life doesn't exist without water and Iranians, knowing this important principle that water flows in deepest parts, invented a method and became able to extract water from depth of 340 meters and it was the beginning of a new civilization.

Experts believe that Ghanats are very valuable because they have been used for several years and can supply water regardless of primary expenses of dredging and maintenance. Because they are owned by farmers, the lands under cultivation will be increased and what is important today is to produce maximum agricultural products by using minimum water and energy. Western countries are going to build such structures with the aim of extracting water without spending huge expenses and by using little fossil and artificial energy to keep the environment clean. Therefore, using modern technologies, we can enhance the efficacy of Ghanats without destroying economical and social tissues of societies. Stability of Ghanats in cities strongly depends on watering plans and experts of performing these plans are of importance. Improving the culture of watering to maintain water and soil needs national attempt but over past years we have observed that most of wells are dried. One factor of dryness is to dig deep wells around Ghanats. In extracting water from deep wells, in the first years fossil water is used and over time, as level of ground water decreases, watering of wells decreases too. On the other hand, excavating these wells needs lots of primary capitals and it is done by unprofessional owners. Therefore, agricultural products are reduced and villagers are forced to move to cities. Ghanats are found in all parts of Iran and experts believe that digging new Ghanats or restoring them is better and economically more efficient than digging deep wells. Unlike deep wells, Ghanats don't need pump, engine and complex equipment. According to experts, performing artificial feeding plans are very essential for Ghanats; in addition to control surface water, these plans can prevent extraction of water and strengthen the groundwater. It results in increase in the amount of watering and increase of humidity in surface soil. Moreover, Soil erosion is reduced because of permanent plants and agricultural products. When Dr. Ali Shariati visited the construction processes of a sewer in deserts around Yazd, he wrote that building an Ghanat is a jihad in darkness to access water, fight with soil to travel into depth of the earth and to look for water.

Sanaii, great Iranian poet, states that one jug of water inside the house is better than a river outside.

Ghanats are distributed worldwide from Japan to Chili but the biggest place where Ghanats are the best sources of water is Iran. In this region, Ghanats technologies are evolved so they are built efficiently in all cities. If Ghanats weren't appeared, cities like Yazd and villages in foothills of Shirkoh wouldn't exist. Ghanats, in history of Iran, were first invented by miners; they explored Zagros Mountains to find cooper and during their attempts, they encountered ground water. To overcome this problem, they use drainage and accidentally found the technique of digging Ghanats. Documents reveal that this accidental invention dates back to the first millennium but making use of water for agriculture started several years later. For feudal, these systems weren't good so they were destroyed during wars and battles and owners should rebuild them. In Ghanats civilization, there was no relationship between cities and villages due to distances so the communities were close and traveling and immigration was so rare. As population grew, the owners of wells increased and this kind of ownership affected different parts of culture and civilization, one of which is political-economical system. In the scope of Ghanats civilization, there was no important organization to supervise and observe the cycle of production and distribution of products; it means that surplus was enough to improve the production factors like development and reconstruction of Ghanats, development of farms and improvement of production tools. Surplus was always less and lack of water and relative weakness of soil didn't allow for more production. Unlike Ghanats civilization, in river civilization people or farmers had vast lands and huge amount of water and produced more products; on the other hand, owners spend their surplus for themselves and could establish their ownership.

Sewer civilization that couldn't bear big wars, aggression and utilization of their lands by people and slaves, had to compensate its shortage of its resources by handcrafts and business. This kind of civilization has its own properties and its people also have their own identities. In this civilization, no big and significant castle and big temples like castles of Shoush, Takht Jamshid, Kangavar can be found but architects make unique small structures and garden making is excellent in this arid area; coppersmiths of Kerman, Yazd and Tabas make some dishes all people of Iran know and create important copper works. Goldsmith and business are very important here and these areas are traditionally the origin of merchants. The practical sciences especially sciences related to excavation and maintenance, repair, utilization systems, pedology and geology are of importance in this civilization. Economical activities and handcrafts are found in this civilization. Carpet weaving is excellent in Kerman and Kashan and is exported to all countries. Kenry Patinher in 1810bc writes that "one third of people in Kerman do carpet weaving, and felting and shawl weaving and their products are very famous throughout Asia".

Great epical warriors like Rostam, Sohrab, Esfandiar and Lohrasb are from feudal civilization and have fought with warriors of pasture civilization like Afrasiab, Hooman and etc. heroes of this territory like Pahlaven Abdol and Pahlavan Hassan were so kind and didn't take part in wars and they always talked about peace and thrift. In fact, they always thought about economics and discussion not about war and spending money. In this area, rubbery, aggression and treachery were so rare and religious minorities lived in peace and their firetemples, temples and churches were built near mosques. In deed, we can say that Iran in today's world has the properties and characteristics of sewer civilization.

Excavating the longest and the deepest Ghanats of the world represents the successful and continuous attempts of Iranian over thousands of years, affecting life and social relationships of these people. In plateaus of Iran, there are 300 thousand Ghanats and according to UNESCO, three fifth of all Ghanats are in Iran; among them, the longest and the deepest ones are in Yazd and Gonabad. It should be noted that Iran was one of the most civilized countries due to numerous Ghanats and water and all cities and villages could survive by the help of these Ghanats.

Not only can Ghanats extract water from underground but also they can sweeten the lands, reduce the salt of soils and prevent over-accumulation of salt in soil; however, it is true for shallow Ghanats. There are vast deserts like Loot and Tabas in Iran and Ghanats are the only sources of water supply in these areas. They play an important role in supplying water and development of villages. In fact, absence of Ghanats destroys the ecological and hydrological balance of these regions and their presence balances the amount of precipitation and cultivation. As document shows, removal of Ghanats destroyed this balance and finally caused abandonment of these areas. Ghanats are located in all cities but they are more in dry and arid areas. The most important Ghanats are: Bidokht, Salehabad and Sanabad Ghanats in Khorasan; Kerman, Mahan, Bam, Gerdoon and Joopar Ghanats in Kerman; Ashkoor, Mehdi Abad, Restag, Dolat Abad, Gahrom and Mamgan Ghanats in Yazd; in Isfahan, Aroone and Ardestan. Researchers and writers have confirmed the existence of Ghanats in more than 24 countries, the most important of which are: in Asia, Jordan, Afghanistan, Emirate, Bahrain, Pakistan, China, Syria, Turkistan, Russia, Iraq, Arabia, Oman, Palestine, Cambodia, India and Yemen; in Africa, Algeria, Tunis, Libya, Morocco and Egypt; in Europe, Germany, England, Spain, Italy, Cyprus and France; and in America, Peru, Chili and Mexico.

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In the forth century A.H, a book termed "extracting hidden water" was written by Aboobakr Mohannadebn Karaji. He, an Iranian engineer, talked about the structure and maintenance of wells. He writes "while penetrating into soils, water is blocked by hard layers and stops there and if a channel is excavated here, water can go up due to its pressure". He pays more attention to the place and location of wells. He states that" you should know that the best place for digging sewers is the plain of mountains that have permanent snow and humidity or is the lands located between the valleys; sometimes deserts which are connected to humid mountains are good places for digging them. If you find these places, don't ignore them and if you see a desert which is far from mountains but has various green plants, dig it because you will definitely find water." One of the other books about Ghanats is "Mafatihol Olom (keys of sciences) written by Aboabdolah Mohammadebn Yosef Kharazmi. It can be said that importance of Ghanats was so much that made this system a laboratory science.

Ebn Fagih Hamedani refers the invention of sewer to Kerman and states that" one of Iranian kings arrested a group of philosophers and told them to bring water to the surface so that they could use it to plant trees and flowers. Therefore, Kerman changed to a city with trees, rivers and springs.

Hamdolah Mostofi talks about sewers in Tabriz and states that" Tabriz has various plants and water of Mehran Rood which is arising from Sahand Mount flows in this region." Estakhri writes" there are popular bazaars and caravanserai in Rey because Roode, Belisan, Dehak and Roode are very green and there are bazaar and caravanseray in Sharstan which is surrounded by walls; it has water of river and sewer and there are a lot of sewers for farming.

Maser Khosro writes in his log" when I left Toon, a man from Gilak told me a story. He said when we went to Gonabad from Toon, bandits attacked us and some of us thrown themselves to sewers and when bandits went they wanted to save the men who were on the sewer but they had been killed because the sewer was 4 parasangs in deep."

It is obvious that Ghanats can cause permanent residency and improve agriculture. There is no complete information about all Ghanats in Iran but as we know, they were the sources of water supply in most cities. Neishabour Desert was watered by 12000 Ghanats and water of city was always supplied by Ghanats that passed under the houses. Yazd had 400 series of Ghanats and water of Sirjan was supplied by Ghanats. Sirjan had 12000 Ghanats and water of Gonabad and Tabas was also from Tabas. Kerman, Fasa, Jahrom and Shiraz also used these Ghanats. Qom had lots of them before Islam and during Islamic period, more than 20 new Ghanats were built there. Around Tabriz, there were more than 900 Ghanats. Henry Goblo, a French hydrologist, estimated in 1929A.D that approximately half of lands in Iran were cultivated by Ghanats. Water and drought have been the most important social problems throughout history. For example, in southern stone bench of Takht Jamshid in epigraph of Darioush, we can see that he asked God to save Iran from drought; or on Saalbi History, we see that in Ardeshir Babakan time, sky hadn't been raining for several years but Iranians tried to use different methods to utilize groundwater and the best method was Ghanat. Therefore, water was very holy in Iran in all faiths before Islam and in Islam, water is respected and there are some rules on it and polluting water ended in death.

In some parts on Iran like Kamare village in Khomein Town, Mime and Lazare villages around Abade City, wild and fast water is considered male and silent and slow water is considered female. There are two springs in Aglan Fire temple; one of them is wild and the other one is so silent so they are called male and female respectively. In some parts of Iran, well digger's palm skin shows if the water is male or female. That is, if well digger's skin gets rough, the water is male and if his palm skin gets soft during digging, the water is female. In some parts, an Ghanat is called male that its water fluctuates. This belief still remains in most parts of Iran like in villages of Arak, Tafresh, Malayer, Mahalat, Khomein, Golpaygan, Delijan, Damghan, Shahrood and Yazd. Only one case is told about the marriage of Ghanats and that is Mohammad Hassan Khan Etemadosaltane in 1256A.D talks about this issue when describing Rad village around Charmahal-O-Bakhtyari. He says that" this village has 300 families and its water is supplied by Ghanat, spring and Zayanderood River. He writes that, there is an Ghanat in Saman Village. If this Ghanat doesn't have a wife, he will die and his water is dried so he should have a wife and his wife shouldn't have another husband. The wife should at least get bared once a month and swims into his husband's water. Marriage party is like this: at first it is tried to convince the female which can be a girl or a widow then, people start the party; like a real wedding party, they play the music, dance and sing. People bring the bride to the wedding clothe which is near the Ghanat. After that, a jug of that water is brought to the party. Finally the bride says yes and the party starts and people eat dinner. When the party finishes, the bride should swim in the Ghanat without any clothes. In some villages in Yazd, when the water of well is dried, people gather together and choose the best man of the village. Then, they take him to the mother well and he calls the mother well loudly and others start the party. In some rural parts of Iran, there are some public bathrooms, one of which is built outside the village on desert and it is only for brides and grooms. Pots of water are kept out of the bathroom and they put some leaves of rose on them. At two o'clock in the afternoon, people take bride and groom to the bath and wash them one by one, dress them up and start the party. However, in Sistan and in Sarabandary Tribe, in the wedding night and near sunset, the bride rides a white camel and is taken near the Hamoon River. Here, the men are separated from women; men start playing the music and the bride who is called Shider, goes under the water and then she wears the wedding clothes. The party continues late at midnight and while dancing, people come back to their village.

In some parts of Iran, to make the dried Ghanats full of water, people sacrifice sheep while in other parts, when the wells are dried, cows and sheep are sacrificed to bring the water back to them. But in most parts, when a well is dug and its water flows, people sacrifice sheep or cows. In Shahdad, during drought, 12 Muslims go to mosque and each reads the following verse of Shora sura for 1000 times: He is the God who brings rain after disappointment of people and enhances his blessings; he is the God who is kind and beloved. In villages of Kashan, people kill sheep and pour its blood into the Ghanat. When the water of Ghanats is lowered, they believe that the demon of Ghanat is sleeping into the Ghanat and wants to marry a woman. Therefore, they choose an old widow and donate her to him and she should swim in this Ghanat every several days and people give her some money in return.

CONCLUSION:

Ghanat or sewer is one of the Iranian's innovations to irrigate and overcome the lack of water; it is considered the main vital factor of development of these areas. It is extended to almost all parts of Iran and if there weren't any Ghanats in these parts, no development would be appeared.

Ghanat is the main resource of water supply for main cities of Iran like Hamadan, Takht-E-Jamshid, Sirjan, Neishabour. Kerman, Tabas, Gonabad, Fasa, Jahrom, Shiraz, Qom, Tabriz and other cities. If the Ghanat systems weren't invented, most thriving cities and communities near Iran, Arabic and African deserts wouldn't exist.

Therefore, Ghanat should be studied and examined considering social, cultural and economical reasons and their distribution worldwide is of great importance so that in America especially in Los Angles, water has been supplied by Ghanat. We should be agree with Abobakr Karaji; he believes that there is no useful profession but extraction of hidden water because the land can be improved, people can improve their lives and can gain more benefits using this profession.

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WATER DIVISION AND TRADITIONAL IRRIGATION IN PERSIAN FOLKLORE

Mostafa Khalatbari Limaki

ABSTRACT

Farmers did water division basically when it was aridity and drought. However in dry and desert lands water division has always been done. Aridity or shortage of water which results water division caused a sort of solidarity, cooperation and unity in order to share water justly for agricultural uses. Water division is a traditional method which was institutionalized in all parts of Iran and everybody obey this method. If this method was not established or obeyed, the result of dispute would be nothing but the waste of main part of the crops. Aridity and the need of farms to more and more water some times caused conflicts and disputes among farmers. Such difficulties usually start from the mid-summer. But generally speaking all farmers respects the conventional, traditional and local method of water division and does according to that.

Water resources either for agricultural uses or for domestic uses provides from different sources. Some of these channels established through difficult processes. But nowadays tap water resolved domestic needs of water. But agricultural needs of water still supplies through local resources. Although nowadays by adaptation of some policies like making dams we try to store water, but in some parts of Iran especially central region, people still use duct and well water and naturally traditional formulas of water and irrigation is run there. At the following, we take a glance over methods of traditional water division and irrigation in different parts of the country.

INTRODUCTION

Iran has an old history of water and irrigation. The first written notice about irrigative arable history corresponds to the time of preliminary myths of Iran. According to most genuine Iranian histories, in the first Islamic centuries (Tabari History, Tha'alabi History, Shahnameh Ferdowsi, Zeinol Akhbar Gordizi, etc.) Hoshang learnt a method of irrigation, aquaculture, wheat cultivation and harvest of wheat for bread to people. In this way the first written and documentary notice of the history of Iranian irrigation goes to Iran's ancient history which is about five thousand years ago.[1] Although gradually a lot of conventional-traditional-local laws have been emerged, developed and

1-Safinejad, Javad, The History of water and irrigation in Iran, collection of articles in Water and irrigation congress of Iran, Shiraz, 1998, page 1.

established in dry and arid areas, but usually there were a lot of strifes on this issue which result local and regional bloody tussles. For example at the beginning of third hegira century, the state of Khorasan - which the most west and south part of it was dry deserts - come into this conclusion to establish laws on this issue. Historical resources related hereupon:

"In 224 hegira, people of Nayshabour and Khorasan asked Abdollah Ebn Taher[1] about disputes over aqueducts, but there were nothing about aqueducts and its commandments in holy religious books and anecdotes of the Profit (God bless him and his posterities). Therefore Abdolla gathered all sernior relious people of Khorasan and some others in Iraq to make a book about aqueducts under the name of 'Ketab-e-Ghana' (Book of Ducts) in order to be the reference for laws and act. That book remained up to now (first half of 5th century) and laws of ducts are still extracted out of it."[2] Thus we are aware of the about time of documented history of water, irrigation and aqueduct in Iran. But some technologies like methods of digging and its techniques were published, generalized, reached beyond frontiers, developed and astonished the people and some other techniques buried in a way that after centuries, there is no precise knowledge about them.

METHODS OF WATER DIVISION AND TRADITIONAL IRRIGATION IN DIFFERENT PARTS OF IRAN

In past at the villages of Abadeh Fars, because clock system was not popularized, people used an instrument which was called 'tašte'. It was a small copper bowl which at the bottom there was a very small hole and people used to put it on the big pan-like vessel, full of water. Water little by little filled the bowl at it sank when it was completely filled. They did it for nine times and it was equal to one hour water. Of course the size of 'tašte' was different and sometime it took twelve times to make one hour water. Every nine or twelve times was called 'habbe'. Water division was administrated by people who was named as 'mirâb'. 'mirâb' was a person who necessarily owned water and land or his job was farming. 'mirâb' did his job in this way: before sun rise, 'mirâb' stood in a high place and observe the full sun, he started water division. Local people called this moment 'âb bandân'. From this moment on, those people whose name was on the list of the day received water and 'mirâb' controlled the process on a way that all people on the list receive their water share. During the irrigation time, 'mirâb' controlled the 'tašte' process and the owner of the farm took care of the irrigation of his farm. 'mirâb' put 'tašte' over a pan full of water. Exactly when 'tašte' is filled by water, he made it empty and put it on the water once again and by doing this, they threw a stone on a big bowl at his side and in this way they took care of the number of 'tašte's. In order to prevent any possibility of dam in the hole of 'tašte', they cleaned and varnished it by a thin stick and this work was called 'kolang zadan'. If a person had an ante, then they didn't use 'tašte' process and instead they gave water to

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2-As cited explicitly by resources, he paid a lot of attention to agriculture, digging aqueduct, refinement of irrigation and water division.

3-Gardizi, Abdollhay, Zein ol Akhbar History, Abdolhay Habibi revision, Tehran: Iran Cultural Foundation, 1968, page 137.

him from one 'âb bandan' to another. Water provided through ducts for farming. 'kadkan' was the name of people who did dredge the ducts.[1]

Farmers in Eghlid Fars did use the 'tašte' system as well. But the interesting notion about their water division was borrowing. In another word, they asked 'mirâb' to borrow water to them for example for two more hours and on the next time when their turn rotates, they returned whatever they borrowed. Although they soldered around the hole of 'tašte' in order to prevent any sort of cheating.[2]

In Ardehal (in Kashan province) people used an instrument under the name of 'aftâb nešân' for timing in water division. It was a stone which set beneath the mosque of the community. Before noon, they pace the distance between the shadow of the wall and the stone by two soles and called it Pay. Each Pay was about 10 minutes. When the sun stood exactly over 'aftâb nešân', it was considered as half an hour. But afternoon timing has different process. The receiver of the water back to the sun, took his hat and stood barefoot. He did point the shadow of his head and pace the distance by sole again, but this time each 'pay' considered about 30 minutes. Later, a copper vessel with a hole in it popularized which was called 'sarje'. There were 5 scales from the bottom of the 'sarje' to the lip of it. Each scale was equal to 2 minutes and in this way the whole time dedicated to each 'sarje' was equal to 20 minutes. The hole of 'sarje' has contrived in a way that it filled in 10 minutes. People used to put it on a container of very clean water which its capacity was about 4 or 5 litters. They also put some gravel beside it. For example if a farmer asked about 10 'sarje', they put 'sarje' over the water and exactly when it had been filled by water, they made it empty and put it over the water again and by putting a gravel from one side to another, they took care about the number of 'sarje'. Each 24 hours irrigation was called 'tâq' and water division was done by 'sar tâq'. Each 'tâq' had been divided to six 'dang'. 'sar tâq' who got more water was named as 'qolom âb' and the one who got less water was named as 'khord âb' and the one whose name was in the end of the list was entitled as 'bon âb'. Formerly, water division was done in the house of 'sar tâq' and he took his division of water by 'sarje' and then he let others to take their shares[3]. This method was used in Joshghan, Azaran, Rahaq, Marq and Aran in

1- Jokar, Mohammad Sadegh, Fars, Abadeh, 1983.
2- Saber, Ali Jan, quoting from Mohammad Hosein Sabet eghlidi, eghlid, 1997.
3- Majedi, Seyyed Khodabakhsh, Isfahan, Kashan, 1971.

the province of Kashan. In Shahr Reza, the responsibility of this job was on a person who was called “Datšban”. He sat on a place under the name of 'qerešgâh'. 'qerešgâh' is a small room in the middle of desert which “Datšban” used to sit their and take care of the timing of water division. 'sar tâq' was a person who Landlords and crofters knew and did not doubt his honesty[1]. In Natanz people used to use Pang and bowl and the person who was responsible to do the job was called 'pang andaz'.

At the village of Chalgar Givi in the province of Ardebil, people in the second month of spring which is irrigation season, dredged the watercourses and then they gathered in a sage man of the village and shared water to the end of farming year by drawing or 'pušk \tm\q'. In this method each farmer assigned himself a 'pušk'. 'pušk' was something like matchstick, gravel, pea etc. which farmers put in a hat. A man will take out the first 'pušk' and the owner of that 'pušk' would be the first person on the list of water receivers. Each 'dang' had two round-the-clock times and in each 'dang' of farming land shared between 3 persons. And these 3 persons shared the time (two days and two nights) in this way: From the night to the next day noon is for the first person, and from another night to another next day noon the second person. The third person used two remained afternoons. After each two days of irrigation, they changed their turns with each other. They did exactly according to this method and there had not been any problem among them. A first person who irrigated was called 'sar ow'. They measured water in watercourse by 'bil' (shovel). And one 'bil' of water was a quantity of water which could turn the millstone of a water mill. In past, when there had been no clock, people used to use sunshine for timing. In front of mosque there was a place called 'qojânešin'. When sunshine rays had reached there, it meant that it is noon. In each turn of irrigation, two or three persons did irrigate their farms.[2]

Farmers of Marand in Azarbayjan Gharbi, as far as they can afford, partook in one of the ducts or motor pumps or bought others share of water in order to provide their need of water. This system was called 'su nobati' which means the turn of water. Water turn was assigned every 10 or usually 15 days. For irrigation, farmer may accept its responsibility himself or take it to the 'su či' who was a professional irrigator. 'su ci' knew all major and minor water canals of neighborhoods and gardens and also he knew how to bring water to gardens and farms professionally and completely. In order to be fair, farmers receive water once daytime and next turn nighttime, because usually irrigation is somehow difficult at night and farmers preferred to receive water during the day. The furniture of 'su či' contained: shovel, Wellington boot and lamp (for nighttime irrigation). He would discuss about his pay before irrigation and usually the owner of the farm borrowed him Wellington boot and lamp, but shovel is a most important tool of him and he must had it himself. The farmer must take care about his meal, but his tea must be prepared by himself. (The contract between irrigator and farm owner is so considerable). If the place of irrigation was garden, it was called as 'baq su vârmâ' and its water was called 'bâq suee'.

In order to facilitate irritation, farmers usually divided land into rectangle terraces or 'Kardi' with different and desirable width and length and make canals between 'kardis'. The irrigation was also called 'zemi su vârmâ'. The irrigation of farm is so similar to the irrigation of garden. The only difference is that at first divide fram (zemi) to two or

2- Tabibian, Seyyed Abdol Rasoul, Isfahan, Shahr-e Reza, 1972.

3- Razzaghi Chalgar, Motalleb, Ardebil, Chalgar, 1990.

three parts and separate each part with 50 cm walls which is called 'mârâ'. Because of the slant of the land they make a canal from the beginning to the ending. At the beginning of the irrigation, 'su či' gathers water in the canal and then just like the irrigation of the garden, he irrigate farm once from beginning to ending and then from ending to beginning.[1]

At the village of 'Momen Abad' in Birjand each farmer took a specific gravel in his hand and each person knew his gravel and that gravel showed finally when would be the day of irrigation. Some one drew 13 lines at ground. Then one of the farmers had quarreled with the others and left them. When that one left the group, they rest of them would show gravels to each other and ask one of them to disarrange gravels and then they asked the one who left them to come back and in order to reconcile they let him to arrange gravels on 13 lines. That guy accept the suggestion smilingly. Then he would put all gravels on lines and the one whose gravel was on the first line, assigned as the first person to use water and the next one was the one whose gravel was on the second line and so on. This process was called 'Ran Kardan'. 'Ran' is the flowing of water. After assigning all turns, each person knew the person before his turn 'Pi[Ran' and the person after him 'Pas Ran'. Each 'Ran' is equal to 13 days of irrigation. Some time different length of days and nights make troubles and also in some cases quarrels happens about 'Tâqehâ' (12 hours water) and 'Nimruzehâ' (6 hours water). Farmers took water to the next one at evening or near nightfall. 'Nimruzehâ' which had the right to use water for half a day, find their turns using cube. The vessel of cube which used for 'Tâs Davâni' had a tight hole at the bottom and around that was solidified by cast iron in order to prevent any sort of cheating.[2]

At the villages near to Mashad, duct water uses for farms. Each share of this duct in this area is called cup (in Persian it is called Fenjan). The circuit of water is 12 there. 'fenjan' (cup in English) which local people call it 'fenju' is a small vessel with a small hole at the bottom of it. They put it on a big vessel full of water which is called 'tas' and it begins to be filled by water. 'fenju' would be filled in 3.5 minutes and each and every 'fenju' full of water is one share. Of course nowadays nobody uses 'fenju' and instead of it, clock is popularized. Every 18 'fenju' is about one hour. In this way when someone has 18 'fenju', he has the right to have one hour water form 12 hours water. Because some villages of Ferdows is located at the border of desert, each share of a 'fenju' deals about 500 Tomans. Therewith, the share of water sometimes is mentioned in women's 'mehriye' (high-priced gift that men must give to women at the time of marriage) and whoever has more shares of water could marry better woman! Formerly there were a few water mill in the watercourses of ducts which are dissolved today. The water of ducts passes different villages and a person who is called 'juyvo' take care of aqueducts in order to prevent any sort of damage and wasting of water. The division of water is something like this: these 12 nights are assigned to 12 farmers who have more right that other. For example one of these nights belongs to renowned Malek Khan who was apparently the king of Ferdows and Tabas. He took a night of the 12 nights and assigned it to himself. Because he had no children, he endowed it to charities. The rest of each “Tâqe” or 24 hours is called 'čekana'. At the time of water division, everybody knows that each partner has how many shares and each person took water as much as he has cup (fenjan) or he uses clock. When his time is over, he would shout and inform other

1-Fazlzadeh, bijan, Azarbayjan Sharghi, Marand, 1978.
2-Saeidi, Ali, Khorasan, Mo'men Abad Birjand, 1971.

partners and his copartner will start irrigation of his own land. They shout 'hoy hoy hoy' in order to inform each other. This is the way which is conventional among the farmers of this region. Each 12 hours water is named one 'Tâqe'.[1] In Farrokh Shahr which is located in Chahar Mahal Va Bakhtiyari province, in order to prevent any trouble in getting water, they divide their farms into seven 'dang' (antes), which each 'dang' is called as a 'nim fard' (half man). In this way each 'dang' is consist of 32 half man. Each 7 'dang' is equal to 28 'nim jub' which is calculated by 14. In other word, every 14 days is equal to 28 days. Once the 14 days, the turn of water shifts between day and night for this 28 'nim jub'. Thereof some crops need water every week, those 'nim jub' which are opposes to each other borrow their turn to each other. All agricultural tasks are done by 8 people, because every 'nim jub' is equal to 8 'nim fard'. Each person is responsible for each 'nim fard' which take water, cultivate and harvest with each other and finally they share the production among each and every person of these 8 people. Each 'nim jub' has its head. The heads of all 'nim jub' choose a president for themselves as the 'dang'. In this way, all these 7 'dâng's have 7 presidents who counsel and arbitrate about cultivating matters like dredging ducts, etc. The method to share water is in this way: from nightfall to dawn is the night turn and from the dawn to the next nightfall is the day turn.[2]

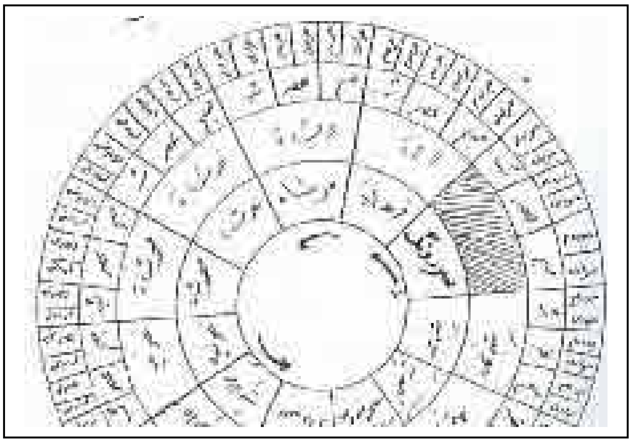
Provincially speaking, in Farnagh which is located at Khomein, farming land divides into 100 pairs of 'gâvbandi'. Nowadays it is called 800 shares. These 100 shares of 'gâvbandi' or 800 shares divide between farmers equally and in different pieces. Provincial term of the people of this region about land division are; 'dâng', 'joft', 'lang', 'pa' and 'fard'. The sources of water in Farnagh are: river, duct and aqueduct, fountain and well. There uses terminologies like 'dan' and 'tâq' as well. Water division - as it was done in past and it is done today- is accomplished by calculation of shadow to 'lang', shadow to 'regâl' and shadow to 'badreie'. 'sang' is another term which is used by the people of this region. 'sang' (stone) is an amount of water which can turn a millstone. Half of this amount is called 'kart' and half of 'kart' refers at 'kiz'. These measurements have been used in Farnagh. Water division in the culture of different khan's of Farnagh is in this way:

The culture of Ghasemabadi khan, so called as 36 pairs or 60 pairs 'gâvbandi': rotation of water division turn was every 8 days in past, but nowadays it is every 10 days. The culture of other khans of Farnagh in Khomein; each is consist of 16 or 18 pairs of 'gâvbandi' and the rotation of water division turn is 9 days which local people call it as 'garde[9'. The water provides through the river and this is the culture of up village and down village. There are some bars on the river in order to prevent any damages of torrents in the farms. The rotation of water in the other cultures of khans in Farnagh, is every 9 days (24 hours) and it is done by appointing a determined time.[3]

In Alvir which is located at Saveh, the base of water division is on the condition of each farm. For example, water division in Ghasbeh farm was done in past in this way: the irrigation was through a string of ducts and it was divided to 126 'šir'. Each day was covered through every 6 'šir's; 4 '[ir's in day and 2 'šir's in night. Obviously if we divide 126 'šir's into 6, we will find out that the rotation of water turn of the farm would be

1-Mirbron, Amir, Khorasan, Mashhad, Ferdows, 1971.
2-Hatefi, Syyed Hasan, Chaharmahal va Bakhtiyari, Farokh Shahr.
3-Ghasemi, Rajab, Hamedan, Malayer, Azna, 1953.

every 21 days. As it is shown in the following table, after the winter, the beginning of irrigation is started by 'sar dâng' and the second turn belongs to Farhad and … . In regional turn of speech 'šir' means 'ju' and in this table each 'dâng' (24 hours) divide into 3 parts: morning, evening and night. Each of these parts is divided into two parts themselves: First 'šir' and second 'šir'. (we write them 'ju aval' and 'ju dovom' as local people call it) As it is shown, the latest circle (which 'ju aval' and 'ju dovom' are mentioned in it) concerns the first encircled circle which 'sar dang' is in it and totally there are 66 'šir's. If we add 60 'šir's of second circle which the place of 'sar dang' is edged to this then 126 'šir's will be completed. If this divides to 6 'šir's the rotaion of turn in every 21 days will be clarified. Once again you can find all 21 'dâng's in order here:



1.Sar dang – 2.Farhad – 3.Arab Shah – 4.Khoram Shah – 5.Mahmood Shah – 6.Khooniye – 7.Jamaleddineh(Jamaleddin) – 8.Allah Dad - 9.Khaje Mohammad – 10.Mohammadiyeh – 11.Khooniye – 12.Farhad – 13.Arab Shah – 14.Mahmood Shah – 15.Mahmood Shah – 16.Khooniye – 17.Jamaleddineh – 18.Allah Dad – 19.Khajeh Mohammad – 20.Mohammadiyeh – 21.Khoniye.

It must be mentioned that it is probable that in the first Mahmood Shah, there might be only one 'šir' and after 21 days his turn arrive. As Moamerin Alvir narrates: apparently the owner of the village at the beginning was a man with 8 sons: Farhad, Arab Shah, Khorram Shah, Jamaleddin, Allah Dad, Khajeh Mohammad and Mohammad. He shared his land between his sons and assigned each irrigation day to one of his sons. Increasing of the number of population forced them to add more 8 'dâng's (shares) to this number but they kept the last names. Some of the owners were the owner of first 8 'dâng's (shares) and the other owned the second 8 'dâng's. Then something unpleasant happened and caused a lot of disputes and tribal conflicts and the people of village decided to pay a man from another place to handle the issue. That man add 4 more 'dâng's instead of his pay and named them as 'khoniye'. In this way by adding the 'sar dâng' we would have 21 'dâng's (shares). It must be mentioned that 'šir' was not the smalls unit for water division. There had been 'nim ju' or half of 'šir' and a quarter of 'šir'. By the beginning of irrigation in order to determine who must receive water at morning, afternoon and night, the representatives of each 'dang' used to draw lot (pešk). Then those representatives draw another lot with their own water share holders in order to figure out who must receive first 'šir' (first ju) and who must receive the second 'šir'. When a person receives water at morning, the next time he would receive water at afternoon and the third time at night. It is a custom to prevent any inequality in the water division might causes between morning, afternoon and night.

People of Azna in Malayer, usually at the middle of the second month of spring which they called it at 'nime sabz bahareh', went to the mad of watercourse in their neighborhood and in a special ceremony opened it. In past people believed that that mad was blessed and if someone swims at it at that day, he would not get any disease during the rest of the year. The water of this river comes from two springs from 'koh sarde' mountains; 'âb morvâri' spring and 'pilasangina' spring. The water of 'âb morvâri' spring was considered digestive and the water the other one was believed difficult to digest. At the top of the river there is a mad which stores the water and is in the form of pool and farmers swim in that. But in the season of farming, they open it for irrigation. Some of the farmers in the day of opening come to watch the incident and count their beads. At the time of opening, farmers sacrifice 4 sheep and divide it among poor people and believed that doing this would increase the level of water. By opening the dam, water will flow in ditches towards farm lands.[1]

Water supply through duct in the city of Hosein Abad in Malyaer. When the level of water decreases, farmers believe that water has quarreled and broke with them, so they come together and collect money to buy a white female sheep. Then they adorn it. A red '[adde'[2] is tied around its neck and a small mirror place on his forehead. They take it to the duct while playing music and keep it there for a while and rejoice there. And then they turn it around the duct 3 times and at least they sacrifice it and divide his meat among poor people. They believe that by doing this they will reconcile with the water and the level of water will be increased.[3]

At the village of Zabol, the water of farming provides through Hirmand river and by small and big watercourses joining to each other it reaches to the farm lands. Each village or region has a person who is responsible for water division and they call it 'mirâv'. He informs the farmers time of dredging. Farmers according to their shares send a man for help. 'mirâv' does not participate in dredging himself (as a farmer) and he only supervises the others. During dredging, a person cry out a religious sentence and ask people to cry out 'yâ ali' (ask help from Ali, the first Imam of Shiite) and he do it by a few changes for 3 times. After a while some one else will ask people to say some religious sentences like the previous one. There is a proverb among the people of this village which means: if you want to increase your crop, you must start irrigation at this time. By making dam, they store water and then by drawing lots or sharing which they call it 'meruzbandi' divide water between themselves. The method of water division is in this way: each person who has a share of land (4 acres of land) get a 'mah' which is 12 hours water at day or night.[4] At Khanchareh in Talegan each farming land divides into 4 parts and each part is called 'zivâr'. The water of this region supplies through river or spring. At the beginning of the second month of spring, from each farm a person participate in dredging. After dredging, 8 representatives of 'zivâr's draw lots 'pešk' to

1-Ghasemi, Rajab, Hamedan, Malayer, Azna, 1974.
2-Sadde: festoon of flower or leaf
3-Abdoli, Morad, Hamedan, Malayer, Hosein Abad Nazem, 1972
4-Mokhtari, Mohammad Reza, Sistan va Balouchestan, Zabol, 1972.

find out who is the first one for irrigation. Each 'zivâr' send a man early at morning to watch out about water and take care about water turn as well as waste of water. Other farmers take care of the irrigation of the farm of that man who is caring about the mentioned issue. Sometimes 'zivâr' lands are link to each other like chain and by irrigation of this land, about 20 other lands would receive water. The all water of a land is called 'vargah'.[1]

At the village of Ardakan in Yazd, the standard in water division was in two forms: 1. By means of 'sabu tašte' 2. by means of sign and the line of the pool. Sign was a thin stick beside the pool. It was at the sizes of 'hasht yek' (equal to 1 hour water), 'shanzdah yek' (is equal to 3.5 hours water) and 'se shanzdah yek'. In the division form of 'sabu tašte', 'tašte' (bowl) sank every 12 minutes into the water. Each 5 'tašte' took 1 hour. In this way, water division is based on the times that 'tašte' sank. In 'meybod' people used 2 'tašt' for water division. The big vessel contained 20 liters of water and the small vessel contained 2 liters of water. At the bottom of the small 'tašte' (which was divided to 6 equal parts and each part was called 'dung') there was small whole. When it filled they put a chip in order to keep the numbers. Sometimes some people cheated in this way: he force the 'tašte' to sink in the water. In order to prevent it, some of the farmers sat beside 'mirâb' and 'daštbân' during water division. The place of water division was called 'keštmân'.[2]

At the beginning of Farvardin (First month of spring) at the village of Lorneshin which is located at Gachsaran, different communities hold a session and discuss about the method of water division and dredging. For example, at the village of 'kete' which has 104 shares of water, each farmer participates in the dredging according to number of his shares. They use a dried reed with the length of 3 to 4 meters as the measuring unit. In the process of measuring the size of land, the length of all lands are the same, and for each share of water they separate about 4 reeds (16 meters) from the width of lands and ask the owner to collect stones, prickle, sticks, etc. The distance between wellspring and farm lands is about 2 km. Dredging of ditches in this collaborative way takes about 10 days. Then the owners of neighbor lands make a 'bonak' which consist of 15 shares of water. In this way at last 7 'bonak' will shake form from all rice paddies. After this, they divide the watercourse to 7 branches and each branch enters a 'bonak'. A representative will be chosen for each 'bonak' to take care about irrigation and promise him to give the man 7.25 for each share of water. Because of the shortage of water sources, some times water thievery happens. Some farmers when 'âbyâr' is at home, go to the farm lands and increase the amount of their own 'bonak'. The next morning, when '\by\r' and other farmers go to the land, and find out about it, sometimes struggles happen, but at last by the intercede of patriarch, the thieve will be charged and everything would end.[3]

At Shahrdad which is located at Kerman province and rather big, there has been an interesting method for water division. It is because of smallholders who are a half of population of the region. The water source is a spring comes from mountains near Kerman. The water unit in Shardad in called 'borq', a traditional name which uses nowadays. If all the water of river divides to 210 in a day, then each part would be a 'borq'. Sometimes one 'borq' divides into half 'borq' and a quarter of 'borq'. They usually

1- Ne'mati, Daniyal, Tehran, Taleghan, 1971.
2- Mosavi, Saeid, Yazd, Ardakan, 1968.
3- Azargon, Qazanfar, Kohkiloye va Boyr Ahmad, 1983.

rent a 'borq' for a year. A 'demn' is equal to 13 days. As the length of night and day are different in the different months of year, in order to prevent any inequality, when a person get his share of water during the day, he will receive his share of water at night and vice versa. For 3 first day of each 'demn' they choose 3 specific names: first day is called 'nexest, second 'bet' and third 'set'. For the other days there is no specific days and call it five, six, seven and so on. Each day or night in irrigation is called 'tâq' and each 'demn' consist of 26 'tâq's.[1]

At the village of Galo which is located at the periphery of Ramiyan Gonbad, in order to share water in the cotton farms, farmers gather in a place like mosque and draw lots among themselves for each duct. For example when a person has two acres of land would have only one drawing cart and a person who got 20 acres of land he would have 10 cards in lottery. Lottery card is a card at the size of 25 cm. Each person writes his name on a card. If the lottery is about 100 acres land, there must be 50 cards (the number of owners is not important and the size of land is the matter of concern). Each piece of paper which a name of man is written on it would be folded and all folded papers will be put in vessel. Then they ask an immature child to take folded papers one by one to a man. That man will unfold the papers and write down the name of people in order. For each lot, there are two days, for example if a person has two lots, would irrigate his lands for four days. Usually irrigation takes from morning to evening. Those who have plenty time of irrigation (for example 10 days and he need only 8 days) would give their extra time to another person as borrowing. It is also possible to change the turn of irrigation by the bilateral consent and no one could interfere in their turn of times.

For the irrigation of rice fields, at the villages of Tonekabon, at first a person is nominated as 'mirâb'. He is chosen for 3 years. In past his paid by people, but nowadays Irrigation Office is responsible for his charges. 'mirâb' has a blank check for his decisions about water division. He has a representative in each 5 or 6 villages which is called 'âbsuvâr'. 'âbsuvâr' must be a good native farmer which others could trust him. At the top of rivers which provides water of villages, there are a lot of big watercourses which 'âbsuvâr' must take care of them and lead their water towards farmlands. He is responsible for all farms and must provide water for all of them. He receives his wages from people or 'mirâb'. 'mirâb' and 'âbsuvâr' receive his wages 6 months a year, spring and summer which are the seasons of rice farming. In summer which the quantity of water reduces in the rivers, 'mirâb' asks 'âbsuvâr' to chose a person in every place which is named as 'âbdâr'. When 'âbsuvâr' takes water from the top of river to the village, 'âbdâr' must lead it to the farms and irrigates it. 'âbdâr' is responsible for small watercourses. In this way, the owner of land could not interfere or two farmers takes others water division. Farmers obey the orders of 'âbsuvâr' in order to prevent lawlessness. The wages of 'âbdâr' is paid by farmers itself which is usually rice or cash money in this way: for each acre of land he receives 3 bowls of grains (each bowl is about 2.5 kilo) or he receives cash money equal to this amount of grains. If they want to pay money, they pay it in cash, but if they want pay it by grains, then 'âbdâr' must wait to fall which is the harvest season. Some of the farmers take the responsibility of irrigation of their lands to 'âbdâr' and rusticate. To the middle of summer (15 Mordad) lands need regular irrigation, but after that because of bunches, there is no need to

1- Khoda Zadeh,mohammad dad, Kerman, Shahdad, 1971.

water. (Grains must become firm in order to be prepared for wind and rain). After 10 to 15 days, they start to irrigate fields again for a few days and in the first days of the last month of summer (Shahrivar) the bunches of rice turn to yellow and ripen.[1]

At Khoy, in Azarbayjan Gharbi, farmers of a region after the 10th of Farvardin (first month of spring) gather at the house of a farmer and choose a trustful man to be the supervisor of the irrigation process. He is called 'juvân'. 'Juvân' in each region enlist the names of farmers in his note book and assigns each day of irrigation to two farmers. When everybody in list received his share of water, he starts again from the top of the list and this system goes on to the end of irrigation. Each farmer gives money to 'juvân'. At khoy, no one irrigates land at night. If the behavior of 'juvân' of a region be considered nice, people will choose him once again for the next year; otherwise, they will choose another person. Each year all watercourses would be dredged. There are three methods of irrigation at Khoy: 1. local irrigation, 2. terrace (kardi) irrigation, 3. leaky irrigation. Local irrigation is uses for tree, especially trees without fruit. In this method all around the tree will be dug 10 to 15 cm and 1 meter diameter and lead the stream of watercourse to that. This method of irrigation is also called 'taštaki'. This method is also uses for new planted trees. Terrace (kardi or karti) irrigation mostly uses for vegetable, beet and other summer planting. Leaky irrigation is suitable for trees. In this method level of water is different from the wide arms 25 to 35 cm. In other words, ditches are deep and when water enters, it takes time to fill it and when it fills, extra water will go to the other ditch through main watercourse.[2]

In Garmsar which is located in Semnan province, the turn of sharing water was based on 'bone'. Each 'bone' was consist of 5 people which were partners at farming and one 'sar bone' (head of 'bone') supervised them. Each 'bone' divided their lands to three part: one part for cotton, the other part for wheat and the third part was dedicated to crop rotation. Each 'bone' have 24 hours water share and sometimes this time divided to smaller parts which was called 'tâq'. 'tâq' like other parts of the country was 12 hours and people used sun for timing; from rise of the sun to nightfall considered one 'tâq' and the other part took as the other 'tâq'. 'nim tâq' (half 'tâq') was called quarter (the time between sun rise to noon and from the noon to night fall, etc). In order to prevent any sort of inequality, they place a piece of wood in the watercourse, if the level of water exceed a specific sign at the wood or fell from determined sign, farmers would figure it out and this method was called 'd\q zadan' and that piece of wood was named as 'čub dâq'. Water sharing was on and on all the time of year, but the day of 'ashora'(the day of execution of grandson of prophet Mohammad and his followers at Karbala desert)which water was named 'qorabâ' and in this day every could use water out of order. They believe that at the day of 'ashora' every thing a person does is unlawfulness, even the result of farming with such water was unlawful.[3]

At Ahrom in Tangestan Boshehr, people used 'kil'(bowl)to share water. They used a big pot and a bowl. The bowl was just like our ordinary bowl and the only difference was a small hole at the bottom of it. At the beginning they filled the pot with water at the land they went to irrigate, and then some trusted people sat around the pot, and after that one

1-Nikdoust, Mohammad Ali, Mazandaran, Tonekabon, 1969, As far as I know (author) this method of irrigation is still popular at the villages of Tonekabon.
2-Kazem Zadeh, Jafar, Azarbayjan Gharbi, Khoy, 1970.
3- Anonymous, Semnan, Garmsar, Bita

of them put the bowl on the pot. Little by little the bowl filled with the water and when it filled completely, it sank and hit the bottom of the pot and made a sound which was the standard for counting. A person, emptied the bowl and put it once again on the water of the pot and this process went on. The man tied a rope whenever the bowl hit the bottom of the pot, in order to remember the numbers. It took 30 minutes each 3 times that the bowl hit the bottom of the pot. The number of bowls was assigned considering the size of land or the number of date trees.[1]

TRADITIONAL IRRIGATION TERMS AND SOME DISTINCTIVE SAMPLES

1. Senfi: 'moqanni', 'mirâb', 'âbyâr', 'moqanni baši', 'kayâl', 'bâ bân', 'âb savâr','âb šenâs', 'daštbân' and so on.

   'mirâb'= supervisor and overseer in water division. A person who is responsible for water division for customers and he takes water to homes, gardens, farms etc.[2]

   How many times you notice windlass, take a look at the 'mirâb'(mulavi Romi)

   Whether or not, the 'mirâb' of this ocean would cut my chest like a shell and give me a drop of water (Kalim Kashani)

2. Traditional irrigation: like aqueduct, duct, dredging, mill water etc.

   Kâriz (aqueduct): kâriz or kahriz, etymologically is a Pahlavi word which in Manavi period it was called 'qyriz' meant 'duct' or 'âb ru'. In Kurdish it is called 'gâriz' and in Arak (Soltan Abad) it is called 'kâriz'.[3]

3. Water constructions like: bars, bridges, cisterns, ducts, watermills, 'âb dang's etc.

   Watermill: a mill uses water as the source of energy. It also calls 'âb âsiâ' or 'âs âb'. 'Tâhun' or 'tâhune' which is Arabic word uses in some cities and villages of Khorasan, Kerman and Isfahan. The pillar of every mill is a wooden wheel which turns by the power of water. Watermill (čarxâb) which is also called 'por' is connected to the upper stone of mill and turns it. It has a cylinder axis which from one ending there is metallic point from another one, there is a metal bar indented through it and some spokes encircled it. This watermill is place vertically and horizontally against watercourse. Horizontal watermill has horizontal axis spokes are placed and fixed horizontally in the sluts of it. This is set under the stones of the mill. From one end it sets in the whole of the bottom of water and from another one it comes cross from the under stone[4] of the mill and fix to the upper stone. Vertical watermill which has vertical axis usually sets beside mills stones. From one end it fixes to the whole of the wall and from the other end it connects to horizontal axis beneath the stones of mill by a wooden gearwheel. From the past up to now there have been 3 different kinds of watermills in Iran; 'tanorei' or 'pari' mills, 'nâvi' or 'nâvdâne' mills and 'čarxi' or 'šibi' mills.[5]

1- Dehdari, Behzad, Boushehr, Ahrom Tangestan, 1973.
2- Moein Dictionary, forth volume, page 4489.
3- The same, page 282.
4- This proverb is perhaps comes from the under stone of mill which tolerate massive pressure: 'man must be under stone of mill when he faces difficulties of life'.
5- A group of writers, Islamic Encyclopedia, First volume, page 373.

ÂB DANG

'âb dang'[1] is another traditional tool which somehow related to water and uses mostly by the people of north. They use it to beat 'šaltuk' and turn it to rice.

4. **Tools and equipments of traditional irrigation:** like shovel, 'pang', water clock, bowl, sprinkler, 'dalv', 'kaval', etc.

   'kaval': ceramic ring which is placed in watercourse of duct in order to prevent duct leaking.[2] 'nây' and 'nâysâr' is a big wide ceramic pipe which people uses in Kerman province.[3] In duct terminology, 'kaval' is a kind of elliptical conduit which its wide and height is big enough for a crouched man. In past they had been make from ceramic (baked clay) but nowadays they made from cement and sandy and there is no need to furnace. Such 'kaval's are made and used mostly near the duct itself. Before 'kaval' people had used bricks to made ducts and recently (might be less than a century) 'kaval' replaced it. At first it made from ceramic material and then people used cement and sandy instead. Using 'kaval' is more economic that bricks, and because of it nowadays neither for building nor for repairing no one uses bricks. The size of templates of 'kaval' are mostly as big as the opening of duct. They put it in places they think might collapse. It covers ceiling, walls and the bottom of duct and the duct man could do whatever he wants (dredging) in it. In order to fix 'kaval's firmly in there places, duct men usually put broken 'kaval's in the empty spaces of 'kaval's. 'kaval' or bricks prevent ducts to collapse, especially during water flows. There have been a lot of cases in which the walls of well had been collapsed and became useless. But because of 'kaval's in ducts, water flow would not be stopped and at any case ducts would be active.[4]

1- This tool used to use in Tonekabon villages. (Author)
2- Moein Dictionary, third volume, page 313.
3- Dehkhoda Dictionary, at the bottom of the reference 'kaval'.
4-Kardavani, Parviz, 'Sources and matters of water in Iran', first volume, Tehran: 1984, page 18-316

OTHER TRADITIONAL IRRIGATIVE TERMS IN PERSIAN FOLKLORE

'habbe': Every 32.5 acre land is called 'habbe' and the owner of the land is 'sarhabbe'.

'dâng': Every 12 'habbe' is called 'dang'.

'âb mâl': This is the name of man who care about bars and edgings and unstopping watercourses. (Esfarjan, Isfahan)

'tâq': a period of 24 hours.

'gholom âb': is a person who get water more that others during 24 hours.

'âb čâq':full water'

'vâl': bar(“band or sad”)

'ziqâv': a little water flows from beneath 'vâl'

'lang kamar': a person who bars water without reason and open it.

'maste âb': water which flow slowly

'donb âv': the rest of water which is barred (Ardehal, Kashan)

'vâr': a piece of land which opened for water entrance

'arx': watercourse

'komoš': duct man

'vargah': where two watercourses meets each other (Joshaghan, Kashan)

'xorâz': the end of water supply to a place

'âbaxš': where there is a dock with several entrances for water division (Bazak, Kashan)

'berja': a big stone, shaved from 4 dimensions. It is set against the water in order to divide it.

'tâq': every 12 hours water is called 'tâq' (Ravan, Kashan)

'rašn': water division

'rašnnume': a piece of paper which the name of people who share water are written in it. (Dastgerd, Golpaygan)

'dombili': the first part of water uses in farming

'ziqâve': little water leaks from places near rivers or watercourses

'owyâr': irrigator

'pâtâq': a person who supply water for his farm in 12 hours

'mazqal': a hole in the corner of dam in order to release water

'pang': a tool for timing of irrigation

'pangandâz': a person who cares about the timing of farm irrigation

'owsâli': 'âbsâli'

'hogsâli': drought

'hanjidan': irrigation

'hilijen': a channel for water under the wall (Natanz, Isfahan) 'abvâbjame': the owner of 'nim tâgh', a person who have a piece of paper and in it there is the right of 17.5 'habbe' water for the other owners and name of them are written in that piece of paper. (Zefreh, mountainside of Isfahan)

'aj' or a⦿: minor strand of duct which meets the major strand of it

'bonkom' the last well of the duct of village. It is also called 'mâdar čâh'

'harim': a region around a duct that others can not dig another duct there

'kharsang': a big piece of stone in the way of duct that must be turn it or break it

'dul' or 'dalv': a leather or plastic vessel uses for carrying water, soil or sand with

'dul gir': a labor who receive 'dalv' full of mud form the bottom of well, empty it and send it back to the bottom of well

'sâvord': a liming surface which usually covers the entrance of ducst

'šulât': unstable or sandy courses of water in ducts which its ceilings or walls collapse and stop the duct

'tuqe': the inside wall of well which covers with brick or sand

'komeš': a person whose job is well digging or dredging, duct man

'komiši': an amount of money which shares between shareholders of duct for dredging and other necessary thing

'gamane': an exploratory well which is dug in order to make sure about the existence of water in a place

'hamâbe': cleaning, sweeping and dredging of duct and the main course of water by a work group of farmers

'boniče': 15 minutes water (Ardestan, Isfahan)

'suči': irrigator

'suquyusi': well of water

'čaylâx': river

'kank\n': well digger

'bâhâlx suye': 'âb gardâni'

'suvârmâx': irrigation (Azarbayjan Sharghi)

'juvân': a supervisor who is chosen for water division (Joyban)

'pandâm': a bar which stop water flow (Khoy, Azarbayjan Gharbi)

'âvsuvâr': 'âb savâr' or 'a person who is responsible to share water

'xalvečin': a person who sweep dirt for the opening of watercourse

'bageh: place where water enters farm

'jub sâlâr': a person who is responsible for the water of each watercourse (Gilan) 'âbdâr': a person who is responsible for the water of several farms (Tonekabon, Mazandarn)

'maqsem': a place where water shares

'terong': where water falls from top to bottom

'katkonj': where water enters garden

'kehkin': duct man

'âster': a bar usually makes from leafage. It is placed against water which reduce the speed of water

'kiš': a very deep watercourse, between duct and ordinary watercourse

'petâr': dust and brushwood which accumulate at the entrance of watercourse

'juq': watercourse (Kerman)

'owdun': 'abdân', basin, wetland

'qeram qeram': continuous sound of water

'owdâr': 'âb dâr', a person who takes care of a land by shovel

'bil dâri': irrigation

'lise': a little water which flows at the bottom of ditch

'owxorân': a measurement gardeners uses during the water timing

'owkluq': the first irrigation of the farm

'peykluq: second irrigation of the farm (Kazeron, Fars)

'bârgâ': a place that water of one watercourse bars to another watercourse

'qombu': the holes of the watercourse which fills with mud

'katkan': duct man (Abadeh, Fars)

'afta xor': a part of duct that human and animals could use easily

'rovanj': a part of duct that in open but human and animals could not use

'pošte': digging between to wells under the ground, considering the level of water (Ghazvin)

'pâkâr': 'dasht ban'

'jurubi': dredging (Malayer, Hamedan)

'sang' (stone): enough water which could turn a stone of mill

'dang', 'tâq', 'sang', 'kart' and 'giz': units uses in Farnagh (Khomein) to share water

'shah joy': general share of water for each farm

'varjuy': minor watercourses which are the branches of the major watercourse

'piluvon': a bar which is made to reduce the speed of water

'valgu': where water stops or flows to farming lands

'sarow': water comes from first and before main water

'tahow': water comes from after the stopping of main water. 'donbale ab' 'xâkow': first irrigation of wheat and cotton

'šakarow': second irrigation of wheat

'zarow': third irrigation of wheat (Garmsar, Semnan)

'dingel': the last 'dâng' in irrigation

'sâlâr': first 'dang'

'dâng': 24 hours irrigation (Zanjan)

'pengü': a vessel which measure the timing of irrigation (Pang)

'pengükaš': a person who uses 'pengu' to measure timing of irrigation

'gilun': the drift of water to farm

'turona': a hole in the way of watercourse

'naqm': passage way from a well to another

'moalef': 'mirâb'

'juvu': guardian of water (Khorasan)

The first irrigation in the farming of wheat and grain is called 'khak ab', the second one 'šokr âb' and the last one 'marg âb' (Shahriyar, Tehran)

'dalm': bucket, well (pail)

'owyâr': irrigator

'kumi': two people who cooperate in the digging of a duct (Borojerd, Lorestan)

'bolgi': place where the water of rivers shares between villages

'čâšt': share of each farmer from water. Each 'cast' has 3 hours irrigation (Meshkin Shahr, Ardebil)

'raqm': a square block which specific signs are on the walls of it. It is placed in the water of spring in order to measure the quantity of water

'qafiz': a unit for water measurement which is equal to 0.1 of 'sang âb'

'madar čah': the first well of each duct. The depth of it does not exceed 20 or 30 meters

'pošte': the upper passageway of duct

'serx': a pool made to store water in the time of water over flow

'pâtâq': holes made for foot during the lifting and climbing in the wells

'mošref': a person who is responsible for water sharing (Sadogh and Bafgh, Yazd)

'kil o piyâle': a tool to measure the timing of irrigation

'banogah': water storage, where water is stored

'čahâv': water well

'nâydun': gutter (Boushehr)

CONCLUSION

A cultivator at the edge of the desert, shoveling the farmland, appreciates the value of water so much, inasmuch as he jeopardizes his life for it. In Iranian culture and folkloric materials like proverbs, tales and stories this respectful point of view to water can be easily traced. The existence of a precise method of traditional irrigation which intermingled with the culture and life of people is itself a reason for the importance of water and its rule in people's life. As this material and the method of irrigation and water division made rules and laws which are indivisible form the culture and life system of those who are engaged with it. The farmer who labors in a rental land, the landlord who in addition to his garden and farm benefits from the share of his water, the craftsman who need to buy water for his cistern, the woman who take water from her family cistern for daily life, all need to obey some specific rules. And because of the antiquity and inveteracy are intermingled with the culture and tradition of the people. Through the evolution and transformation of human life, sometimes we lost our connection with values and in some cases we lost them completely, and all these have its ill-impact on the methods of traditional irrigation and it made sometimes disputes, but all those who are involved in farming are still dealt with these methods directly. Because all these rules and bylaws of water division are not developed causeless, so going over these different methods of irrigation in different regions of Iran make us familiar to the life and culture of the people from different parts of the country and tell us the vital value of water in the life of Iranians.

ANCIENT RAINFALL HARVESTING AND STORAGE SYSTEM IN KISH ISLAND PERSIAN GULF, IRAN

Shahab Daneshvar[1] and Farshid Morshedi[2]

ABSTRACT

Our intelligent ancestors have tried to convey fresh water from mountain downhill areas into desert lands through a system they themselves had invented: QANAT. One of the interesting qanat systems is located in Kish Island in Persian Gulf. This qanat system has drawn attention since 1992. Surveys show that the system dates back more than 2000 years ago. The system and its associated underground city is one of the worth-seeing places of Kish Island. There are several qanats in the island. Numerous wells have been installed along the qanats paths, mainly used for recharging and dredging purposes. The wells are spaced about 15 meters from each other. Qanat top consists of coral formations with 2 to 15 meter thick. Qanat bed comprised of impervious marl stones. This combination cause the percolated rainwater through the coral layer is stored over the impervious marl layer developing shallow groundwater aquifers. Overall function of the Kish qanat system is rainwater harvesting and collecting, underground storage of water, conveyance and distribution of the stored water. This paper intends to introduce this amazing unique qanat system and its functions and performance.

INTRODUCTION

In the ancient periods, when our ancestors understood the value of water for agriculture, they recognized the importance of water control and storage. Actually, the controlled water we have nowadays in our dams reservoirs and the measures undertaken to exploit and recharge the groundwater resources is the pure fruit of an attempt began on those era. In this regard, the Iranian nation has contributed a lot to this issue. One may recognize the Iranian approach, methodology, level of knowledge and experience towards qanat installation upon observing these historical workman pieces. Investigations show many similarities between modern and ancient hydraulic systems. Scrutinizing these valuable historical heritages would help us to resolve the complicated problems we encounter nowadays in water resources issue.

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Iranian people whose lands are located in an arid and semi-arid climate have prevailed on climatological constraints by incorporating several different techniques originated from their inherent intelligence. Construction of different structures for water control, storage and conveyance such as dams, barrages, water stores (ab-anbar) and Qanats reveals their wise attention for optimum water resources exploitation. Most of these structures and systems are considered among successful architectural structures drawing applause and wonder of those who carefully observe them. In this regard, qanat systems that were usually exercised in arid areas around desert lands to exploit groundwater resources are considered as one of the oldest groundwater conveyance systems. This article intends to introduce one of these remarkable qanat systems located in Kish Island, Persian Gulf, Iran.

HISTORICAL BACKGROUND AND LOCATION

Kish qanat system is one the most ancient hydraulic systems in Iran being still operated in some parts. Based on conducted scientific investigations, this system is one of the historical proofs of comprehensive understanding of its designers and constructors regarding meteorology, hydrology, climatology, geology, structural materials and groundwater hydraulic behaviors.

Kish qanat system is located in Kish Island in Persian Gulf, south of Iran. The system had been installed to optimally store rainwater in underlaying geological layers to supply drinking and agricultural water demands. In far past, the system also supplied water to sailing ships and inhabitants of neighboring islands and cities. There were totally 5 qanat systems located in north, west and south parts of the island. Nowadays, there are traces of only 4 of them. Time of construction of these systems is not known specifically. However, the Dahou qanat system, which is one the main qanats still being operational and located in northeast of the island, dates back to 300-500 years before Christmas with an age about 2300-2500 years. Location of Kish Island and its qanats is shown in figure 1.

Figure 1 - Location of Kish Island and its Qanats

CLIMATOLOGY OF KISH ISLAND

Kish Island is one Persian Gulf Islands located 50 km in south west of Lengeh Port in Hormozgan Province. The island has an elliptical shape with 15 km length in east-west direction and 5 km width in north-south direction. Area of the island is a bit more than 90 km^2 with its highest point at +45 m above sea level. Having a dry climate, the island mean annual rainfall is about 183 mm. Recorded rainfall statistics show irregular and severe variations in rainfall distribution over the island. In this regard, more than half of annual rainfall occurs in just three days in most years. Considering monthly distribution of rainfall reveals that there is about 66 percent of annual rainfall in winter (indicating Mediterranean system domination), 29 percent in autumn, 3 percent in spring and only 2 percent in summer. Amounts of maximum daily rainfall based on Gambel probability distribution are presented in the following table:

Maximum Daily Rainfall Based on Gambel Probability Distribution

Return Period (Year)	2	5	10	20	50	100
Max. Daily Rainfall (mm)	49.97	58.58	109.5	132.2	161.5	179.9

Average annual temperature in the island is about 26.7 ^{o}C with 6 months having an average temperature above 30 ^{o}C. Also, the monthly mean temperature is never below 18 ^{o}C. Reviewing the temperature records of the island shows that the island does not have a four-season climate. In other words, the island only has one hot season (from April to September) and one cool season (from October to March). The notable fact regarding temperature variations in the island is its fluctuation being occurred all above zero ^{o}C. Relative humidity is more than 70 percent in 11 months while only in November it is between 50 to 70 percents. However, the island suffers sultry only during 6 months with southern parts being more humid than the northern part.

TOPOGRAPHY AND GEOLOGY OF KISH ISLAND

Kish Island is one of the Zagross foot stretched folds with low amplitude. The island, contradictory to other Persian Gulf islands which are originated from Camberian mass grouts, is originated from Zagross orogenic activities. From a geomorphological point of view, the island is a plain and even island with a few scattered features having a maximum elevation at +45 m above sea level. Topography map of the island is shown in figure 2.

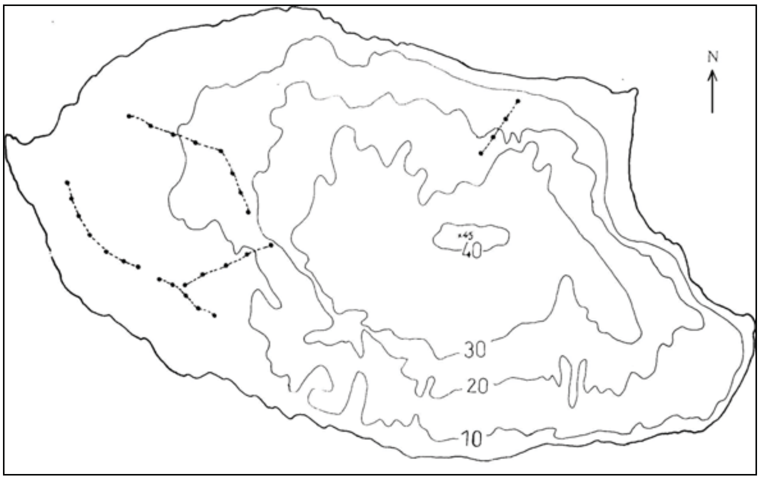

Figure 2 - Topography of Kish Island

Surface of the island is covered with fresh sediments due to repeated advance and recession of water over the island. The majority of island surface area is covered by loose and firm coral limestones (about 91 percent). Some very small areas are covered by clayey soils and wind and coastal sands. Loose coral limestone covers about 72.6 km^2, 80.7 percent, of the island surface. Permeability of these materials is about 10^{-3} cm/s. The high permeability of these materials together with gentle slope of the island are the two dominant factors regarding rainfall absorption.

The Kish Island body is comprised of alternate coral and lime stones with an impermeable marl layer being in between. Permeability of the marl stone is about 10^{-7} cm/s. In fact, these coral and lime stones are good reservoirs to store rainfalls fresh waters. Thickness of upper permeable layer is decreased from the island centre to coastal areas. This results in reduction of potential volume of water storage and groundwaters become shallow. Investigations show that moisture regime of island soils is Aridic border to Ustic. Therefore, soils are dry during more than 9.5 months and they are semi-dried or moist only in the left 2.5 months. Temperature regime of island soils is Hyperthermic indicating a mean annual temperature above 22 ^{o}C.

PHYSIOGRAPHY, HYDROLOGY AND HYDROGEOLOGY OF KISH ISLAND

The Kish Island surface is comprised of 11 subbasins. Three subbasins covering one third of the island area lack any water courses. Therefore, one can conclude that only the rainfall over remaining 57.7 km^2 of the island is runoff producing. According to conducted investigations, average runoff coefficient of the island is about 17 percent. Accordingly, considering the infiltration potential of the upper surface layer of the island, more than 80 percent of precipitated rainfall in infiltrated into the surface layers of the island. In other words, there is a potential of 16 Mm^3 of infiltration into the island upper layers. There are also 6 groundwater basins in the island. Watersheds and groundwater basins of the island are shown in figure 3.

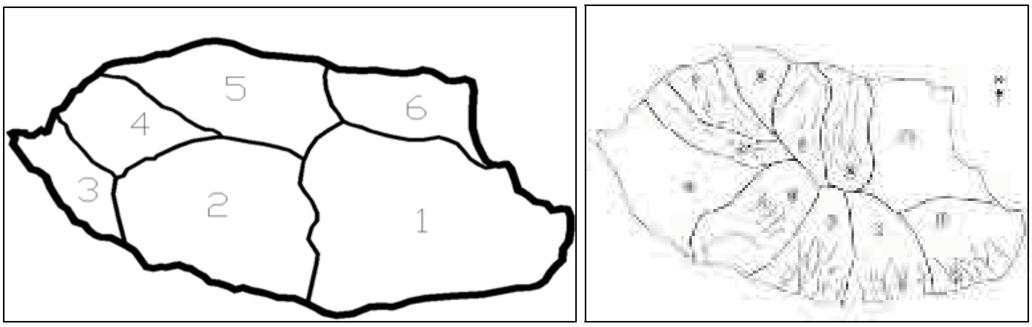

Figure 3: Watersheds (right) and Groundwater Basins (left) in Kish Island

Investigations of marl layer topography throughout the island show different groundwater storage potentials due to unevenness and slope the layers. In this regard, groundwater subbasins 1 and 2 receive the largest amount of infiltrated water with more than 60 percent. Subbasins 5 and 6 in northern part of the island have no groundwater aquifer. Finally, subbasins 3 and 4 in west part of the island store groundwater in the depressions existing on the marl layers.

SYSTEM OF QANAT IN KISH ISLAND

Kish Island inhabitants have tried to make maximum use of scarce water resources in any practical form. To make use of surface water resources several techniques have been incorporated including construction of Ab-Anbars (water stores), and dams and exploitation of springs. To do so, 6 ab-anbars, 5 dams and 3 springs have been applied. The outstanding feature regarding the dams is their dual purpose function. The dams, rather to controlling and storing the surface runoff to prevent them from evacuating to the sea, were used to facilitate recharge of groundwaters. Groundwater resources were exploited through digging of wells and construction of qanats.

The remarkable and think-worthy issue regarding the Kish Qanat system is its functioning mechanism. Typical qanats have been usually constructed to exploit the existing groundwater aquifers of the area. In all known qanats systems scattered throughout Iran, the main function is transferring water from upstream groundwater aquifers (wet part) to downstream areas (dry part). The conventional qanat galleries are run through permeable layers to be recharged by aquifers. Qanat wells have a dual purpose function including qanat gallery 1) maintenance and dredging, and 2) system ventilation. Kish qanat systems have been installed in places where no groundwater aquifer exists. Thereto, qanat gallery is not recharged from its surrounding since it is running through the impermeable marl layer. Longitudinal profiles of typical and Kish qanat systems are shown in figure 4.

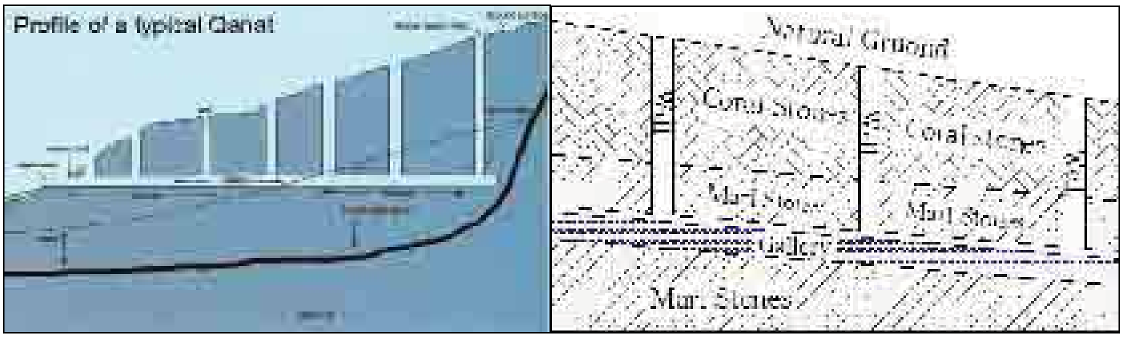

Figure 4: Longitudinal Profiles of Typical (left) and Kish (right) Qanat Systems

The Kish qanat system has been innovated by the island inhabitants to store the rainfall infiltrated fresh water since reliable surface and groundwater resources were not possible in the island due to its climatological and geological characteristics. The qanat gallery runs through an impermeable marl layer at a depth of about 4m. The marl layer lies underneath a permeable 2-10 m thick coral limestone layer. The qanat gallery receives rainfall water directly from the wells installed on it. It also receives the infiltrated rainfall into the coral limestone layer through its wells. The wells are located about 15 m apart. The gallery bed slope is very gentle considering looseness and vulnerability of the marl layer. Passage of qanat gallery through the impermeable marl layer prevents water losses through capillary rise and evaporation due to high temperature. Investigations show that there are about 9400 km galleries in four existing qanat strings with 611 wells in the island.

Water withdrawal had been performed through two methods. In the first method, similar to typical qanat operations, water was withdrawn from qanat wells or its outlet. However, the Kish inhabitants innovated another method to withdraw qanat water. They managed to dig special passages directing to marl layer depression where water had been stored along the qanat gallery. A typical profile of such passages and an 800-year old existing passage are shown in figure 5.

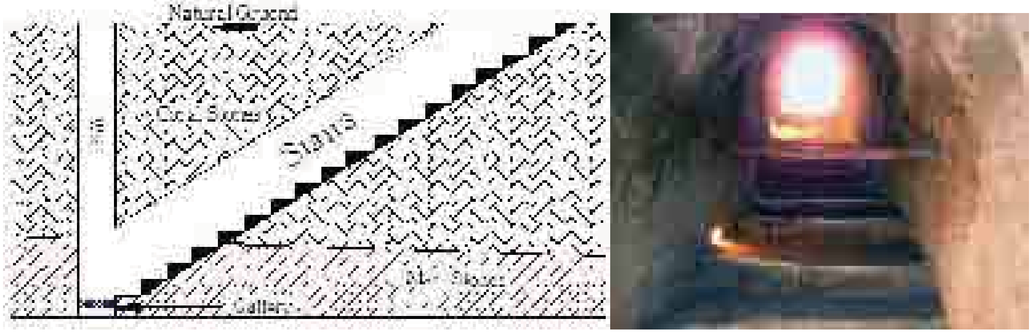

Figure 5: Typical Profile of an Access Path (left) and an 800-year old Access Path (right)

Unfortunately, due to obsolescence of the Kish Island form 2nd century the qanats were ill-considered or disconsidered thereafter. Hence, they were not properly maintained and as a result wells were filled up by debris and galleries were damaged. Interviews with some of old native inhabitants of the island indicate that they do lack a specific methodology to operate and maintain the qanat systems. However, considering the very long age of these qanats, their state of being so scattered, and their locations at upstream of most of agricultural and residential zones of the island one may highly recognize their importance and unique role and also their superiority on typical wells regarding the Kish island unique characteristics.

CONCLUSION

With no doubt, technology development in the ancient civilizations was an answer to mankind needs for optimum exploitation of natural resources, safety towards natural hazards and improvement of individual and social life standards. Man intention to control the environment and exploit its natural resources has resulted in opportunities and challenges leading to increase of his understanding of natural resources and materials and construction of structures. The Kish Island Qanat System is a significant proof to this claim. The 2300-2500-year old Kish Qanat System takes us into deep thinking since rainfall harvesting and groundwater recharging have just been taken into consideration in the past recent decades. Let's hope that specialists and engineers take proper lessons for correct management of natural resources and environment upon observing and studying such cultural heritages of the world along endeavoring to protect them.

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LAND AND WATER MANAGEMENT PARADIGMS IN IRAN: TECHNICAL, SOCIAL AND ETHICAL ASPECTS

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ABSTRACT

With respect to land and water management in Iran, three paradigms can be distinguished. The pre-modern paradigm can be characterised by its key technical system (the ‘qanat’ underground irrigation system), its main social institution (the ‘buneh’ cooperative organisation of agricultural production), and its ethical framework (Zoroastrianism and Islam). The paradigm of industrial modernity can be identified by the partial replacement of ‘qanats’ by dams, the substitution of the ‘buneh’ by a system of smallholding, and the emergence of a mechanistic worldview. Since the 1970s, industrial modernity has gradually given way to what has come to be known as ‘reflexive modernity’. In Iran, the new paradigm is still in its first stage, and must be conceptualised and developed in terms of new technical systems of land and water management, of corresponding social institutions and of a new ethical framework that is sensitive to the specific features of the region.

Kewords: land degradation, water scarcity, pre-modernity (tradition), industrial modernity, reflexive modernity

1. INTRODUCTION

The main challenge confronting Iran is to continue the expansion of food production to meet future demand without imposing negative effects on the environment. Since the country has a long history of agriculture, its habitants have already occupied almost all the fertile land. In the more recent past, however, there has been a slight increase in the total area under cultivation. This was achieved by bringing under cultivation the barren lands that have only a marginal agricultural potential. A comparison of the 1973 and the 1998 agricultural census show that in a quarter of a century only 483,000 ha (2.8%) of

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new land areas were brought under cultivation. On the other hand, the negative water balance implies (1) that no more new land can be brought under cultivation, and (2) that the country is already facing a critical situation regarding the management of water resources and sustainable food production in existing cultivated lands (Moameni, 2000). This means more pressure on the resources. The question is if and how we can stop this process. In order to answer this question, use will be made of the three paradigms with respect to land and water resource management identified by Allan (2006), the pre-modern paradigm, the industrial modern paradigm, and the reflexive modern paradigm. The aim of this paper is to study the technical systems, social institutions, and ethical frameworks of these paradigms, in order to get some theoretical and practical grip on the conditions for a successful transition from industrial modernity to reflexive modernity in Iran.

2. PRE-MODERN PARADAIGM (2500 BC-1960)

The pre-modern land and water management paradigm in the pre-capitalist Iran can be distinguished by its main social institution ('*buneh*'), its key technical system ('*qanat*') and its ethical framework (Zoroastrianism and Islam).

2.1 THE MAIN SOCIAL INSTITUTION: BUNEH

The pattern of landownership and the relation between peasant and landowner that played an essential role in the process of agricultural production in Iran were to a large extent determined by the circumstance that approximately 90% of Iran is arid and semi-arid. The annual evaporation loss is high, ranging from about 700 mm to over 4,000 mm, amounting to 16 times the annual average rainfall of 250 mm (Moameni, 2000).

The general pattern of land ownership in Iran prior to the land reform of 1962 was a combination of large-scale feudal landownership with small-scale absentee and peasant proprietorship (Lahsaeizadeh, 1993). Because of the importance of artificial irrigation to Iranian agriculture, sharecropping (*muzara-eh)* was dominant among the different types of relation between the peasant and landowner. In the arid and semi-arid areas of the country, a cooperative form of organization of agricultural production, *buneh*, prevailed. The major function of the *buneh* until the land reform of 1962 was the efficient exploitation of productive land and the careful use of scarce water resources. It was a complex system of the interrelated activities of crop farming, animal husbandry and handicraft production (Farshad and Zink, 1997). Although *buneh* had some disadvantages (e.g., an internal unequal division of labour and crop), it strengthened the socio-economic position of the peasants (Lahsaeizadeh, 1993).

2.2. THE MAIN TECHNICAL SYSTEM: QANAT

More than 3000 years ago, the inhabitants of the dry, mountainous regions of Iran perfected a system for conducting snowmelt through underground channels, the so-called '*Qanat*', which began in the mountains and carried water downwards to the plains by gravity, to farms, country gardens and towns (Foltz, 2002). About 73.5% of *Qanats* were located in the eastern half of the country; whereas the western part was mostly dependent on rivers and rainfall (Lahsaeizadeh, 1993). The *Qanat* irrigation system rests on indigenous knowledge and experimental hydrology. Moreover, *Qanats* reflect collective and cooperative work, and, in areas where *Qanats* are constructed, labour or work opportunities are provided for the local community. *Qanat* systems are closely linked to the local community and its ability in planning and management of their own water resources, especially for agriculture. The management system is such that the water is distributed equitably. As a result, water security supply and water access equity are supporting the foundations of the local community (Haeri, 2006). It has been claimed that before the land reform, the life of about 70% of Iranian villages was totally or partly dependent on the *Qanat* system (Lahsaeizadeh, 1993).

Because individual peasants possessed neither the capital nor the manpower that was needed for construction and maintenance of the Qanat system, independent production was at a disadvantage compared to other systems of production such as the *buneh* or the multi family collective.

2.3. THE ETHICAL FRAMEWORK: ZOROASTRIANISM & ISLAM

From an ethical point of view, Iranian civilization recognized both the ecological realities of the plateau's desert climate and the social imperative of conserving and distributing water in a way that ensures its availability to all. This ethical system is rooted in the two religious value systems, namely Zoroastrianism and Islam. Since the Islam has entered into Iran, these two belief systems have co-evolved to a large degree and are profoundly interconnected. The *qanat* system, for example, which originated long before the Islamic period, was incorporated into the developing Islamic legal code (Foltz, 2002).

Zoroastrianism, the dominant religion in the pre-Islamic era, rests on three pillars: *Humata* (Good Thoughts), *Hûkhta* (Good Words) and *Hvarshta* (Good Deeds). By "Good Thoughts", a Zoroastrian is able to concentrate his mind in divine contemplation of the Creator, and live in peace and harmony with his fellow man. By "Good Words," he is obliged to observe honesty and integrity in all commercial transactions, to prevent hurting the feelings of others, and to engender feelings of love and charity. By "Good Deeds," he is directed to relieve the poor, to irrigate and cultivate the soil, to provide food and fresh water in places where needed, and to devote the surplus of his wealth in charity to the well-being and prosperity of his fellow man. Nature is central to the practice of Zoroastrianism and many important Zoroastrian annual festivals are in celebration of nature: New Year on the first day of spring, the water festival in summer, the autumn festival at the end of the season, and the mid-winter fire festival (Jafarey, 2005).

Like Zoroastrianism, Islam also offers a basis for ecological understanding and stewardship (Foltz, 2002). According to the *Qur'an*, the universe and everything in it has been created by God and is considered a sign (*āyāt)* of God. Human beings, although at the top of creation, are only members of the community of nature. Humankind is considered as a trustee for the planet: humans are entitled to live on the earth and benefit from it but they are not entitled to pollute or destroy the environment. Any behaviour that can jeopardize the future of the natural resources is seen as an act against God and its creation (Abdel Haleem, 1989).

Nature has been created in order and balance, and with extraordinary aesthetic beauty, and all these aspects of nature, while enhancing humankind's life should be honoured, developed and protected accordingly. All patterns of human production and consumption should be based on an overall order and balance of nature. The rights of humankind are not absolute and unlimited: we cannot simply consume and pollute nature as we wish, carelessly (Özdemir, 2003).

Water like all other natural resources is considered as a gift by God. Mohammad attached great importance to the moderate use of water and forbade the excessive use of it even when performing ablutions, saying that to do so was "detestable" (*makrūh*). He even prevented people from using too much water for ablutions when preparing to enter the Divine Presence for prayer.

It should be obvious by now that the social, technical and ethical aspects of the pre-modern paradigm were highly interconnected and compatible to one another in many respects. The key technical system ('*qanat*') of the pre-modern paradigm was dependent on its main social institution ('*buneh*') to operate properly, while Zoroastrianism and Islam, the two belief systems that co-evolved in Iran during the past fourteen centuries, can be considered as an adequate ethical framework for both these technical and social aspects of the pre-modern paradigm.

3. INDUSTRIAL MODERNITY PARADIGM (APP. 1960-APP. 1980)

Industrial modernity in Iran can be characterized by the substitution of the *buneh* by a system of smallholding, the partial replacement of *qanats* by dams and the emergence of a mechanistic world-view with important ethical ramifications. These changes have been brought about as a result of the adoption of development models imported from the West (Foltz, 2002).

After the land reform of 1962, the major pre-capitalist collective organization of production (*buneh*) was eradicated and sharecropping (*muzara-eh)* gave way to individualism. Moreover, the indigenous knowledge acquired through *buneh* systems was neither used by nor transferred to the new generation. Although it was believed by the land reform officials that rural cooperative societies[1] could replace the *buneh* system and would fill the gap that would result from its destruction, no village-level institution has ever taken over its function (Lahsaeizadeh, 1993). These traditional systems are increasingly being abandoned in favour of such 'modern' practices as the damming of rivers and the pumping of groundwater. As in the United States, it was assumed that Iran's arid regions could only be industrialized by making the necessary water resources available through building dams[2], pumping up groundwater and bringing in water from remote sources (Foltz, 2002).

1- Recent studies show that the modern Agricultural Production Cooperatives (APCs) were unsuccessful in achieving land consolidation and group work, which were the main reasons for their establishment (Karami and Rezaei-Moghaddam, 2005).

2- Despite the incompatibility of damming with the ecological condition of Iran, the storage of water, the control of floods through the routing of excess water, the production of electricity and the preparation of water for irrigating new arable land are the arguments used to support the continuation of dam building (FAO, 2005)

As a result, the role of Qanats in securing all the functions of water in the country has decreased from 70 percent prior to the year 1950, to 50 percent around 1950 and to 10 percent in the year 2000 (Haeri, 2006). Likewise, control of the water resources has been transferred from pious endowments to government bodies.

The value system of industrial modernity is also at work in contemporary Iranian agriculture. Industrial agriculture rests upon a conception of nature based on the mechanicist world-view that has increasingly defined modern Western science since the Renaissance. According to the mechanicist view, natural systems are believed to be understandable, predictable and manipulatable.

The mechanicist view of nature promulgates a specific economic model of human-nature interactions: the farmer is to produce as much food as possible, and neither the producer nor the consumer should make value judgements about the non-economic worth of the land. Modern agriculture has become highly industrialized in order to reliably produce the largest amount of plant and animal product possible while minimizing labour inputs. Under the industrial production paradigm, the prime objective is to improve the productivity of a select set of plants and animals. At the heart of the production paradigm is the realization of the greatest possible quantity of agricultural product. Agricultural systems based on the production paradigm do not recognize ecologically important values that are hard to quantify. Although the structure, functioning and values of natural systems could provide important clues as regards developing sustainable agricultural systems, little effort is devoted to investigating them (Keller et al., 2002).

Thus, the design of agricultural systems is based on commodity production and its attendant economics, while the importance of modelling farming systems after natural systems, based on ecological principles, is widely overlooked.

4. REFLEXIVE MODERNITY PARADIGM (1980-)

The ideas underpinning industrial modernity were challenged during the 1960s and the 1970s. The disastrous effects of industrial modernity have begun to appear in Iran as in the US, Israel, India and elsewhere. Over the past four decades, Iranian farmers and others close to the land have watched water table drop as one well after another dries up and formerly fertile lands are forcibly taken out of production (Foltz, 2002). As a response to these challenges a new paradigm emerged, the paradigm of 'reflexive modernity' (Allan, 2006). This reflexive phase can be shown to have three sub-phases. In the first sub-phase, awareness of the environmental costs emerged. In the second sub-phase, there was growing attention to the economic value of ecosystem services, such as water resources. In the third sub-phase, these environmental and economic aspects were completed and combined with socio-political aspects. This is the case in integrated water resource management (IWRM), as well as in integrated pest management (IPM), integrated crop management (ICM), and integrated soil fertility management (ISFM).

The third sub-phase is leading to approaches that include participation, consultation and inclusive political institutions to enable the mediation of the conflicting interests of water users and the agencies that manage water. Moreover, Allan (2006) emphasizes that water users could adopt IWRM if the innovation of 'integration' would be appreciated as a political process and not just as a technical investment or information sharing process. Therefore, this paradigm requires a new holistic approach and an unprecedented level of political cooperation.

Allan believes that the semi-arid North can be shown to have partially adopted all three reflexive management paradigms. In the South, by contrast, the professional community generally, and all water users and politicians have resisted the adoption of these reflexive paradigms. Allan concludes that, with some exceptions at the local level where small communities manage their water via transparent institutions that have been tested over time, the South is still very much involved in its 'hydraulic mission' that is characteristic of the industrial modernity paradigm. Socio-economic development priorities are considered more urgent than environmental priorities.

However, in Iran there are also signs and indicators of a turn to reflexive modernity, for example the change in water pricing and delivery methods, the announcement of a national strategic plan by the government (which is considering a land-use planning strategy based on integrated ecological and socio-economic issues rather than solely socio-economic ones), and the promotion of NGOs and community participation in the 1990s. This movement is continuing in the first decade of 21 century. For example, since 2002, Iran has joint the international Challenge Program on Water and Food (CPWF) with a project in Karkheh river basin.[1] Other clear signs of a reflexive turn are the emergence of the Iranian association for the ethics of science and technology in 2003 and of the International Center on Qanats and Hydraulic Structure (ICQHS) that has been founded in 2005 in collaboration with UNESCO.

5. TRANSITION TO REFLEXIVE MODERNITY PARADIGM IN IRAN

However, in Iran the new reflexive paradigm is in the first phase and should be conceptualized and developed in terms of new technical, social and ethical systems that are sensitive to the economical, environmental and political features of the region. To this end, the traditional paradigm needs to be revitalized and integrated with the industrial paradigm, in such a way that the benefits and advantages of both will be maintained as much as possible. We will sketch the contours of the new ethical framework, the institutional and technological requirements, and the scientific approach that are required for the transition to the reflexive modernity paradigm.

5.1. THE NEW ETHICAL FRAMEWORK

First, this transition requires a holistic, inclusive and participatory approach to rethink agricultural practice within a post-mechanistic (rather than a mechanistic) framework that will provide the basis for the development, maintenance and improvement of sustainable agro-ecosystems. With respect to a post-mechanistic ethics, it is contended that the methods used to mechanistically dissect agriculture and its components need to be revised and that the non-mechanistic aspects of agricultural systems (i.e. ecological and qualitative values) need to be considered when constructing sustainable systems.

1- CPWF is an international, multi-institutional research initiative with a strong emphasis on north-south and south-south partnerships. Its 5 themes are: 1) Increasing crop water productivity, 2) multiple users of uppers catchments, 3) aquatic ecosystems and fisheries, 4) integrated basin water management systems, and 5) the global and national food and water systems.

Therefore, in order to develop an ethical framework that can accommodate the passage from industrial modernity to reflexive modernity, different philosophical sources should be explored, particularly Iranian pre-Islamic and Islamic ethics. Because of its inclusiveness and community-based character, another source of moral inspiration is the 'land ethics' of Aldo Leopold. Its goal is to strengthen the ties between humans and between the human community and the larger ecological community. According to Leopold's land ethics, land is not merely soil: it is a fountain of energy flowing through a circuit of soils, plants and animals. He therefore concludes that the land ethic simply enlarges the boundaries of the community to include soils, waters, plants and animals, or collectively: the land.

The next philosophy that should be taken into account for developing an ethical framework of reflexive land and water management is *pragmatism,* in part because it is better equipped to deal with technology than current ethics (Keulartz et al., 2004). The core moral intuitions of pragmatism revolve around the possibilities for living and working together. Because of its attention to the settlement of conflicts for the sake of further cooperation, pragmatism has always been interested as much in the *process* of moral inquiry as in its ready-made *products.* To promote the fairness and quality of the process of inquiry and deliberation, it is essential that all those concerned in the issues of land degradation and water scarcity can have their say and that decisions are made on the basis of a careful consideration of all relevant conflicting moral claims and arguments. A second shift to which the standard of fruitful cooperation and peaceful cohabitation gives rise is a shift in emphasis from the context of *justification* to the context of *discovery*, from the cognitive capacity for argumentative problem-solving to the creative capacity for the innovation and invention of vocabularies that provide new meanings and open new perspectives. A pragmatist ethics should pay special attention to the exploration of future worlds disclosed and shaped by technology and the management of deep value conflicts inherent to a pluralist society.

5.2. INSTITUTIONAL AND TECHNICAL REQUIREMENTS

The high variability of ecological processes and their interactions with heterogeneous social, cultural, political and economic factors generate local systems that are unique in countries like Iran with its dominant small farming systems. Altieri (2002) believes the only way that the specificity of these local systems, from regions to watersheds, and all the way down to a farmer's field, can be taken into account is through site-specific natural resource management, based on agroecology, which incorporates elements of both traditional knowledge and modern agricultural science. Agroecology provides the basic ecological principles for the design and management of agroecosystems that are both productive and natural resource conserving, and that are also culturally sensitive, socially just and economically viable (FAO, 1993).

Altieri (2002) mentions that since the early 1980s, hundreds of agroecologically based projects have been promoted by NGOs throughout the developing world. There is a variety of projects that feature resource-conserving yet highly productive systems such as polycultures, agroforestry, and the integration of crops and livestock. Moreover, the analysis of dozens of NGO-led agroecological projects shows that agroecological systems are not limited to producing low outputs, as some critics have asserted.[1]

However, despite increasing evidence and awareness of the advantages of agroecology, it has not spread worldwide. According to Altieri (2002), a key obstacle to the use of agroecology is the demand for specificity in its application. Contrary to conventional systems that feature homogeneous technological packages designed for ease of adoption and that lead to agroecosystem simplification, agroecological systems require principles to be applied creatively within each particular agroecosystem. Field practitioners must have more diversified information on ecology and on agricultural and social sciences in general. Thus, major changes must be made in policies, institutions and R&D agendas to ensure that agroecological alternatives are adopted, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food security can be realized. It must be recognized that a major constraint on the spread of agroecology is that powerful economic and institutional interests have backed R&D for the conventional agro-industrial approach, while R&D for agroecology and sustainable approaches has been largely ignored or even ostracized.

What is needed for a more reflexive land and water management are changes in attitudes and philosophy among decision makers and scientists who should acknowledge and promote alternatives. Also needed are strategies of institutional innovation to encourage equitable partnerships with local NGOs and farmers. The top-down model of technology transfer should be replaced by the bottom-up model of participatory, demand-driven and farmer-centred, technology development (Altieri, 2002).

5.3. A NEW RELATION BETWEEN SCIENCE AND SOCIETY

Finally, reflexive modernity, with its emphasis on participation and inclusion, requires a new social contract between science and society. Such a contract is strongly needed not just as a procedural means to ratify the new arrangements but also as a necessary requirement to settle a concomitant crisis that is linked to the changing character of science and society in our times. The image of science as an objective and impartial provider of the empirical facts and rational explanations upon which politicians and policy makers can safely rely has become outdated. Especially in the case of environmental sciences and the life sciences, which deal with very complex problems, this traditional image does no longer match with reality. With these disciplines we find ourselves each time in a situation where the facts are uncertain, values in dispute, stakes high and decisions urgent.

Under these conditions the puzzle-solving strategies of ‘normal science’ (in the Kuhnian sense) are no longer appropriate and we have to switch over to what Silvio Funtowicz and Jerome Ravetz (1992) have called ‘post-normal science’. The most prominent feature of post-normal science is the extension of the peer community and the inclusion of an ever-growing set of scientific and non-scientific stakeholders.

1- Another example of the integration of indigenous and scientific knowledge can be found in Wessels and Hoogeveen (2006). They show how in Qarah, Syria, the combination of ancient qanats and modern drip irrigation systems for fruit trees might prolong the life of some qanats and encourage younger generations to commit to their conservation.

All these new developments indicate that the societal relationship with the environmental sciences and the life sciences are very dynamic and produce new controversies, dilemmas and ethical problems. In addition, all these developments make one thing clear: the values, standards and competences of food and agriculture professions are not sufficiently endorsed by society at large (Korthals, 2004). Therefore, it is necessary to study research ethics for the soil and water science profession to communicate with the public (e.g. by improving and redeveloping the ethical statements of soil and water science professional organizations). This profession should take its responsibility with respect both to the general public as to those who are directly involved (stakeholders), by encouraging public participation respectively stakeholder participation.

6. CONCLUSION

To highlight the problems and perspectives of land and water management in Iran and comparable (semi-)arid countries, three subsequent paradigms have been identified: pre-modernity, industrial modernity and reflexive modernity. The technical, the social and the ethical aspects of the pre-modern paradigm have in some respects been more compatible with the ecological and social requirements of the country than the current paradigm of industrial modernity. Since the 1960s and 70s the technologies, organizations and ethical underpinning of industrial modernity have been challenged. In the industrialized North industrial modernity gradually gave way to what has come to be known as ‘reflexive modernity’. In Iran too there are signs and indicators of a turn to the paradigm of reflexive modernity in the 1990s. But, the new paradigm is still in its first stage and must be conceptualised and developed in terms of new technical systems, social institutions and a new ethical framework. The traditional technical, social and ethical structures need to be revitalized and integrated with the structures of industrial modernity, in such a way that the benefits and advantages of both will be preserved as much as possible. The contours of reflexive modernity have been sketched in an Iranian context: a post-mechanistic ethics as a new metaphysics, agroecology as a natural resource management strategy, and post-normal science as a soil and water science approach.

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WATER MANAGEMENT IN ARID AND SEMI ARID ZONE: TRADITIONAL WISDOM.

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ABSTRACT

Thar Desert covers the area of 44.6 million hectare, out of which 27.8 million hectares lie in India and the rest in Pakistan. The average annual rainfall is ranging from 500 in the east to 100 mm in the west. It is an ill water sandy tract of Rajasthan. As the rainfall is very erratic, the ancestors developed various wise and sustainable traditional ways to harvest the rain water. Most of the villagers in the desert tract have small ponds, covered pits called as kunds or simple excavation called as sar. They developed mixed cropping pattern in which human and animal population benefit from each other. Around 15th Century, the paliwal Brahimans community of the Jaisalmer district of the Rajasthan have been developed Khadin system of cultivation. The system is based on the principle of the harvesting the rain water on farm land and subsequent use of this water-saturated land for crop production. Khadin system has great similarity with the irrigation methods of the people of Iraq around 4500 B.C. This paper deals with the skillful traditional water management practices like Kund, sar, roof top rain water harvest, tanks and Khadins etc.

INTRODUCTION

Several Period of prosperity are quite discernable in the history of India. Numerous documentary and field evidences based on well conceived planning and regulation are extant in different parts of India. The methods of water development of respective periods have long been closely linked to the Indian climate, social fabric and living style. At majority of the sites, this historical management system can again brought in be operation with minimal financial provision and public participation. They may continue to function for several decades on zero budgets provision. Traditional water management practices in the Thar Desert of India provide the guiding principles in the current water crises problems in arid and semi arid zones. In this paper the traditional wisdom is discussed.

Thar Desert of India receives very meager amount of monsoon rains. This is highly erratic in nature. When the monsoon clouds came to pouring down on them, there was

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water and life. Once the rains disappear the lands become dry, life becomes difficult and water scare to find. The ancestors realized that human society can not grew without extending the bounties of the monsoon water, from the dry months to the wet months. And thus slowly grew the extraordinary traditions of water harvesting. They developed techniques to divert the rainwater in to a storage structure so that the water could be used in the dry period for human and animal consumption and for agriculture. People's participation was the base of those techniques. The experience of the local inhabitant can provide valuable lessons for designing and sustaining water developing programs.

KUNDS

Kunds found in the sandier tracts of the Thar Desert are covered underground tanks with artificially prepared catchments area to increase the runoff. This traditional surface rain water is continue to be important and assured source of drinking water.

Kunds are circular in shape tank constructed at the centre of a selected catchments area, the depth and the diameter of the kunds are nearly kept same. Generally it ranges from 3-4.5 meter. Lime mortar or cement mortar is used for the construction of the tank. A soccer shape was given to a catchments area. The size of the catchments area ranges form 20 square meter to 2 hectors. After cleaning of vegetation from the soil surface the land was given a smooth gradient of 3 to 4 percent towards the kund. The cleared surface was lined with silt. In places where a calcium –carbonate zone was available below the soil surface at shallow depth, water proofing of the soil was done with murum i.e. earth from disintegrated rocks. Run off generated over the surface enters the kund through the openings provided on the wall of the kunds. The openings or the inlets are generally guarded a wire mesh to prevent the entry of the floating debris, birds, reptiles. The top is covered with a lid, from where water can be drawn out with bucket and rope. Cattle are not allowed to graze the saucer and shoes have to keep off. It is calculated that a kund having 100 square meter catchments area with 100 mm effective annual rainfall could easily collect 10000 liters of water. The rainfall data collected shows that areas with 100 mm rainfall can use the kund system very effectively. Even if the kunds do not collect sufficient water in scanty rains they can be used as water reservoir, which can be filled by transporting water by tankers.

Now a days tap water schemes are provided in these areas. Though the tap water scheme is important from health and other aspects, will take a long time because it is dependent on electric supply, which is extremely unreliable. Moreover, the supply from ground water source, which may run dry over time. Therefore, traditional kunds can supplement the piped water supply system to improve sustainability. The public kunds built by the people have improved water accessibility. On an average a kund measuring 5 m deep and 2.5 m in diameter takes 25 days to build and costs about $300. After the constructions is complete, a convex lead locally called as Bhida, is placed over the Kund as cover. Traditionally this was made from the easily available wood, and plastered with mud. Now a days either sand stone or Ferro-cement is used to make the bhidas. Bharat Singh Punia, a lanky farmer from Village Lahsedi says that "Kunds are our treasury in which we store the sweet nectar from the heavens and quench our thirst when all other sources are dry up." Kunds are privately owned as well as community owned. Sunga Ram Sharma care taker of a community owned Kund proudly says that "Their kund serves about 1.5 millions pilgrims, who throng the shrine of our warrior saint Geoaji Chauhan in the month of August. It also serves the travelers round the year"

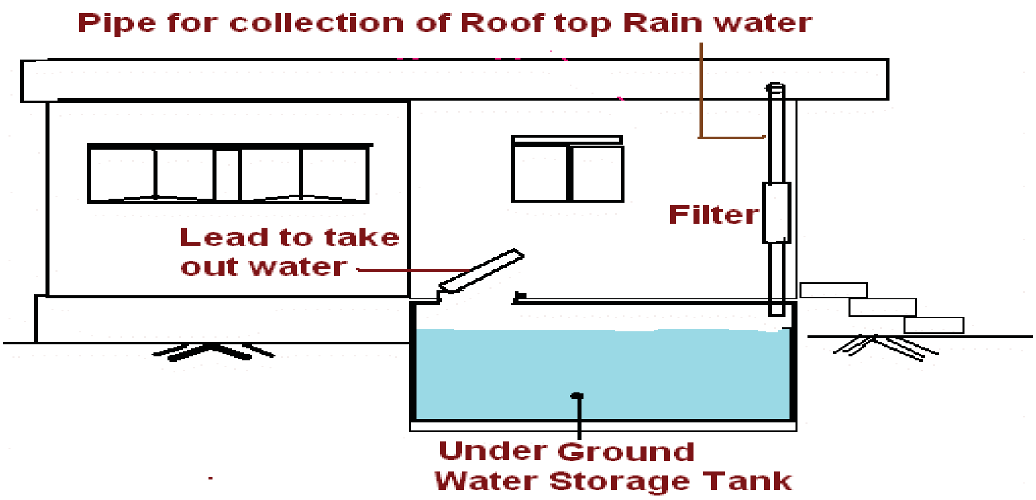
SAR

Sar means tank or reservoir. It is suffix used after the name of a tank. A tank constructed before 600 hundred by the King Ghdasi of Jaislamer (India) is named after him as "Ghadasisar".

This tank is still supplying water to The Jaislamer town. In the arid zone of Rajasthan the water harvesting is deeply rooted in its social fabric. The other name of the tanks in these region are Govindsar, Badalasar, Gulabsar, Bhatiyasar, Ratansar etc.

ROOF TOP RAINWATER HARVESTING

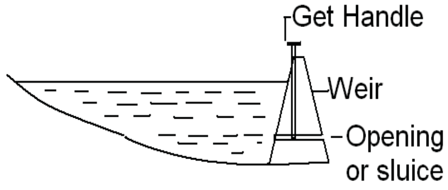
Under ground water storage tanks were found in most traditional houses in Bikaner town of the Rajasthan State (India). They were like a circular hole made inside the ground below the floor of a room. They are polished with lime, beautifully decorated and covered with tiles. Roof water is collected during the rains and used only when all the other supplies failed. It is preferred to give water from this tank to an ill member for drinking than the tap water. Thus they have great faith on the purity of the rainwater. Such types of roof top water harvesting techniques are also prevalent in Indian states like Mizoram, Himachal pradesh, Gujarat, Rajasthan, Tamilnadu etc. Now a days the water storage tanks are constructed by using Brick masonary, stone masonary, ferrocement, or Reinforced cement concrete.



Average water requirement for domestic consumption is 10 liters per day. The quantity of water required for a family of five persons is 50 liters. The quantity of water in liters that can be collected from the rooftop can be calculated as follows. It is simple multiplication and can be = Area of roof in Square meters X annual rainfall in Meters X 1000. A house with roof of measuring 6 meter length, 4 meter breadth, and annual rainfall 400 mm i.e. 0.4 meter, will able to yield 6 X 4 X 0.4 x 1000 = 9600 liters. This much water is sufficient to the family under consideration for (9600/50) 192 days.

TANKS

Eri irrigates approximately one third of the irrigated area in Tamilnadu state of India. Eris are the ancient tanks. Eris have played several important role in maintaining the ecological harmony as flood control system, preventing soil erosion and wastage of runoff during period of hevy rains and recharging the ground water in the surrounding areas.

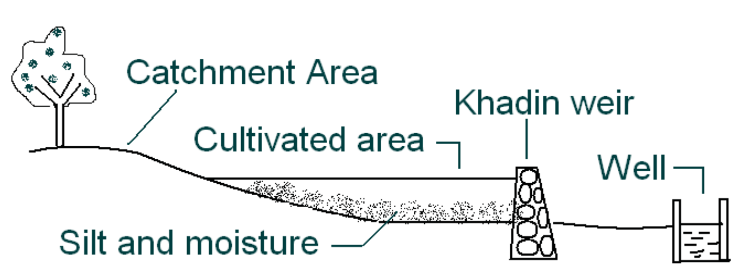


Eri (Tank)

Until the arrival of the British in 1600 AD, Eris were maintained by the local communities with resources. Historical data from the Chegalpattu district indicates that in 18th century about 4.5% of the gross produce of each village was allocated for the maintenance of the Eris and other irrigation structures. The village community has to decide the water distribution, opening and closing of the sluices, water allocation to a field and to a particular crop. Every village has an informal organization, which consists of all irrigators.

KHADINS

The climate of the Jaisalamer region is hot and arid, with an average rainfall of only 164 m. The average rainy days in a year are only 7.7 days. Considering the general water requirement of agricultural crops, which are much above 250 mm, rain fed cropping is impractical in such tract. Though in the deep desert of Jaisalamer district, where agriculture is hazardous the Paliwal Brahmin community has devised the khadin cultivation techniques to ensure at least one crop a year at specific sites. This land use techniques built around takes in to account the vagaries of the weather and makes the best use of the meager rainfall and prevents the soil deterioration of farmland. Khadin is the skilful and sound scientific practice of harvesting of rainwater. Scientists of the arid zone believe that it has great importance even in the present day Thar agriculture and land-use.



Khadin

The Khadin system is a runoff agricultural system. The runoff water from the high catchment area is arrested with the help of a Khadin bund. The water is impounded on the upstream side of the bund during the rains. The stored water gradually recedes into the ground increase the soil moisture content. On this soil moisture deep-rooted crops are raised. These Khadin soils remain moist for a long time. Khadin soils have relatively high organic matter and also rich in nutrient in comparison to other desert soil. Khadin have functioned efficiently for centuries maintaining the soil fertility.

The king would give land to the Paliwals an ask them to develop Khidns on the land. The ownership of the land would remain with the King. Out of the grains that harvested from the khadin land, one forth would have to be given the King. Thus they develop a whole net work of Khadins in Jaislamer district. Khadins are also found in Jodhapur, Bikner and Barmer district of Rajasthan state of India. There are still 500 big and small khadins covering an area of 12000 ha. This system has great similarity with the irrigation methods of the people of Iraq around 4500 BC. A similar system is also reported to be practice in Negave desert, and southwestern Colorado, 500 years ago.

Khadin is an earthen embankment built across the general slope. It conserves all the rainwater runoff to the maximum possible extent within the agricultural field. The height of the earthen embankment is generally kept as 1.5 to 3.5 meters. On one side of the embankment waste weir is provided to take out the excess runoff safely. The length of the embankment varies from 100 to 300 meters according to the site requirement.

CONCLUSION

kunds in the desert fulfill the drinking water needs at low cost. If maintained well it provides portable water. Rain water harvesting is a long term solution for the hilly area, remote area and in the scared water area. It case of contaminated ground water, harvesting the rain is a good solution to fulfill the drinking water needs. Traditional water harvesting system definitely has relevance in areas where water scarcity is acute or where ground water is either brackish or too deep to obtain cheaply. khadin makes possible to raise crops in the scanty rain fall zones which or and other wise impracticable in the arid sandy track. It conserves the soil and soil moisture. This helps in crop production. khadin have also created a positive impact on the ecology of the region, effectively checking the soil erosion and increasing the vegetative cover. The traditional water management practices are sustains for a long period. The technology has proven over the time. The wisdom can be still used to solve the present water crises to some extant.

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TRADITIONAL WATER HARVESTING SYSTEMS COLLECTIONS IN IRAN

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ABSTRACT

The fact that rainfall is very meager in the Arid and semi-arid regions of Iran and that one millimeter of harvested rainfall is equivalent to one liter of water per square meter, suggests the importance of WH apart from the quantity of rainwater collected.

During the summer season, warm and humid air of the Oman Sea and Indian Ocean influence the southern barrier of Elborz Mountains. In the same time, strong northerly cold currents flows to the northern barrier of Elborz Mountains and into north-south channel of Dasht area, located between Khorasan and Golestan provinces. Mentioned condition cause a convective instability in accompany with heavy rainfall. Three types of synoptic patterns have been introduced for development of heavy rainfall of the northern parts of Khorasan province and eastern area of Golestan province, located on the north east of Iran: upper level trough, twin surface pressure systems and composed jet-streams.

Arid and semi-arid regions occupy more than 80 percent of Iran's land. Short duration and high intensity are common characteristics of rainfall in these regions. The most optimistic estimation of average precipitation stands at 273 mm, which is less than a third of the world's mean annual precipitation. Temporal and spatial distribution of rainfall is quite unfavorable. The mean annual precipitation is less than 100 mm in 13% of total land area, between 100 to 200 mm falls on 61% of area, 250-500 mm are fallen in 17% of land, while only less than 8% of land get 500-1000 mm of precipitation. It should be noticed that about spatial distribution of precipitation in Iran is about %75 precipitation In %25 area and %25 precipitation in%75 area. Also temporal distribution of precipitation %25 precipitation in plant growth season and %75 precipitation in off season. The temporal variation in rainfall in wet and dry years is also large, e.g. in 1969 was high and in 1970 was low.Similar conditions prevail not only in Iran, but also in many other countries in the region. High density, short duration rainfall often generates destructive floods. At present in many parts of the country, the water levels have been falling rapidly. The demand for drinking water is also has been increasing manifold in the last three decades due to rapid increase in the population. Due to this, the stress on exploitation of water resource increased everywhere in the country. The most notable

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consequence of the agricultural development strategy has been the depletion of ground water resources. Artificial recharge techniques have become a pragmatic approach to augment depleting ground water resources. Utilization of floodwater for groundwater recharge can be a reliable solution. As, this will improve both groundwater quality and quantity.

The aim of this paper is to briefly outline the traditional water harvesting systems and the lessons learnt from the traditional activities in semi-arid and mountainous areas of Iran.

At first, the importance of soil, water, and natural resources in sustaining daily life in arid and semi arid conditions is highlighted and the recent problems aroused was discussed.

The paper also attempts to suggest ways to incorporate the traditional practices with modern water management activities to promote water harvesting in these areas. It was concluded that the traditional and modern methods have merits and limitations. By incorporating beneficial elements of both into one, a water management system can be developed that result in more water harvest and at the same time is sustainable and environment- friendly in the long run.

Finally, the strategy and action plan needed for the watershed development as well as up scaling rainwater harvesting into watershed management activities including micro and macro-planning framework in which the optimized utilization of precipitation can be ensured was discussed.

Keywords: catchments, water-harvesting system, rainwater, semi-arid.

INTRODUCTION

In Iran, for instance, Average Renewable Water Resources Precipitation is 413 Billion CM , Evaporation is 270 Billion CM ,Water renewable resources 130 Billion CM, Recharging ground water resources 38 Billion CM and Available Surface Water 92 Billion CM.

Arid and semi-arid regions occupy more than 80 percent of Iran's land. Short duration and high intensity are common characteristic of rainfall in these regions. The most optimistic estimation of average annual precipitation stands at 273 mm, which is about one third of world average annual rainfall. Spatial distribution of annual precipitation is quite unfavorable. The mean annual precipitation is less than 100 mm in 13% of the area, between 100 to 200 mm in another 61% of area, 250-500 mm in 17% of land, and 500- 1000 mm in the remaining 8%. It should be noticed that about spatial distribution of precipitation in Iran is about %75 precipitation In %25 area and %25 precipitation in%75 area. Also temporal distribution of precipitation %25 precipitation in plant growth season and %75 precipitation in off season. The temporal variation in rainfall in wet and dry years is also large, e.g. in 1969 was high and in 1970 was low. Similar conditions prevail not only in Iran, but also in most country in the region. Under such conditions, desertification and drought are threatening the livelihood of millions of people living in arid and semi-arid areas all over the region.

Meeting the water demand is a major challenge in Iran. On one hand, use of groundwater resources plays a critical role in food supply and security of rural areas. On the other hand, over abstraction will accelerate desertification. Thus groundwater recharge is considered as an effective practice for improving water supply and to meet the water needs during drought. High intensity, short duration rainfall often generates floods.

The first objective of this paper is to outline the water harvesting systems for semi-arid and mountainous areas of Iran and the futures strategies to optimize the benefits and utilization of rainwater harvesting in the semi-arid areas in the region through sharing of technology, and best practices. The next aim is to discuss the importance of up scaling and integrating rainwater harvesting into watershed management activities for a comprehensive water resource management.

Compared with other liquids such as petroleum, water cannot be easily transported. It flows under gravity and easily escapes access. Under semi arid climatic conditions, it is one of the most scarce and most vital resources with drastic quantitative seasonal and periodic fluctuations. Water inflicts great damages to human beings and property during floods and endangers social life during droughts. It is, therefore, essential to establish a balance between supply and demand prior to, and as a preparation for, the emergence of water crises. Plant and animal resources in the semi arid regions have been undergoing corresponding variations. As a result, production relies heavily on underground and surface water, which become increasingly scarcer. Water will remain a barrier to the achievement of poverty alleviation and food security. Most of renewable water resources have already been committed by conventional method of dam construction but the demand for water is exceeded renewable water supplies

WATER HARVESTING (WH) CONCEPT AND DEFINITIONS

Many definitions of WH appear in the literature. The common factor in these definitions is that WH is the capture, diversion, and storage of rainwater for many uses. therefore, the main objective is to manage the rainwater from the moment it falls and ensure that most of it used productively before it returns to the atmosphere by evaporation (Ahmed & Eldaw, 2003). WH may occur naturally or by intervention. Natural WH can be observed after heavy storms, when water flows to depressions, providing water for areas of farmers. WH by intervention involves inducing runoff and either collecting or directing it, or both, to a target area for use. WH may be developed to provide drinking water for human and animals as well as for domestic and environmental purposes. Whether used for irrigation, augmentation, or as an alternative to traditional supplies, rainwater harvesting is a viable option as water source. Depending on local environmental conditions water form of rainfall over an area is called the rainwater endowment of that area. Out of this, the amount harvested may provide a supplementary supply, an alternative supply or the only feasible supply especially in rural areas of arid and semi-arid zones

Rainwater harvesting is a popular term used for a tradition of collecting rainwater, improved by modern concepts and technologies, a result of more than two decades of research work. Today, rainwater harvesting is used in wet and dry countries, in poor and modern situations, for water supply and for homes sanitation. It is utilized in addressing agricultural productivity and food security for poverty alleviation, even in places with 200 mm of rain. Rainwater harvesting is employed in flood mitigation in rain-drenched countries, and in solving infiltration problems of sealed surfaces in urban areas and industrial complexes, or in avoiding polluted water and toxic ground water.

Most of all, Rainwater harvesting, is environmentally sound as it assists in recharging ground water, enhances wetlands, assists forest conservation, encourages ecological farming, and slows down construction of new dams for water supply thus helping the ecological flow.

It is certain that increased upstream infiltration and recharge will create a more balanced hydrological regime, providing better opportunities for direct and sustained consumption of water by various users with different environmental benefits and higher aquatic yields. In addition to this, there will be ample opportunities for multiple reuses of the existing resources when evaporation is reduced as a result of the new hydrological regime.

LITERATURE REVIEW

In the arid and semi-arid regions, the limited availability of water in most cases is a major constraint to rain fed agriculture. In these regions, the amount of rainfall is usually not sufficient for sustainable agriculture system. In the semi-arid areas, uneven distribution of rainfall, spatially and temporally, makes rain fed agriculture a risky enterprise. There are many examples of traditional use of runoff in areas where the rain is not sufficient for crop farming.

Soil erosion caused by rainfall along with flash floods is among the characteristics of these regions. So we are, in many places facing with both drought and floods. What should be done? Seemingly there is a simple solution. Here are several examples presented by Norman Hudson (1999):

In North America, Indian tribes use simple methods of floodwater farming. They use runoff from sandstone to water alluvial soils in Arizona.

UNEP (1983) reports Hopi tribe in south west of North America; cultivate three quarters of their land using floodwater.

Kenya, in pastoral community with annual rainfall of less than 200 mm, small patches of sorghum are grown using floodwater. Morgan (1974)

Kovda (1961) reported the use of natural runoff in arid areas of the former USSR called Kair farming which the name is given to cropping on flood terraces.

Trails of runoff farming have been seen in Khost plain, Paktia province in Afghanistan.

Evidences of flood farming can be found in different parts of Sudan, Morocco, Syria, Jordan and many other countries with similar climatic condition.

Gupa et al. (1995) have investigated different water harvesting and conservation techniques. The research indicates that benefit of water harvesting is high and shows an 8 times increase in total biomass compared with the control plot and also proved that there are an increase of tree height by 20% and water use efficiency from 4.78 to 39.6 Kg /Cm Ha. (Gupa et al., 1995)

Kowsar (1991) argued, ground water recharging via floodwater spreading have been carried out in Iran some 3000 years ago. He pointed out to the residences of North-eastern part of Iran have been recharging ground water by alluvial fan irrigation.

In Iran, there are different traditional methods such as Bandsars, Khoushab etc. These methods will be described in the following pages in more detail.

IRANIAN EXPERIENCES, PAST HISTORY

How People have coped with Natural Climate Change and Aridity issues in the Past?

Some of the remarkable accomplishments can be listed as follows (Karamoz 1997).

• Construction of a 50 Km water transfer tunnel (Aqueduct) from the Karkheh River to Chogha-Zanbil south west of Iran more than 3000 years ago;

• Hydraulic structures - Chogha-Zanbil temple, 3000 years ago;

• Invention and development of 80000 Qanats for groundwater extraction and utilization over the last 3000 years;

• Dam construction over the last 2000 years;

• Mizan dam in Shooshtar and bridge-dam of Shooshtar, 500 meters long with 40 bays;

• Amir dam located 35 Km from the city of Shiraz, 1000 years ago. It has been used as a bridge, for irrigation and as a water mill;

• Bahram dam on Gharah-Aghage, south of the city of Shiraz, 2000 years ago;

• Sheikh-Bahaii water allocation scheme, 400 years ago.

• In recent years, dams with a total capacity of around 20000 MCM have been built in Iran.

Iranians have a long and notable history of water resources development relying on traditional techniques. The exploitation of floods and rainwater harvesting have been practiced through flood spreading and groundwater recharge systems using BandSars, recharge ponds and Ab- Anbars by ancient Iranians.(Koochecki 1992, Ghoddousi, 1995).

BANDAR

The people living in arid and semi-arid regions are facing with water shortage and have to invent ways to overcome with this important obstacle. One of the most famous techniques vastly used is Bandar. It is widely used in north-eastern part of Iran. In fact it is somehow a flood farming method, still in use. An embankment system to use floodwater in farming and groundwater recharge called BandSar which is practiced widely in the north east of Iran (Arabkhedri and Partovi, 1997).

Bandar is composed of a small stream that conducts water from Ephemeral River to Bandsar's inner part. This decreases water speed and supplies soil moisture. In the method, natural location of floodwater spreading is formed on alluvial fans. Bansar is a plot or pond formed by embankment construction in direction of water flow. So flood is taken, water is retained until infiltrated.

Bandar has a very simple construction. It is made of the following parts:

A shallow water drainage (ephemeral stream called Kal)

A check-dam made of river sediment called Tarkehband

Embankment (the main wall of the dam)

Some parallel subsidiary walls for balancing water spreading called Mewband

A waterway for overflow of water called Goushband

Bandsars covers different areas e.g. 1000 square meters in valleys to 30 ha in low slope lands. Generally in alluvial fans, the land situated between two streams is suited for constructing Bandar. Arabkhedri (1999) reports: most of Bansars of Iran are located in the central and southern parts of Khorasan province in areas with low annual precipitation (less than 200 mm per year).

Sediment deposition in Bandsars, changes both chemical and physical characteristics of their original soils. Sediments being deposited in Bandsars are usually fine grained which decreases the permeability of the soils over the time, but annual ploughing, cultivation of divers plants along with root infiltration into soil, all improve permeability and this is the main difference between a traditional multi-purpose flood spreading system and modern recharging systems. Its simplicity in design and operation and costing effect along with public acceptance and reliability has caused to be still in use after so many years.

Fig. No.1: a Bandsar project

KHOUSHAB

Other examples of successful water harvesti ng projects over the world. Among various water harvesting methods, some use rainfall and others use flood caused by rainfall. Here are some examples.

Water collecting for agricultural purposes has been accomplished in Iran, Pakistan and India. The traditional methods are including Khoushab, Degar, etc. It is believed that these methods have transmitted from Iran to adjacent countries and visa versa. Degars and Khoushabs are only different in size and their local names.

PONDS (GOORAB AND ABANBAR)

Ponds are one of the most reliable and economical sources of water. Abanbars are the most effective way of rainwater harvesting in some regions, especially in places with very low amount of precipitation, lack of stream and river flow and lack of suitable groundwater resources.

Water tanks and ponds were dug in rain fed areas of South Iran as early as 3000 years before.

Ponds can serve a variety of purposes, including water for livestock, for field and orchard irrigation, fish production, wildlife habitat, recreation, landscape improvement,

Fig. No.2 : a Khoushab project

and with proper modifications for domestic and household use. In addition to irrigation,

Ponds are used in fish culture, breeding ducks and waterfowl as well as for landscape irrigation in parks. Thus, ponds can have an important role in the economy of villages and city life. Considering the importance of ponds in irrigation, economic and social applications, it is necessary be considered and rehabilitate as a means of water harvesting in semi-arid to humid regions.

In some cases, which topographical conditions permit ponds can be considered as detention basins and recharging spots and the recharge from it might be accelerated by equipping it with injection wells. The floodwater of small catchments or drainage of small areas in plains may be controlled by ponds.

Ab-Anbar or Berkeh is an excavated reservoir in the ground which is covered with a masonry dome roof and collects rain for drinking purposes (Movahed Danesh, 1997). A successful combination of the old practices and new technology in flood spreading aiming at groundwater recharge and regeneration were formulated and implemented by Iranian. Some of these projects have been working and promoting farmers lives since the establishments. The most striking feature of traditional water harvesting system is that the people had the right to construct and manage them. There is ample evidence to show, historically, that even when the government financed the construction or repair of water structures, some of these were quite big, the ultimate responsibility for devising the micro-level distribution and maintenance systems were left to the local communities.

ARTIFICIAL RECHARGE OF AQUIFERS AS A WATER HARVESTING SYSTEMS

This technique has become a pragmatic approach to augment depleting ground water resource. Artificial recharge of aquifers can be achieved using three different methods, namely surface spreading, watershed management (water harvesting) and recharge wells. According to the former Soil Conservation Service (USDA undated) "water spreading is a specialized form of surface irrigation accomplished by diverting flood runoff from natural channels or watercourses and spreading the flow over relatively level areas." Artificial recharge by the spreading method consists of increasing the surface area of infiltration by releasing water from the source to the surface of a basin, pond, pit or channel. This is certainly the most efficient and most cost-effective method for aquifer recharge. However, only unconfined aquifers can be recharged by the spreading method. Watershed management offers an effective method to intercept dispersed runoff. Many techniques of water conservation have been developed along hill slopes with the intention of preventing soil erosion and reducing surface runoff, then increasing the infiltration in the ground, thus recharging the aquifers. Artificial recharge by injection consists of using a conduit access, such as shaft or connector well, to convey the water to the aquifer. It is the only method for artificial recharge of confined aquifers. Traditional methods, based on centuries of experience, are well adapted to the conditions of arid lands. They consist of the construction of earthen bunds and deflectors across the land to divert the flow into the fields. But large spates usually destroy the bunds and reduce irrigation of the fields. Furthermore, the very high sediment content of spate water tends to fill the diversion canals, which have to be cleaned regularly. So, although the bunds are relatively inexpensive to rebuild, the overall cost of seasonal maintenance and repair of the scheme is high. Artificial recharge also can be classified either in-channel or off-channel. In-channel constructed facilities are recharge facilities built into a river or stream bed to retain water while it infiltrates through the stream bed into the underlying aquifer. These structures include gated structures, levees and basins, or other devices designed to impede water flow. Levees are the least expensive of these alternatives, but are the most subject to damage from flood flows. Also operating in-channel, managed facilities allow water to infiltrate the stream channel without the aid of structures to impede flow. Off-channel artificial recharge facilities include shallow spreading basins. These basins are dug up to 2 meters deep and are usually constructed with earthen walls to hold water in place.

☐ Figure No.1 shows a schematic plan of one of the patterns used in floodwater spreading projects.

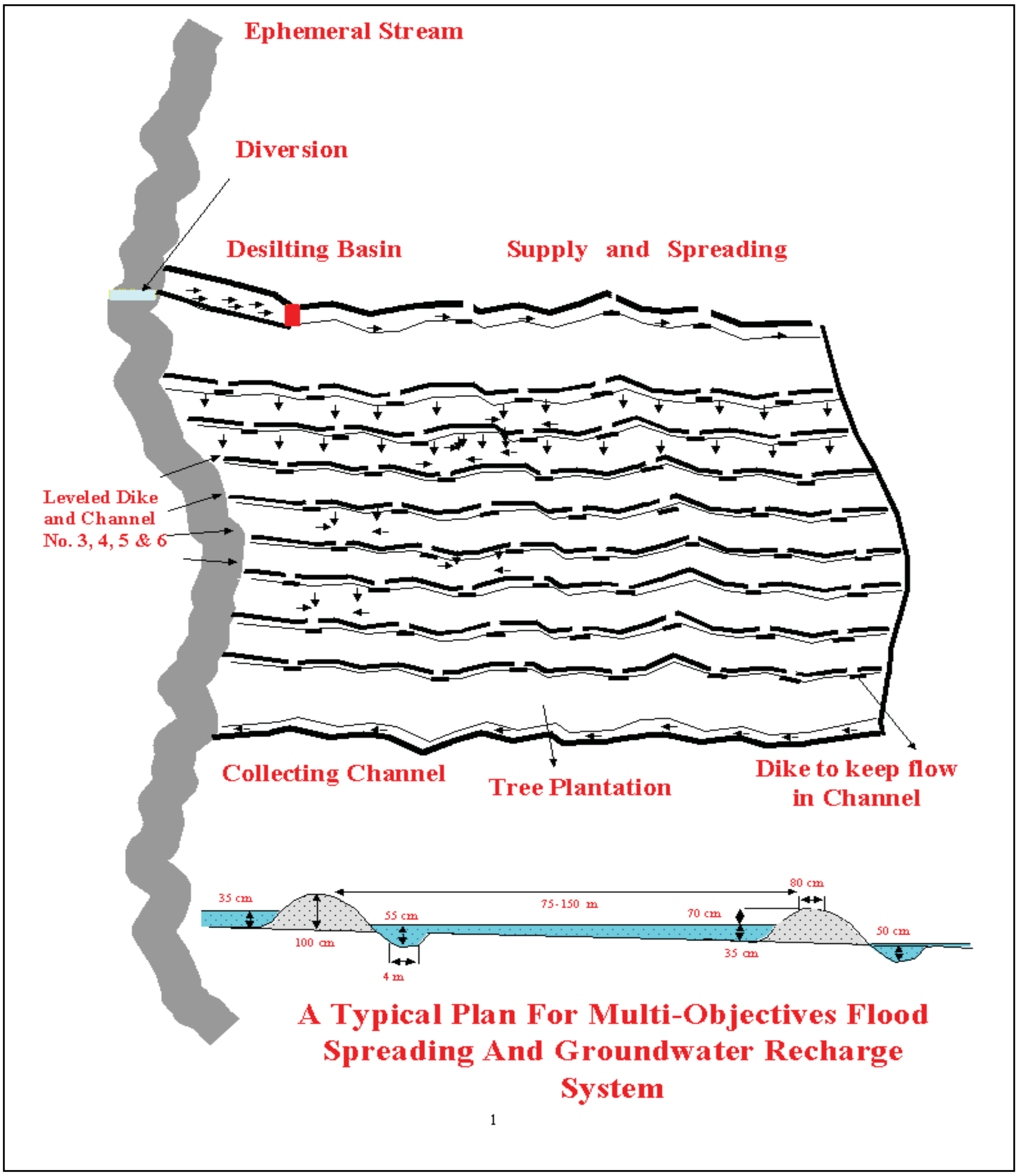

Fig. No.3: a schematic plan used in floodwater spreading projects

Floodwater spreading may be considered as a method of water harvesting too. So we should mention different old and new methods of water harvesting methods. In some traditional methods, our ancestors tried to find suitable ways to use both water and the sediment coming along with floodwaters. These sediments would be suitable for crops and were (and in some parts of the country are still) used as fertilizer or particles, which could improve the soil texture for cropping.

The most important condition in setting up floodwater spreading project is considering the slope, which should be between 1 to 5 percent. Also a floodwater-spreading site should have high infiltration soil. At low initial soil water content, rainwater infiltration is controlled by rainfall depth while at high preliminary soil water content, the rain drop impact forming the surface crusts is a deciding factor. Rainwater infiltration significantly decreases with increasing basin slope. So this indicates that the texture of the flood plain is very important for infiltration of water. Nowadays, floodwater spreading is used as a part of watershed management activities in rural areas under impact of high population and soil erosion. In fact, floodwater spreading involves operations that will increase the time and area over which water is recharged. So this involves upstream management of the flows as well as channel modifications and the plain area. As for soil characteristics, we need deep medium to moderately fine (coarser types are better) with moderately permeable subsoil. Moderately fine-to-fine textured soils are next best and may be used if land slopes are low enough to allow pounding. Topographically, land should be smooth and gently sloping. Also it is essential that expected runoff events occurred at times when the soil can store added water. Water must not contain excessive bed load, which would deposit in the spreading area. Or it must be removed from time to time. Anyhow, the catchments should not be made of marl or marl-like formations or it will cause difficulties. Floodwater spreading is an inexpensive means of applying water to an area in order to supplement rainfall. If properly designed and implemented, the system can result large returns for relatively investments. Of course, there are disadvantages in any system. Sedimentation is the most important disadvantage. Concentrated flows may cause soil erosion and sediment deposition.

The major Project components are:

River improvement work

Construction of small-scale diversion and intake structures

Construction of conveyor-spreading channel

Construction of small-scale water conversation facilities

Construction of flood control structures

Construction of sediment control structure

There are different methods of using floodwater. In rangelands, one can design special flood spreaders. These spreaders are systems of dikes constructed to divert flood flows automatically from the gullies and spread them over the adjacent rangeland. Bennett (1965) reported that: “Areas having an annual rainfall of less than 8 inches, or a growing season rainfall less than 4 to 5 inches, may not produce sufficient runoff to justify the installation of water spread system.”(Miller et al., 1969) Naturally, the diversion and spreading is controlled by a system of bunds structures, ditches or a combination of these. These constructions are designed to moderate and optimize an estimated rate and volume of flow. This is suitable in alluvial fans with good to moderate infiltration.

These systems can be divided into two types: Flow type & Detention type.

The first category incorporates free drainage from the area while in the second systems, the water retains on the area until it has infiltrated. Both two systems are further divided into subtypes as follow:

Spreader ditch & Syrup –pan & Dike and bleeder &

Detention type: Manual inlet control & Automatic inlet control

In spreader ditch flow system, short time flow of water is considered to be concentrated and distributed. The ditches are constructed to carry less water when further from the water source. The slope is reduced to 0.4- 1 percent. Water is collected from upper spreader ditches to lower ones redirected laterally.

In syrup-pan flow system, there is a single spreader ditch at the upper end of the field. Water spills over the sides of the spreader into the field below. As the water flows down the slope, it is infiltrating and its excesses, flows to the next field. The dike end is broken, leading to the next and this goes on to the last field. At the end of last field there is a waste way or channel leading possible excesses to the main channel

Dikes and bleeder flow systems are a modified type of the syrup pan system. In the system, water flows through dikes to lower portions of the field via tubes or weirs placed at intervals along the dikes. Also emergency waterway is provided in the system.

These three systems are changed or manipulated and are used in some pilot sites in different parts of the country. Normally we have built a kind of check dam to reserve water in a turkey nest or pond and then it is spread to the fields. The second category systems are not widely used in Iran. These systems are suitable for long duration flows such as from snowmelt etc.

Floodwater spreading advantages and disadvantages

a) Advantages of the project are as follows:

Increasing soil moisture & increasing farm lands & improving the fertility of the soil & Improving soil texture & Optimum use of water & Artificial recharge of ground aquifer & Increasing resident’s income & preventing migration to the cities & Flash flood controlling with minimum cost & Flood farming where it is possible &Rehabilitating desert type lands

b) Major disadvantage of the project may be sedimentation. Sedimentation after flood spreading is a normal consequence. This is very important in where erosion is particularly severed. Rates may reach 10000 Tons/Km2/ years. “Studies have shown that the domains of this range could be much more (100 –2000 times).” (Meijerink 1995) in sensitive floodplains (Marl or marl-like watersheds) the floodplain is threaten by large amounts of small particles coming from top of the catchments. As a result, infiltration rate decreases rapidly and sediments are deposited in transit channels, causing great decrease in transferable magnitude flood. Sometimes degrading or flooding occurs.

COMMENTS AND CONCLUSION

Most people consider the muddy floods of winter as a useless phenomenon. While these floods are God's gift and are very useful for the human welfare. The advanced science and technology makes it possible for us to use these types of water resources.

Using these waters and make them to infiltrate into the ground may be the best method of controlling, storing and using this resources. Being practical in south of Iran, confirms this idea. In arid and semi-arid regions, precipitation is not enough. The method of artificial water recharge is a method to make maximum use of these precipitations. Although enough data gathering and scientific research has not been carried out on these projects, but farmers are very satisfied with the results of these projects.

As a result, people and farmers using underground water for agriculture are ready to take part in the investments of such projects.

A distinguished advantage of these projects relative to other projects of water harvesting like dam construction is its low cost and short construction periods. The change in water table, one to two years after finishing the project is detectable. Controlling flood hazard and stopping salty ground water attack on fresh ground water aquifers are other advantages of these projects.

Governmental executive organizations are responsible for use of simple and low cost methods for reclamation of land, natural resources, and environment. The flood spreading project has been accepted by some local NGO` s in arid a semi-arid regions of the country. Executive organizations are normally interested in a short time periods. NGO` s are eager to extend such simple approaches with low investment. Executive organizations and NGO` s can participate in providing funds, to encourage local people to co-operate as voluntary labors in several stage of executive works, especially in non-agricultural seasons. It may be easy for executive organizations and NGO` s to help project managers in planning, design, and implementation. Most of the necessary construction and plantation material may be supplied with low transportation cost.

Generally speaking, flood hazard problems, soil erosion in watersheds and farms, desertification and movement of sand dunes, low productivity of the soil and shortages of water are major obstacles toward sustainability in most parts of the country. More specific to this project, incoming sediment carried with the floodwaters impedes smooth recharge into the aquifers and must be properly dealt with. Regular maintenance and appropriate funding should be carefully planned for since most water resources projects suffer from lack of attention in their long-term existence. Mechanisms to assure sustainability may include:

Government loans with low interest rate should be made available for implementation of similar projects where needed.

Local co-operative communities have the opportunity to receive bank load to implement large-scale projects for their community.

Design and construction standards must be developed for easy application.

More economically optimized structures should be proposed.

Plants with higher-value are to be researched for adaptation in various regions.

Finally main recommendations &key messages are as follows:

1. Recognize RWH as basic strategy for poverty alleviation
2. Government should invest in rainwater harvesting for agriculture - a small fraction of investment in infrastructure for irrigation.
3. Integrated Water Resource Management should integrate rainwater harvesting as the third source of freshwater in its concept.
4. Harness rainwater for drinking and non-drinking use. It is a major Freshwater Source.
5. Advocate for mix and advanced technologies for rainwater harvesting
6. Integrate RWH in catchments management to mitigate flood
7. Local government should get involved and pass guidelines and policies
8. Local government should raise awareness by having Rain Centers for technology information
9. Rainwater Harvesting should be integrated in school curriculum for continuing education.
10. To recommend to the UN RWH as another major option of water supply in order to support choices of users for their water supply source.
11. Establish rainwater harvesting index system.
12. Harvested rainwater is a major water supply option, as important as runoff surface and extracted ground water.
13. Bring down every drop of water from the managing agencies to the communities...
14. Decentralize water utilization using rainwater harvesting for the sake of Earth...
15. Giving adequate attention, founding to RWH
16. Placing RWH in the agenda as a part of water resource management

In National level & Regional level should be:

1. Initiate Strategies and Plan of Action for Management and Preparedness Planning.
2. Enact appropriate laws and legislations to formalize and put a legal framework at the National level.
3. Ensure coordination and collaboration among various governmental institution involved.
4. Promote the exchange of information and data at national, sub-regional and global levels.
5. Give due support to sub-regional, regional and international Network, for the exchange of cross-country experiences.
6. Give due support and make necessary steps towards creating a Regional Cooperation Center of Excellence information.

7. Establishing regional network for Environmental Degradation mitigation
8. Establish and support public education centers for more awareness and good practice
9. Establishment of intra-regional economic and technical cooperation, to enhance the exchange of information and expertise among the regional countries.
10. Establishment of International Alliance for watershed development and combating desertification
11. Establishment of hazard and risk information and mapping system
12. Formulation of regional strategies for catchments management for highlighting the common problems and natural hazards facing watersheds in the region

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BANDSAR, A SUCCESSFUL STORY FOR FLOOD AGRICULTURE IN ARID REGIONS OF IRAN

A. Dadrasi Sabzevar[1] and Y. Hasheminejhad[2]

ABSTRACT

Bandsar is an ancient system for flood farming invented by the farmers of Khorasan provinces. This paper had introduced some basic characteristics of this system, spatial distribution of constructed Bandsars through Khorasan province and its correlation with climatologic and topographic indices. The rules or agreements used to determine the priority rights for flood irrigation are some special ones, which are explained in this paper. Technical design, cropping system and advantages of this system are discussed too.

INTRODUCTION

Generally speaking, Iran is an arid semi- arid country located between 25 and 40 degrees of northern latitudes. The major characteristics of these regions are obviously high evapotranspiration and uneven distribution of precipitations throughout the season. One of the strategies used by farmers of these regions to adapt with these hard variable conditions is flood agriculture. Different methods had been used by farmers throughout the world to control and use flood irrigation. Flood irrigation is reported from north America, Arizona state (USA), Kenya, the former Soviet, occupied Palestine, Australia, Afghanistan, Pakistan, Yemen, Tunisia, Burkina Faso and India (Qoddusi, 1999). Many years ago flood irrigation was popular among Iranians. The history of flood agriculture is reported to be related to more than 3000 years ago (Kovsar, 1993).

Different methods had been used for flood farming throughout the country with different names among them are Bandsar, Khooshab and Degar. In this paper we will introduce the Bandsar system in Sabzevar region as a successful story in flood farming.

SITE SPECIFICATION

This investigation was done in Sabzevar town which is located in the west of Khorasan-e-Razavi province, I.R. Iran. The center of town is located on 57˚, 30′ E and 36˚, 12′ N beside the Tehran- Mashhad road at 664th Km. Its long term average annual precipitation is 209.8 mm and yearly average temperature is 17.6˚C, Annual evaporation

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is calculated to be 1436 mm from the pan data (Dadrasi Sabzevar, 2004). Fig. 1 shows position of studied site in Khorasan-e- Razavi province.

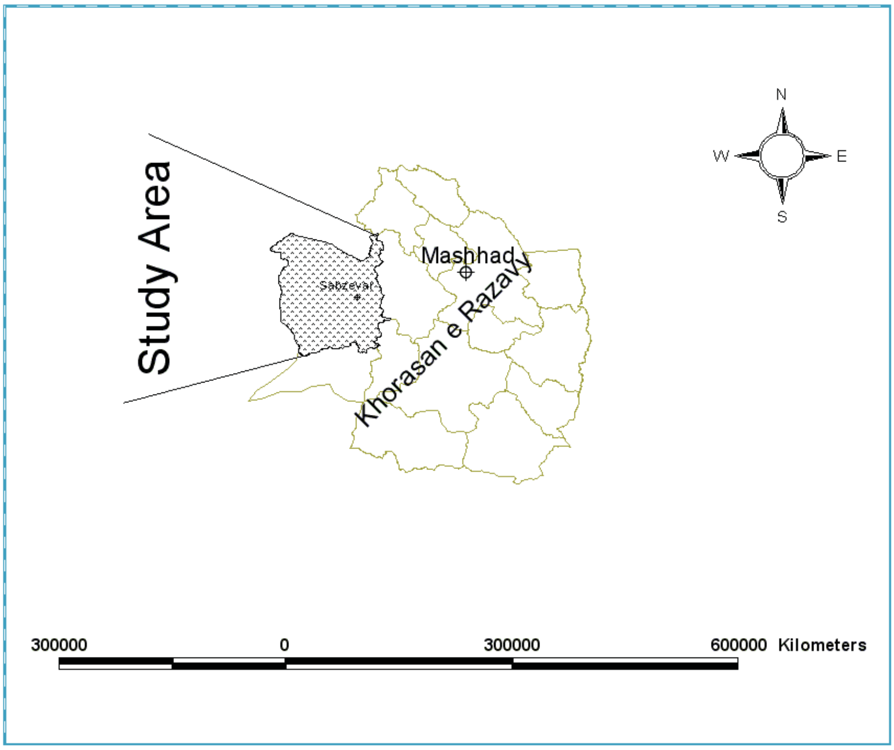

Fig. 1: Location of studied site in Khorasan-e-Razavi province

TECHNICAL CHARACTERIZATION

Bandsar which is one of the most ancient human made structures, had been reported only in Khorasan provinces. It is consisted from a basin with a weir which is constructed on the contour line. This basin in fact is a plot or a field for farming and is irrigated by two methods:

1- Conversion of surface run off of impervious surrounding lands which have small elevation difference to a main canal and conveyance of this water to a pre constructed basin (Bandsar).

2- Conversion of run off or floods from seasonal rivers to the field with a canal diverted from the river.

Fig. 2 represents a scheme from Bandsar in Sabzevar region and Fig 3 shows Bandsars in the satellite imagery.

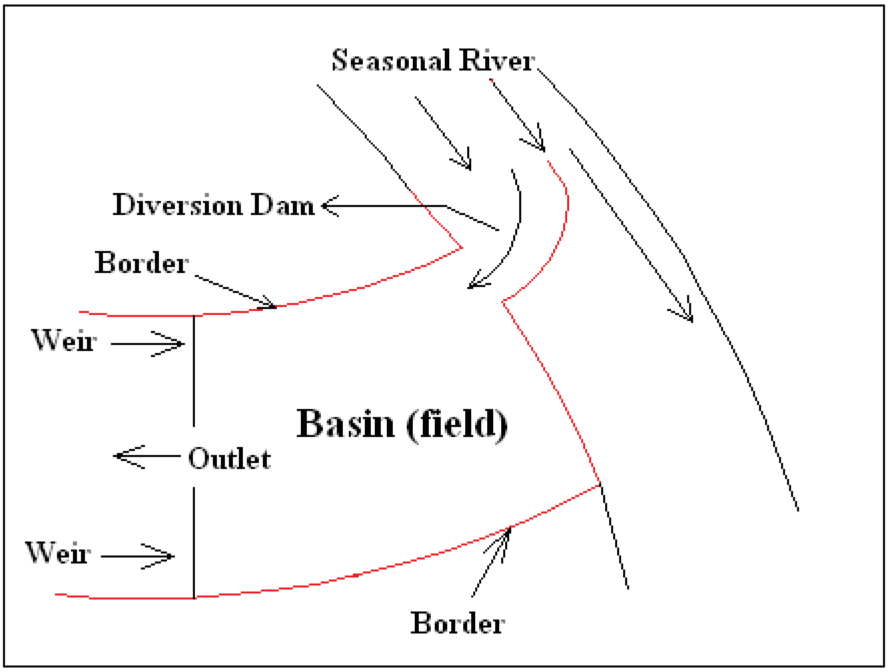

Fig. 2: A scheme of Bandsar in Sabzevar region

Area of each field or basin varies between more than 20 m^2 up to hectares. In the homogeneous low steep slopes basins are larger. The steeper the slope, the smaller are the dimensions of basins. The height of boarders in these basins varies between 0.5-4 meters depending on the discharge rate of flood and dimensions of basin.

PRIORITY IN IRRIGATION RIGHT

There are two local agreements two determine the priority in irrigation right:

1- Upstream agreement: Based on this agreement the irrigation right in each flood event is belong to the farmer whose field (Bandsar) is located near the river at the upper point. After full irrigation of upstream Bandsar, the farmer gives the permission of irrigation to the next farmer whose field (Bandsar) is located in the lower part of stream. In the next flood event the irrigation right is belonged to the first farmer again. On the other word the upstream farmer has the right to use water in all flood events.

2- Weekly cycle agreement: due to this agreement each day of week is contributed randomly to a farmer. Depending on the day of flood occurrence the first farmer to use water is determined. The next farmers are determined based on previously randomized schedule. These Bandsars do not benefit floods but generally they use surface run off of slopes.

Fig. 3: TM False Color Composit (FCC 731:RGB**)**

DISCUSSION

As previously mentioned the Bandsar system is invented only in Khorasan provinces. Sabzevar is one of the most important cities of Khorasan-e-Razavi province which has the most number of Bandsars. Previous investigations show that Bandsars had been constructed in regions with 75-257 mm annual precipitation. In Sabzevar, Bandsars are constructed in a region with 194.5 mm annual precipitation. Precipitation regime in this region is Mediterranean in which the dry season occurs at summer and precipitations take place in the winter and early spring. Coefficient of variance for precipitation varies between 25.7-42 percent. On the studied site this coefficient is 35.7%. Yearly average of air temperature in these regions is between 14-26˚C and for the studied site is 16.9˚C. It had been reported that the rainfall/evapotranspiration ratio has a good agreement with the areas of Bandsar development (Arabkhedri, 1996). This ratio is measured to be about 0.027 to 0.078 in the studied site while its value was about 0.9 in the surrounding lands.

Trapped sediments behind the bandsars are rich of organic mater which are consisted of animal manures and crop residues which can improve soil fertility. On the other hand high porosity of these organic residues will improve the infiltration rate of heavy textured soils accumulated behind them. The other benefit of this system is periodical leaching of soil profile through out the root zone with high quality flood water which can control soil salinity within the tolerable limits for the crop in the next season. The main crops cultivated in this system are wheat and barley in rotation with melon and water melon. The other crops are cumin, sunflower and peas which can produce acceptable yields. On the other hand agricultural return flow of Bandsars can recharge the groundwater table for the farmers of lower parts who have limited access to the flood water and in turn have positive social- economical effects for clients.

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HISTORICAL, STRUCTURAL AND ENVIRONMENTAL FEATURES OF THE QANAT IN IRAN

Ghasem Zarei[1], Abolfazl Nasseri[2]

ABSTRACT

Average rainfall in Iran (With 250 mm) is less than one-third of the global average annual rainfall and similar to that of arid and semi-arid countries of the world. For overcome water shortage in Iran, an old and interesting technique called as qanats was devised which convey water from an aquifer to lower-elevation fields. The qanats consist of a horizontal tunnel that taps ground water in an alluvial fan, brings it to the surface due to gravitational force. It provides required water for production of agricultural crops. Construction and exploitation of qanats have some environmental benefits. For instance, qanats waters don't have any contaminations. Also, improving vegetation cover without a biological changes in vegetative population are local achievements of the qanats. Other environmental advantages, historical and structural features in Iran were presented in the paper as detail.

Keywords: Qanat, Irrigation history, Structural and environmental features of the qanat.

INTRODUCTION AND HISTORICAL FEATURE

Water and its resources is development key for Iran. Therefore, the qanats as a main water resource is very valuable natural resources in arid zone in Iran. There are some 22000 qanat units in Iran, comprising more than 170000 miles of underground channels (Saffari, 2005). Some qanat advantages are as follow (Davarpanah, 2005):

a) Utilization of gravity force for bringing out water.
b) Lack of need to fuel, electric power, and motor pump station.
c) Existence of local specialists for building and repairing and dredging qanats and is consistent with culture and environment.
d) Ground water utilization in mountainous regions.
e) The qanats don't impair the quality and quantity of ground water.

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The qanat innovation is belonged to Iranian and has developed in the other countries over the world (Glober, 1992). Also, the Greek historian Polybius in the second century B.C. described a qanat that had been built in an Iranian desert "during the Persian ascendancy" (Saffari, 2005).

The qanats are extended in the arid and semi-arid zones of Iran. The provinces benefiting from important and longest qanats are as follow:

A) EAST-AZARBAIJAN

The longest qanat is Dagh Cheshmeh located in Bostan Abbad - Estyar. It is 8000 m. long and its mother well is 20 m deep. Vakil & Cheshmeh Armanistan qanats are the longest ones in Azar shahr. They both enjoy a length of 6000 m. and the mother wells are 15 and 30 m deep, respectively. The deepest recorded mother well of the region (115 m) belongs to Hassan Abbad and Bareh-khuni of Mamaghan. Kalantar qanat in Tabriz and is more than 10000 m long.

B) KERMAN

There is no agreement regarding the longest qanat in kerman. For instance, Hashu-eieh located in Baghein (31 km long with 22 liters discharge) is the longest qanat according to the Regional Water Organization. Safi-Nejad believes that the Kerman qanat which is 40 km long with the depth of 120 m. of the mother well and 20 l/s discharge is considerable. Petroshevski has recorded the Mahan qanat 50 km and Bastani- Parizi believes that there is a qanat in Kerman which is about 42 km long with a mother- well enjoying 145 m of depth. The most splendid qanat of the province is called pa-ye-kam on the outskirts of Bam with a length of 4600 m 4000 of which is the wet zone. The mother well is 47 m deep. In Bam and Narmashir, Rashidi qanat in Barvat and Fazl-Abbad dates back to Rashid-Al-Din Fazlolah's Children and Gardun qanat precedes Mongols.

C) KHORASAN

Bidokht and Saleh Abbad are the active qanats in Gonabad. Bidokht enjoys a mother well depth of 350 m. with a discharge of 150 l/s irrigating 150 ha of the agricultural lands. The Keikhosro is another qanat in Gonabad with 400 m. depth of the mother well according to Saed-lu. Kurus believes that the biggest qanat gallery in Gonabad is 70 km long. This is probably the one with a mother well depth of 140 m according to Saed-lu. It is believed that the Sanabad qanat in Mashhad is 1200 years old and dates back to pre-Islamic-era.

D) SEMNAN

Shah-rud qanat is considerable due to its discharge in this province which exceeds 250 l/s with a mother well enjoying 60 m of depth. It is to be notified that this qanat is the only source of water in the town.

E) YAZD

The claims concerning the lengths of qanats in Yazd seem rather doubtful. Saed-lu believes that the longest canal is 120 km. long with a 116 m deep of mother well while Afshar claims that the longest one is and 84 km. long and its mother well enjoys a depth of 100 m. The Programming and Budget Organization have announced that the qanat of Mahdi Abbad Rostagh whose mother well is 50 km. away from the appearance with a discharge of 40 l/s is the longest. Djalal Abbad qanat (48 km. long 80 m. deep of mother well) is considerable as well. Sadr Abbad qanat with a 70 km gallery is considered long. As well one of the ancient qanats of Yazd Yaghubi is 900 years old.

ENVIRONMENTAL FEATURE

This structure was made by an ancient civilization to a specific environmental condition. The qanat water does not transport any external materials and so is friendly environment. Water transportation to surface consumes energy, which raises water-harvesting cost. Although, electric pumps are using in wells but in most rural regions pumps works with fossil energy, so qanats that works with gravity energy can reduce production cost and has positive effect on environment. It had and has high effect on economic, social and cultural life of huge plains in Asia, Africa, and South America. The qanat improves ornamentals and agronomy, and new ecosystem helps neighbor lands to preserve land race species, typical genitors, old trees etc. The qanat improves wild animals. There is a shelter for migrate birds and drought escape animals. Researches for suitable fish species for pisciculture in qanats make some financial advantages. Solute water and suitable media for high quality red and poultry meat without any contamination are some qanats advantages. The qanats regulate ground water discharge with optimum watersheds hydro-geologic cycle. There is no negative effect on watershed.

If qanat discharge the underground reservoir, lagoon, or marsh, it will have negative effect on environment but if it regulates the period or extent of underground reservoir, it will have a big positive effect. Because lagoons are hatching place of birds, and discharging these by an undesired qanat may destroy the animal species and led to migrate them to other regions.

STRUCTURAL FEATURE

The methods used for qanat building in Iran today are not greatly different from the system devised thousands of years ago (Saffari,2005). The building project begins with a careful survey of the land. A qanat system is usually duf in the slope of a mountain or hillside.

The qanat include some wells and one gallery with slope less than earth surface which drainage water from saturation layer or river or wetland by gravity. Figure 1 shows all parts of qanat (Agazari, 2005). The qanat becomes a ditch near its destination. The qanats depths reaches 30 m (the record is about 60m) and can cover distances of many km (the longest Iranian qanat is 70 km long.). A qanat, once built, can exist for a long time, but agriculture with qanats is extremely labor-intensive. Not only is it difficult to dig an underground canal, but it also needs a visit every spring to clean it out. Here, some of important elements of qanat were presented and was demonstrated by Figure 1.

- (1) *Mother well*: is the farthest water infiltrating well.
- (2) *Appearance:* is the place where water comes into view on the surface.
- (3) *Gallery:* is the canal whose section resembles a horseshoe inside the ground enjoying a gentle slope for water conveyance from the aquifer to the appearance.
- (4) Dry zone: is a portion of the gallery between the wet zone and the appearance.
- (5) Wet zone: is referred to the infiltrating walls inside the gallery of a qanat. The discharge rate is directly dependent upon the wet zone.
- (6) Pish-kar: is drilling along the wet zone for having excess to water.
- (7) Shaft: is the dry wells situated across the gallery in order to facilitate soil extraction as well as ventilation and dredging. The distance between two shafts was based on the depth of the qanat and the air passage. The nearer the shafts were to the mother well, the deeper they were.
- (8) Poshteh: is the distance between two shafts.
- (9) Mound: is the soil and sediment extracted from a qanat well, is heaped like a frustum.
- (10) Abandoned gallery: is that portion of wet or dry zone of the canal abandoned.
- (11) Well curbing: is inside the shaft curbing is devised 20-30 cm wide and 40-50 cm high to prevent any collapse. Curbing is done near to the mouth, in the middle and close to the gallery. In mouth curbing they use bricks, stone and mortar to prevent floods, floating sand or every other thing from entering the qanat passage; they block the mouth with brick, stone and mortar. This procedure was once called kamar-gir.
- (12) Kaf-shekani: is digging the qanat gallery deeper due to the decline of the aquifer.
- (13) Baghal-bor: is a portion of the qanat passage is blocked and there is no possibility to unblock it.
- (14) Dredging: is removeing soil and sediments from the qanat galleries.
- (15) Edge Cutting: is widening the qanat passage.

CONCLUSION

Qanat has been made in ancient ages and help to establishment of agriculture in arid and semi arid regions. some of important elements of qanat are Mother well, appearance, gallery, dry zone, wet zone, pish-kar,shaft, poshteh, mound, well curbing, abandoned gallery, baghal-bor, kaf-shekani, The 22000 qanats in Iran with their 170000 miles of underground conduits deliver a total 19500 cubic feet of water per that would be enough to irrigate 3 million acres of arid land for cultivation if it were completely used for agriculture. Utilization of gravity force; lack of need to fuel, electric power, and motor pump station; Existence of local specialists for building; don't impair the quality and quantity of ground water are advantages of qanats. The qanat improves agronomy, ornamentals and new ecosystem helps neighbor lands to preserve land race species, typical genitors, old trees and wild animals. On the other hand the qanats regulate ground water discharge with optimum watersheds hydro-geologic cycle. The qanats are extended in the arid and semi-arid zones of Iran. The provinces benefiting from important and longest qanats are East-Azarbaijan, Kerman, Khorasan, Yazd, Semnan provinces.

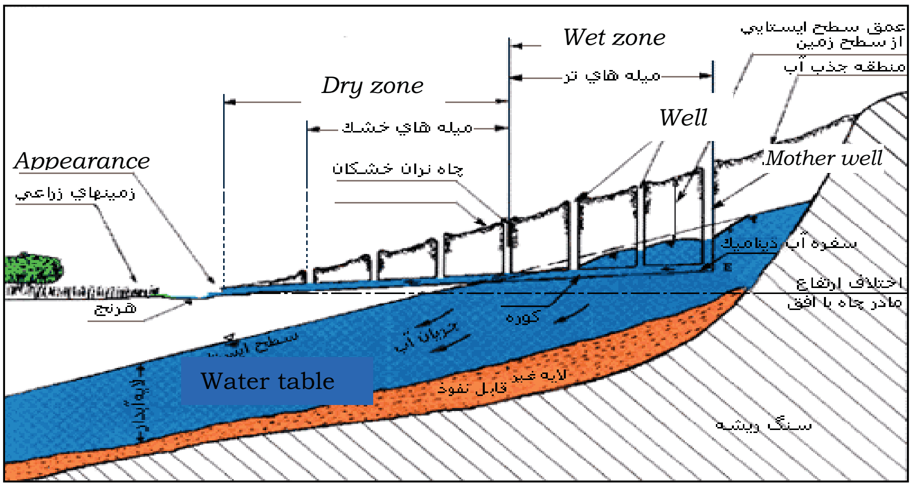

Figure 1- Characteristics and building terms of qanat (Nasseri, 2005).

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THE QANATS EXPLOITATION AND GROUND PENETRATION RADAR

Aynur Nasseri[1], M. J. Mohammadzadeh Fakhri[2], H. Agababaie[3]

ABSTRACT

Exploitation of qanat water is one of the most important problems in Iran and other countriesover the world; therefore this study aimed to deep the understanding of the usability of ground penetrating radar in the groundwater and qanat studies. Ground penetrating radar is a geophysical technique that has been extensively used to map the relatively shallow subsurface features at scales from kilometers to centimeters. It is useful to determine the behavior of groundwater table; to estimate of water content, properties of aquifers and qanats; to detect the hidden canals and qanats, etc.

Key words: Qanat, Ground Penetration Radar (GPR), ground water and Aquifer,hidden canals.

INTRODUCTION

A qanat is one of the most common ways of underground water exploitation in Iran and other dry countries in the world. It is a water transporting system that can reach to surface without having a mechanical force. Its cross-section is shown in Fig1.Lenghts of qanat are from 5km to 30m and its mother well depth is normally less than 50 km. Qanat discharge varies seasonally. Generally, applications of geophysical methods for groundwater exploitation are similar to qanats one.Therefore in the present study, investigations are focused on both ground water and qanats.

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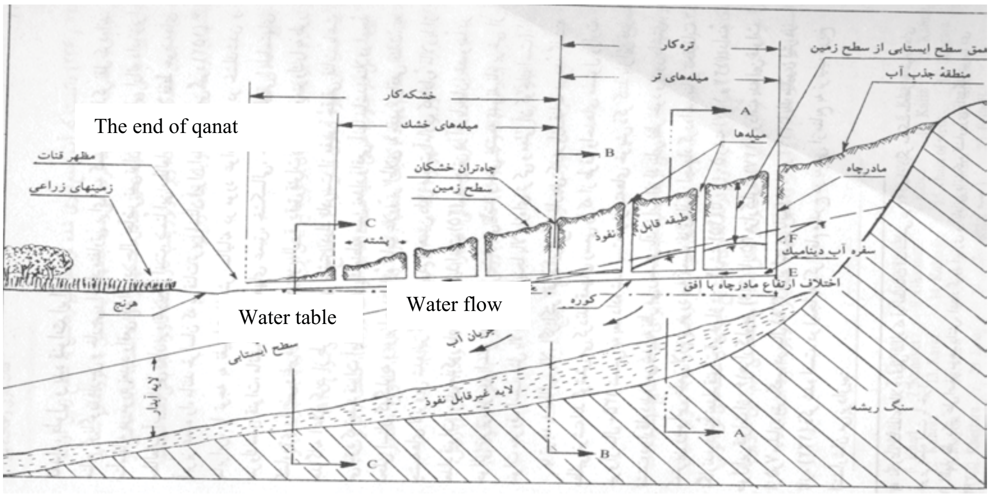

Figure 1. A cross-section along a qanat [1].

Because of the correlation that often exist between electrical properties, geologic formations and their fluid content, electrical and electromagnetic techniques can be employed in groundwater and qanat geophysical investigations.

Ground penetrating radar (GPR) is an electromagnetic technique for measuring the displacement currents in the ground and based on the measurement of the rate of propagation of electromagnetic waves through the subsurface. It is a tool for tracking the movements of the water table that its top has a very high electromagnetic impedance contrast. Also it can be used to locate buried objects; to calculate the change in water stored above a buried object, water content in a hidden canal (such as qanat); to locate metallic and non-metallic objects (such as water pipe), to map the geologic conditions that include depth to bedrock, depth to the water table and thickness of soil and sediment strata on land and under fresh water and the location of subsurface cavities and fractures in bedrock, cavities utilities, voids, fill layers and materials. Some specific applications include the location of underground storage tanks and the delineation of drum piles, the locations of pipes or other buried man made objects such as timbers.

Advantages

GPR measurements are relatively easy to make and are not intrusive. Antennas may be pulled by hand or with a vehicle from 0.8 to 8 kph, or more, that can produce considerable data/unit time. GPR data can often be interpreted right in the field without data processing. Graphic displays of GPR data often resemble geologic cross sections. When GPR data are collected on closely spaced (less than 1 meter) lines, these data can be used to generate dimensional views of radar data greatly improving the ability to interpret subsurface conditions.

Limitations

The major limitation of GPR is its site specific performance. Often, the depth of penetration is limited by the presence of mineralogic clays or high conductivity pore fluid.

MATERIAL AND METHODS:

These EM instruments do not require any ground contact or surface disturbance; therefore, they are rapid, relatively inexpensive, and can be run with little or no exposure to buried toxic materials. The basic principle of operation of the EM method is illustrated in Figure 1. A transmitter coil radiates an electromagnetic field, which induces electrical currents (termed eddy currents, Je) in the earth below the coil. These eddy currents in turn generate a secondary magnetic field (Bs). The receiver coil detects and measures this secondary field. The instrument output, calibrated to read in units of terrain conductivity (apparent conductivity), is obtained by comparing the strength of the quadrature phase component of the secondary field to the strength of the primary field. The apparent conductivity measurement represents a weighted average of subsurface conductivity from the ground surface to the effective depth of exploration of the instrument. The depth of exploration depends on the separation between the transmitter coil and the receiver coil, as well as on the coil orientation (coil axis/dipole horizontal or vertical).

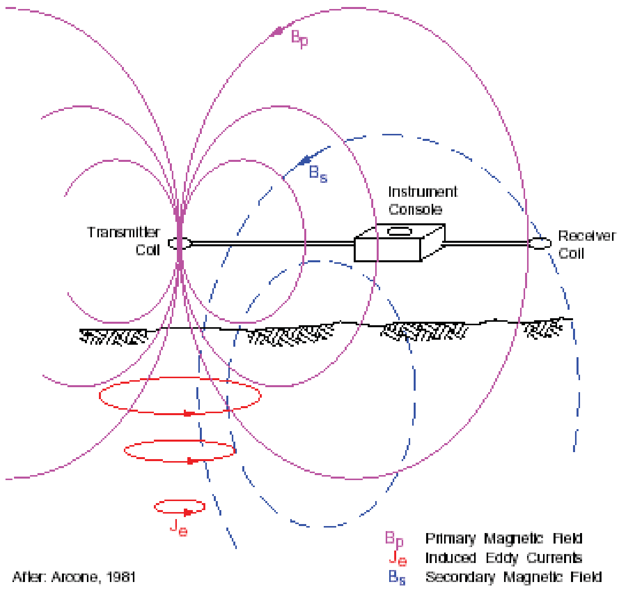

Figure 1. Operation of electromagnetic survey.

In the GPR method, a transmitter is used to send electromagnetic energy into the ground that then reflects from geologic interfaces where a dielectric contrast exists. The reflected energy is recorded by a receiver and produces a picture of the reflected waves. If the system is used over water, it will be placed on or immediately above the surface of the water. The transmitter produces short period (frequencies in megahertz range) pulsed electromagnetic signals at regular time or distance intervals as it towed across or above the surface of the water. Some of this pulsed electromagnetic (EM) energy is reflected from the water bottom and other prominent dielectric interfaces (facies contacts) and returned to the receiver. The arrival time and magnitude of the reflected energy are recorded at the surface by the receiver antenna. Traces from adjacent source locations are generally plotted side-by-side to form an essentially continuous time-depth profile of the stream bottom and shallow sub-strata (including in-filled scour features). Estimated EM velocities can be used to transform the time-depth profile into a depth profile. Velocities are a function of suspended sediment load and can vary appreciably. Figure 2 shows the GPR transmitter and receiver along with the transmitted and reflected waves. Also analysis & interpretation of GPR pulses is depicted in Figure3.

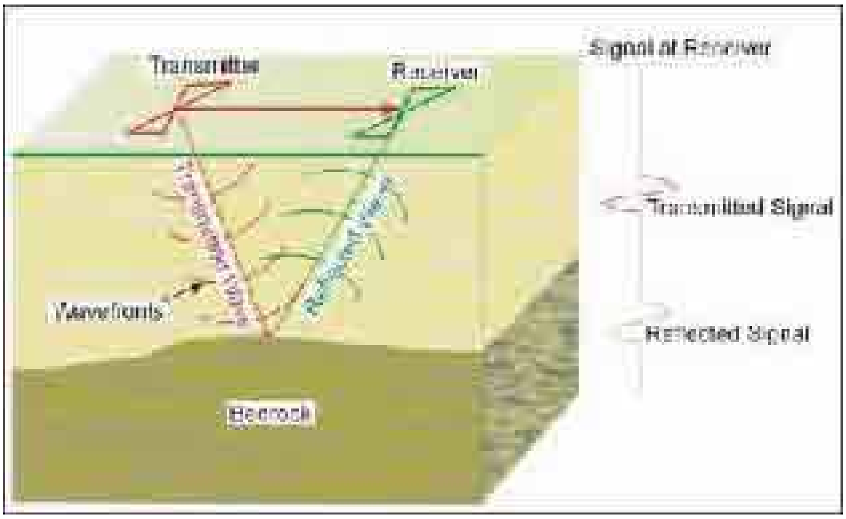

Figure 2. Ground Penetrating Radar System.

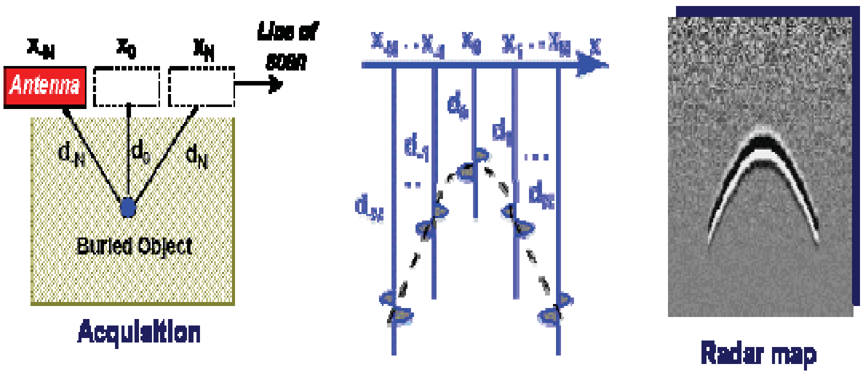

Figure 3. Analysis and interpretation of GPR pulses.

GPR data can be viewed without any processing. However, some processing is often desirable. The common processing steps used are:

1- Distance normalization
2- Horizontal scaling (stacking)
3- Vertical frequency filtering
4- Horizontal filtering
5- Velocity corrections
6- Migration
7- Gain

The above processing steps usually increase the interpretability of the GPR profiles by removing unwanted random noise and enhancing the amplitude events of interest

RESULTS

As illustrated above, GPR is a powerful tool for solving the hydrology and geology problems. This example shows that the GPR led to the detection of abrupt variations in the depth of the water table, which are caused by steeply dipping clay layers. The top of the water table appears at a time between 120 and 170 ns, which corresponds to a depth between13m and 15m.At the abscissa of 285m on the line, the 30ns jump corresponds to an abrupt 1.7m drop of the water table. Notice that the right axis has been converted to depth through the use of an assumed water content profile through the subsurface. GPR has been used to identify soil stratigraphy, to locate water table (Fig 4), to map the location and burial depth of drums, underground storage tanks (Fig 5, 6), to follow wetting front movement, to measure soil water content, to identify the subsurface hydraulic parameter, to assess soil salinity, and also to support the monitoring of contaminants.We propose to use GPR to measure the water content of the shallow subsurface beneath the qanat bed and to detect hidden qanats, underground water flow.

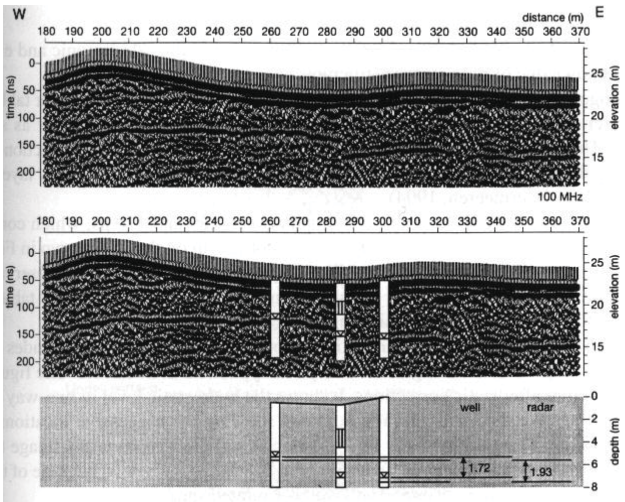

Figure 4- Detection of the top of the water table by GPR [11].

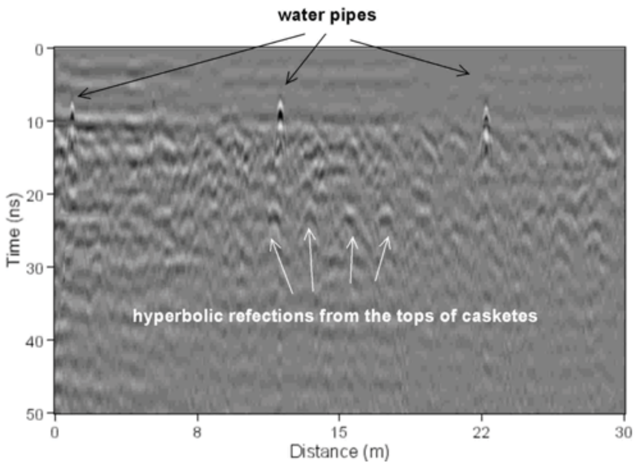

Figure5.Water pipe detection using GPR

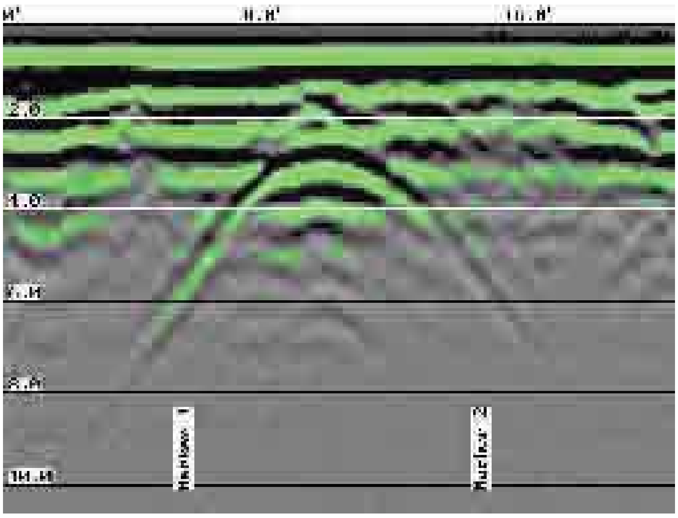

Figure6. GPR profile across the apex of an underground storage tank.
The two markers indicate the edges of the associated metal detector anomaly.

The soil water content is an important variable in soil physics. At small scales, TDR-probes (Time Domain Reflectometry) can measure the water content and especially changes of water content with very high accuracy. But there is still a lack of methods suitable for areas and measurements of heterogeneity of soil water content. Using TDR, a high number of probes have to be installed, which leads to considerable costs and work. To determine small-scale heterogeneities, the TDR also has the disadvantage of disturbing the area by installing probes. For these cases, GPR is an alternative measuring device. It can be used for areas in the range square meters with high spatial resolution. A shielded antenna was used with centre frequency of approximately 750 MHz. GPR measurements were carried out on different soil surfaces (bare soil, grassland and on an organic layer in a forest) and compared to TDR measurements. All measurements showed a good agreement between GPR and TDR results.

Figure 7 (left) shows the in-crease in water content over a 60 by 60 m area measured with GPR, witch was calculated by subtracting the water content map before irrigation from the water content map after irrigation. The resulting soil water increase map for TDR is presented in Fig. 7 (right). Clearly, there is a good general agreement between both methods since they show similar patterns in soil water increase caused by the heterogeneous application of water.

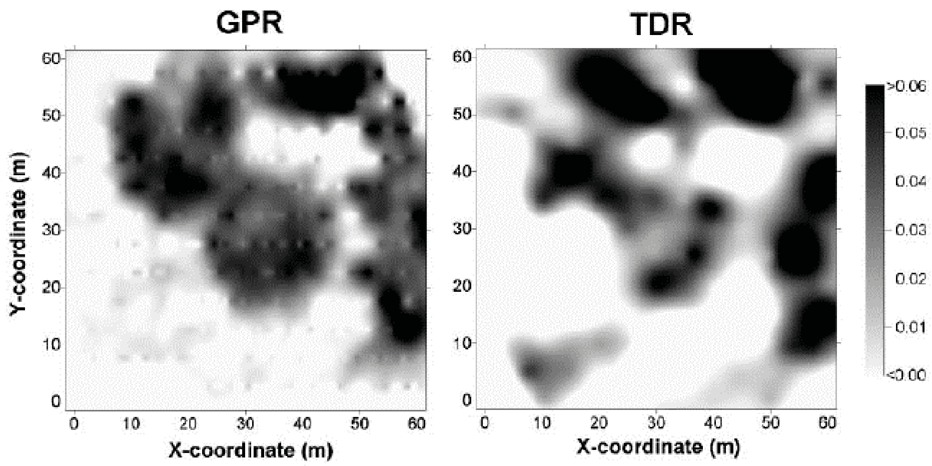

Figure7. Maps illustrating the increase in soil water content obtained using ground penetrating radar (GPR) ground wave and time domain reflectometry (TDR) measurements.

Soil and groundwater quality are geoindicators that assess the effect of human activities on environment. Some potential causes of contamination are industrial and agricultural activities, leakage in municipal landfills, septic tanks, underground storage tanks, ducts and injection wells. Contamination modifies soil properties such as hydraulic conductivity, wettability, dielectric permittivity, swelling potential, crack formation and electric conductivity. The influence of contamination on soil electrical properties allows using geophysical exploration (based on electrical properties or electric waves propagation) to detect the presence of contaminants.

GPRused to calculate the discharge of a river without having any of the measuring equipment in the water. The combined radar data sets were used to calculate the river discharge and the results compared closely to the discharge measurement made by using the standard in-water measurement techniques.

CONCLUSION

GPR is a relatively modern technique; it is used widely in the last decades to explore the shallow subsurface phenomenon In this study, applications of Ground Penetration Radar (GPR) for explorating & exploiting of qanat systems and groundwater were presented. Some presentations are:

- Detecting the water table level; estimating of water content, depth of aquifers and qanats, substructure layer thicknesses; detecting the hidden canals and qanats
- Mapping the location and burial depth of drums, underground storage tanks
- Imaging man-made subsurface structures
- Delineating disposal pits, trenches, and landfill boundaries
- Locating voids and washouts along pipelines, under roadways, parking lots, and building floors

- Delineating inorganic and organic free-phase contamination plumes
- Evaluate mine and quarry rock
- Investigate archaeological sites and cemeteries

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AB-ANBAR, THE ANCIENT UNDERGROUND WATER HOUSES OF KHORASAN

J. Tabatabaee Yazdi[1]

ABSTRACT

Through out history, the people of Khorasan have battled the dryness by innovations to preserve every drop of water that lands from the rare clouds, or from a stream flowing out of distant springs. Water is precious and held with highest respect, whether stored for drinking at an Ab-Anbar, or for washing and farming at the Houz in the middle of their oasis homes and orchards, or sourced at a Qanat spring or Jooy under ground.

How it is that drinking water as cold as a mountain fall is found in desert of Khorasan? Ab-Anbar is an ancient means of water preservation and cooling through an underground building structure. These underground structures have been present in Khorasan and other desert provinces of Iran as public or private water storage facilities, widely used before the installation of public plumbing systems in the late 1950s. Although today many of these structures are still functional most have been protected by the Historical Heritage Society, for restoration or viewing by the public as museums.

Khorasan natural dry climate and the massive surrounding deserts have been a breeding ground for many designs of Ab-Anbars. Today the existing number of such facilities stands in the province of Khorasan. Usually these structures are built in populated areas, also there are some forms of such structures on old trade routes and roadways leading to and from populated towns.

The proposed paper is to be considered the history of Ab-Anbars in Khorasan as well as other aspects such as types, components, construction methods and materials together with water supply and withdrawal systems.

1. INTRODUCTION

The term ab-anbar is common throughout Iran as a designation for roofed underground water reservoir.

The ab-anbar was one of the constructions developed in Khorasan (north east of Iran) as part of a water management system in areas reliant on permanent (springs, Qantas) or

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on seasonal (rain) water. A settlement's capacity for storing water ensured its survival over the hot, dry season when even the permanent water supply would diminish. Private ab-anbar*s* were filled from Qantas (man-made underground channels), while surplus flood water could often be stored in open tanks, as well as in the large, public, covered cisterns. Water was brought to the ab-anbars by special channels leading from the main quanta or holding tanks and was controlled by sluice gates. The ab-anbar, with a proper ventilation system, could then provide cool water throughout the summer months. Often rooms or pavilions were built within the complex of the ab-anbar to provide a comfortable resting place as well.

Two types of structures have been noted, a cylindrical reservoir with a dome and a rectangular one supported by piers or pillars each was marked by a portal. The portal opened into a steep, barrel-vaulted passageway, leading down to the reservoir.

The prime objective in constructing an ab-anbar is to provide a totally waterproof container for a large volume of water while allowing for proper ventilation and access. The excavation was lined with overfired brick and it was then covered with a layer (about 3 cm) of waterproof mortar (sarooj). Larger ab-anbar*s* were often lined with an additional double layer of bricks, covered with another layer of sarooj of slightly different composition, and finished with a hard plaster coat.

Ab-anbar*s* are built in towns and villages throughout Khorasan, as well as at crossroads, caravan series. While town ab-anbar*s* may be filled with rain water or from Qantas, most ab-anbar*s* along caravan routes are filled from the spring torrents of nearby streams; during the dry season gradient weirs are constructed in the stream bed in order to divert water to the ab-anbar*s* when the winter snows melt and the streams rise.

2. MODE OF CONSTRUCTION

Ab-anbar*s* built inside private dwellings are usually square or rectangular; public ab-anbar*s* in towns or along the caravan routes are generally round. While the former have a flat roof and are often built into the foundation of the house, the latter have a distinctive hemispherical or almost conical roofing.

Water remains quite cool inside the ab-anbar, since it is generally built beneath ground level and is insulated by very thick walls. In the south of Iran, most particularly in Yazd province, one or more ventilation towers (*badgir*) is built along the edge of the ab-anbar′s roof, directly on the tank wall and connected by a duct to the upper part of the ab-anbar chamber under the domed roof. Fresh air entering through these ducts keeps the air inside the ab-anbar chamber circulating and the water cooled. In the case of ab-anbar*s* with domed or conical roofs, the center of the roof is sometimes pierced, and a short ventilation chamber made of brick is built directly over the ab-anbar chamber. A duct inside the ventilation chamber leads from the openings or slats (that catch the breeze on top) directly inside the roof, again circulating air inside the ab-anbar chamber. The height of these ventilation chambers is generally about one meter, though some can occasionally be seen that reach a height of two or even three meters (Fig. 1)

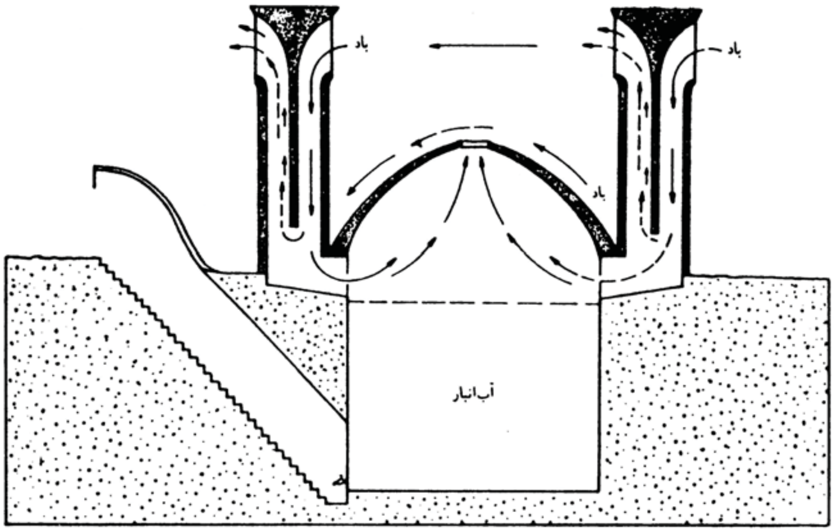

Figure 1: Cross section of Ab-anbar with ventilation tower

3. CONSTRUCTION MATERIALS

Materials used consist essentially of stone or baked brick with lime-mortar and plaster. After the pit that will house the ab-anbar has been hollowed out, the bottom is covered with slaked lime-mortar. When this floor hardens, the builder erects the tank's walls, made of baked brick or stone. The bricks are generally plunged in water before being laid. The filling between bricks or stones consists of lime-mortar. After the roofing of brick and slaked lime is laid, the tank's floor and walls are finished with a coating of plaster.

A type of ab-anbar, made of poured lime-plaster, is considerably cheaper to build. First the perimeter of the tank's walls is marked out, and the earth within the wall area is dug out to the desired depth. Next lime-mortar is poured into the square or rectangular trench until it is filled nearly to the ground level. This is left for a week or two until the mortar settles and is solidified. Then the area of earth bounded by the mortar walls is dug out down to the prescribed floor level. The floor is built by pouring lime-mortar; and, finally, when the walls and floor are dry, they receive a coat of plaster.

Plaster is an indispensable material in the construction of the Iranian ab-anbar, since the essential function, containment of water, is achieved by the watertightness of the plaster. The type of plaster most commonly used, called *sarooj*, is a compound from six parts clay, four parts lime, one part ash, and an amount of seed's pod sufficient to keep the compound from cracking. The first step in the preparation of this plaster is the mixture of the clay and lime, to which water is added. All of this is made into a relatively hard, clayey substance which is worked for one or two days. Next the ashes and pods are poured into this mixture until the various components have been thoroughly blended. This pounding is done with wooden sticks about 10 cm in diameter and one meter long, one end of which has been tapered to serve as a handle. This last step is important, because the more the mixture is pounded and kneaded, the more durable it is. When the plaster compound is ready, it is spread on the walls and the floor of the ab-anbar with a trowel. The next step is to score the plaster surface with a stone that fits in the palm of the hand. This scoring goes on for several days until the walls and the floor of the tank begin to perspire, a sign that the components in the plaster are holding together fast. Only then is the ab-anbar filled with water.

4. DRAWING WATER

Ab-anbar*s* may be provided with a tap. When the place for the tap is reached in the course of construction, an additional pipe for it is built into the wall; and a plaster compound (half clay and half lime) called "batard" is pounded into the space above the pipe. Water is taken from this type of ab-anbar by means of a separate chamber, containing a staircase, about as deep as the adjoining tank chamber. The stairs are wide enough so that persons going up and down with buckets, gourds, or leather bottles will not get in each other's way. Two, three, or even more taps are sometimes installed. A few ab-anbar*s* have been observed to have two separate stairs on opposite sides. In the case of the ab-anbar*s* built alongside roadways, however, the normal procedure is to construct the staircase within the ab-anbar chamber itself, so that the water is drawn directly from the tank.

5. CAPACITY

The capacity of the traditional cylindrical ab-anbar varies generally from 300 to 3,000 cu m. This upper limit is dictated by the fact that the maximum diameter allowed by the method of construction is about 20 m. If the depth of the tank is up to 10 m, its capacity would be about 3,000 cu m. In a few localities the ab-anbar*s* have an even greater capacity, and some exceptional examples have been cited as able to hold up to 100,000 cu m. These are not round tanks, however, but square or rectangular ab-anbar*s* with columns placed in the middle of the tank chamber in one or two rows. These support a roof consisting of a series of domes or barrel-vaults.

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INVESTIGATION ON HISTORICAL LESS- IRRIGATION MANAGEMENT METHOD UTILITY IN AGRICULTURAL PRODUCTION IN YAZD PROVINCE

J. Salem[1], M.R Danaian[1], M.A. Dehgani[1]

ABSTRACT:

Water is one of the important basements in the agricultural production. Shortages of water quality and quantities from the ancient in the kavir area of Yazd province caused utility of specific management method to increase profitability of irrigation .less-irrigation is one of the methods which has been used from the ancient . In this management method, its tried to maximize the profitability of pure profit due to unit volume of water, considering conditions and effective elements.

Biography of agricultural activities in Yazd province shows that less-irrigation method was used for the old times in surface irrigation. This method mainly include providing the best planting pattern and agricultural activities such as vegetation density , fallow and alternation for using precipitation and storing humidity, changing plant time to shorten growth period, planting resistant and tolerable plants to drought.

The quality of using this method in different parts of Yazd was studied. In Abarkooh to keep and preserve pistachio gardens, farmers take the latest water of wheat and irrigate pistachios. In Sadoogh to plant summer crops farmer use the latest water of wheat or barely.

Investigation showed that using this method may increase profitability and exceeding valuation of whole agricultural productions, because agriculture is mixed of different activities.

Keywords: Historical study, agriculture, kavir, less-irrigation (few-irrigation)

INTRODUCTION:

Due to dry and ultra dry climate in Yazd province and little precipitation (mean annual about 105 mm) agricultural activities are difficult .Ground waters resources are the only resources which used for agricultural production. Despite of extended area of province which include 4.5% of whole country but agricultural lands are only 0.74%. This

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percentage of agricultural lands is based on utility of dry land agricultural methods using less irrigation and Qantas water. Basically less irrigation is a technique for irrigated vegetations (Faryab) to use maximum profit of water volume unit and maximum benefit of land unit to obtain maximum pure benefit. Shortage of water resources in agricultural section of province caused extension of using this method before drilling deep wells and 3000 Qantas are constructed.

This article is based on investigation as: Collection and record of native knowledge in agricultural section in Yazd province during 1382-1383(2003-2004)

In this study historical resources around water and irrigation water used .In addition , field study has been done anal , query forms was filled by qualified farmers and experts .Analysis of data and information fulfilled by SPSS software.

Fig 1- Situation of Yazd province in Iran

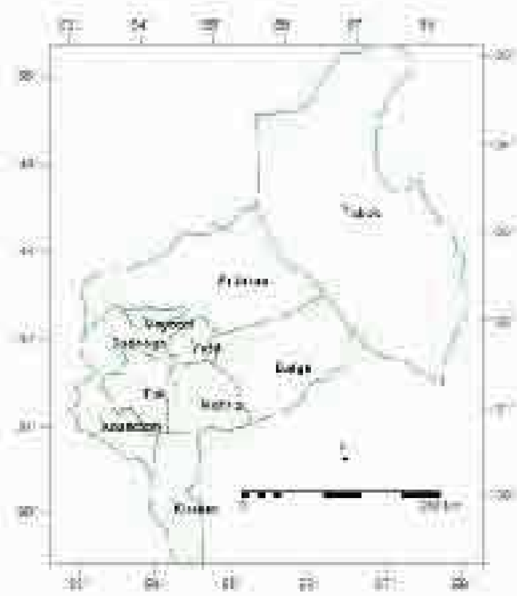

Fig 2- Map of Yazd province

LITERATURE REVIEW:

Sharifi (2003) studied influence of minerals such as bentonite and soil mixture with mineral cartridge (5%) on little irrigation of vegetation and introduced them as increasers of vegetation tolerances facing drought. [9]

Dehgani Tafti (2005) introduced sand as mulch for preserve soil wetness and conserve root and curb. [4]

Silspour reported that applying of plastic mulch may improve efficiency of used water from 4.77 to 6.26 kg/m3. [8]

Solimani poor et al (2004) studied plastic mulch influences on cucumber production and found that benefits coefficient is 3.19 to normal production which is 2.11.

Campos et al (1992) studied red soil mulch effectiveness on cucumber production and report that production increased to 60 ton/ha rating to 47 ton/ha in normal way. [15]

Amiri Ardakani (2002) reported the using of khake-sokhteh (burned soil) in Vashanaveh of Kahak (Qom) to reinforce hazelnut gardens.

Naraya Nasami (2002) reported using of clay, red soil, salt and calcium carbonate in ancient India. [17]

Amiri Ardakani (2002) reported a kind of irrigation management to combat crack at pomegranates [1] which is confirmed by Hydary (2003). [2]

1-LITTLE IRRIGATION IN LIGHT LANDS DURING WINTER AND SPRING TO PREVENT DRYNESS IN SUMMER:

Since, irrigation on level lands is more easy and exact, farmers tried to shape slope lands as small trusts and fix them with rocks (boulders), which prevent to soil leaching and waste of water(fig 1). Channel slope and erosion of walls and bed is decreased by constructing pads (clappers) to conserve more water in dry times. Karts (land section or partition) in village of Taft are around 25 to 35 m2 and in slope lands 10 m2, length of karts normally decreased to 7 m (fig2).

2-LITTLE IRRIGATION CONSTRUCTING SMALL SINK AROUND TREES (AGENE BANDY) TO DECREASE TRANSPIRATION OF SOIL SURFACES:

In drought times or dry seasons, farmers are concentrated to irrigate trees. In this condition just trees are watered. Due to canopy cover area of each tree, circular basins (karts) are made and filled with water. The other parts of land are cultivated to conserve the soil wet and absorbed by trees. This kind of irrigation is named as Jabieh Bandy. Irrigation Jabieh is ploughed and fertilized by animal manure to minimized surface transpiration (fig3).

In this innovation, water need of garden is minimized according to: Te= Eterop [Ps + 15(1-Ps)]. Which:

Te= need water in critical condition (Volume/ area unit)

ET= need water in normal condition (volume/ area unit)

PS: wet percentage of land

3-LITTLE IRRIGATION USING DIFFICULT MULCHES TO PREVENT SOIL SURFACE TRANSPIRATION:

For old times , wind sand was used to conserve soil wet in Taft for production of cucumber and the other summer crops in Taft.(Yazd province),(fig 4,5,6).To conserve wet in farm, decrease soil surface transpiration and prevent grounding when harvesting of alfalfa and so keeping of its root. For small saplings which need more wet washed sands are added around the root to conserve wet in early years.

Black sand (Rig-e-Siah) which is a kind of shale is used to grow summer crops seeds in Nasrabad (Yazd).

Bentonite and minerals cartridge which is mixed with soil (5%) is introduced by Sharifi as increased of vegetation tolerance to dryness.

Straw, date's foliage, walnut leaves are used as soil wet keeper. Animal manure as a thin layer is applied to keep wet in alfalfa and orchard frees while water shortage.

In recent years, plastic foils are used to keep wet in summer crops. Before cultivation narrow partitions (kart) are formed and covered by plastic foil, then seeds are planted. In this way , water is consumed to ¼ normal volume .Tunnel cultivation using plastic foil for cucumber , tomato, water melon, marrow is normalized , which decrease water consumption and protect weed growing and so to premature of product, accelerate germination of seeds due to high temperature under the tunnels and decrease damages of storm and hail.

Using mulches of tree's leaves, decayed animal manure, mineral materials may conserve humidity and cause strengthening of soil. Several kind of weeds are applied by farmers to cover the soil in front of sunlight, wind and storm to prevent of soil surface dryness. As farmer believe, garden weed or wild millet consume little amount of water and food but it has more advantage.

4-LITTLE IRRIGATION WITH SOIL OPERATIONS TO PRESERVE SOIL MOISTURE:

In dry season, around the trees are ploughed slightly after every irrigation to prevent soil surface transpiration, in this way without any damages for trees, duration of irrigation will increase to 2 times. To keep soil moisture and grow seeds in good condition , soil is scraped by rake after planting the seeds and primary irrigation, which preserve soil humidity for a long time , this way named as: <<Rehtah kashy>> . This method may break soil and prevent capillarity and deep transpiration to combat dryness and water shortage.

Black marl and red shale which are exposed in the area were used to modify the soil texture (30ton/hec) in Nasrrabad named as :(Rige-siah) and Eslamieh, zainabad, Taft named as: (khak-e- sorkh).

Using a kind of soil by the name of khak-e-sokhteh (burned-soil) in hazelnut gardens of Vashnovah village of Kahak (Qom) is reported by Amiri Ardakani.

5-LITTLE IRRIGATION USING CANAL AND LEVEES (JOO AND POSHTEH):

Summer crops planting are done in Joo and poshteh method, because it's believed that more water would be saved. In this way, 1/3 of soil surface or canals which is covered by gravel will be drowned and levees will keep water for crops, consequently transpiration is decreased to 1/3. This method was named as :<< Moreh kary>> (fig7).

6-LITTLE IRRIGATION WITH BUILDING MOUND BETWEEN THE TREES:

Soil mound with one meter width are made in Almond and pomegranate orchards, after spring time ploughing. The other way to prevent of stress to trees is using mound with 0.5-0.7 meter height and 1 meter diameter which is named as:<< Band and pazman >>(residual soil) or (khak dehi paye derakht). The soil of mounds are exposal to the sun and changeable with land soil for next year which may reinforce fertility of soil (fig11).

This method may intense prevent of cold stroke of curb of pomegranates trees, transpiration stress in leaves before reaching water, and so crack of pomegranates [7].

7-LITTLE IRRIGATION USING MANURE PIT (CHAL KOUD OR KOUD DEHEE) IN SUMMER CROPS:

There was a method in planting of watermelon and marrow which used holes(50*40cm2) filled with soil , 1/3 decayed animal manure and 1/3 range bushes such as Peganum Harmala, Ephedra Strobilacea, Hertia Angustifolia and amount of garden leaves and chips. Using this way may preserve water in holes due to high permeability and reinforce soil fertility caused by manures which leads to prolog irrigation duration.

8-LITTLE IRRIGATION USING PLANTING MANAGEMENT:

There were found several plantation management in village of study area:

a- Discipliner plantation to adapt with drought.

A cultivar land is divided to: a strip around (1/3 area) for fruit trees and the inner part (2/3 area) for farming which is named as:

Derakht kary va Sadeh kary (fig 8).In wet years whole land is planted, but in dry years or summer just trees are irrigated and inner part is fallowed. Spring planting inclusive: wheat, barely, cucumber in middle, part and after harvesting would be ploughed immediately. This manner is managed to control fluctuation of water resources (Qantas and springs) and maximize water utility.

B: selection of adaptable plants

Pomegranates, Almonds, Berries, walnuts are selected trees which are adapted with dryness.

Alfalfa, turnip, carrot, summer crops and cereals are planted in wet years but irrigated spring barely or wheat and peas are cultivated in dry years. Off course in ultra drought these kind of culture are fulfilled under the shadow of trees, solely (fig…).

Considering to harvested water from Qantas or spring more area of surrounding lands of village would be selected for farming or managed to be left.

In drought, just closest gardens to water resources would be irrigated and the others would be left. In this way, peach, hazelnut, pear and cherry trees are planted in the closest gardens to the water resources, almonds are cultured in far gardens, almonds, and berry and oleaster are planted, sparsely.

Vegetables, cucumber, marrow and tomato are cultured around the pool. In some villages, every family has a small land around the pool or Qantas to be able to supply its needs.

Special irrigation duration selection is a kind of management which is allocated for vegetables and summer crops, for example if duration is 16 days its increased to 18 day , but in every 8 day one time water is used for vegetation and summer crops. This is named as : Ab-e-tar(faster irrigation) Alfaalfa,cotton.summer crops , wheat , barely and pomegranates , pistachio are cultured in separate lands in plain village which have more stable water condition oleaster ,pedeh,berry,willow are planted in the margin of water canals. Wheat, barely, alfalfa, cotton, madder and beet are cultivated in the pistachio gardens of Ardakan, solely and marginal trees are pedeh, oleaster and tamarisk. In more dry areas, pistachio are selected to be cultured in salty and alkaline soils of Chahafzal (Ardakan).

9-LITTLE IRRIGATION USING WATER ABSORBING MATERIALS:

Red soil (Gel-e-sorkh or khak-e-sorkh), Black gravel (Rige-e-siah), salty soil (khak-e-shoreh or gel-e-yogheh) are used material to modify soil texture. These kinds of soils include marl or clay which keep water and were used with animal manure to reinforce the soil. In Taft, Nasrabad percentage of water absorption and absorbable potassium ratio of some samples were tested in lab that is 38% of weight and 292 ppm.

Salty soil named as shoreh which is a kind of clay and evaporational sediments including K,Fe an Mg were used for pomegranates, wheat, barely, cotton, alfalfa, beat and poppy , mixing 1/3 animal manure.

10-LITTLE IRRIGATION WITH ELIMINATING LAST WATER:

In dry years, farmers plant wheat and barely in fall and winter, and irrigate it. In spring that orchard trees and vegetables need water last irrigation would be eliminated. In Abarkouh, last eliminated water is given to pistachio orchards and summer crops.

SUGGESTION:

1- Publication of valuable experiments of kavir area farmers such as Yazd and as native knowledge.
2- Support of village to use native knowledge of little irrigation or providing new methods to keep village stand up.

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INDICES:

Fig 1: less irrigation with terrace building for wheat growing (Sanij)

Fig 2: less irrigation with partitioning (little partitions 3*4 m2) (Sanij)

Fig 3: less irrigation with making sinks around the trees.

Fig 4: less irrigation using sandy mulches (Aliabad).

Fig 5: less irrigation using black sandy mulches (Aliabad).

Fig 6: less irrigation using plastic mulches (Hemmatabad).

Fig 7- Little Irrigation with building mound between the trees (Nir).

Fig 8- Discipliner plantation to adopt with drought.

Fig 9-Discipliner plantation to adopt with drought, potatoes and beans within almonds garden (Sanij).

Fig 10 -Nasrabad black sand mine.

Fig 11- Ephedra Strobilacea is used in manure pit.

EVALUATION OF ECONOMICAL AND HISTORICAL IMPORTANCE OF EXISTING RESERVOIRS AND GANATS IN SHAHROOD SUBURB

Khalil Azhdary[1]

ABSTRACT:

Iran has situated in hot and dry zone, so Iranian have been understood the value of water from long time ago. This factor was the important reason for familiarity and optimum use of water resources by the technical people. If we carefully see the construction of reservoirs, ganats, locks etc we can understand that each of them has been constructed based on technical and engineering principals with respect to climate conditions in each area. Ganats and reservoirs of Shahrood area show the importance of water resources use in past years. Present research work has been conducted based on importance and old of ganats and reservoirs in Shahrood suburb. Results of study showed that there were 100 ganats in shahrood and Bastam up to 55 years ago which are working only 10 ganats in present time. In Bastam the biggest and full water ganat is Sadeg Khan ganat and it is working more than 200 years. This ganat belong to different people and discharge of that is 50 lit/s. In a arid area like Shahrood such ganat improves the Bastam agriculture and it is so important to environment of this area. It is irrigating more than 200 ha gardens in Bastam and increases the economic in this area. The optimum use of water of this ganat and Black ganat in Galeh Now Kharagan village and springs in Meyghan are the main objectives of their designers.

Key words: Ganat, reservoir, spring, discharge, tube well, volume of water.

INTRODUCTION

All living beings of earth require four elements water, soil, air and light for continuity of existing. For this reason may be old Iranian people believed these are respect. Water is the shear of creature body from one side and from another side it is working as a human enemy.

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Ganats and springs are the important resources of each country. In arid and semi-arid zone the importance of this resources is double. In this countries, deficit of water is not improving the agriculture and environment of such area have so many problems.

Saem (2005) reported that for drinking and agriculture propose, ganats are the only water resources in Shahrood before 45 years ago, but after some times discharge of ganats limited and decreased. Azhdary (1999) reported that controlling of ganats and springs water is effective method for solving the economic problem.

The big area of Iran has arid climate with less rainfall in half of year, so some controlling systems have designed for providing the drinking water. The reservoirs were saving the water in rainy season for optimum use in other season (Divandary, 2000).

MATERIAL AND METHODS

GEOGRAPHICAL SITUATION

Shahrood situated in southern part of Alborz Mountain in east of Semnan and west of Khorasan state. It has limited to desert from south. Shahrood area is 51420 km^2 with longitude of 54^o 25’ 57” to 57^o 9’ 34” and latitude of 34^o 22’ 37” to 37^o 19’ 04” and has1321 miter height from sea level. This area has 160 mm rainfall in year and it is one of the Semnan state city. This city has 7 part and 296 village. Shahrood has 10 in depended watershed. Figure 1 shows the Shahrood area.

EXISTING LANDS

Study of different references shows that each part of Shahrood has a big plain. Water resources are situated in plains in each part of area. Famous plains are: Shahrood plain, Bastam plain, Mojen plain, Byarjomand plain, Mayamey plain, Torood and Khartouran plain. Bastam is one of the Shahrood part and it is very important incase of agriculture. Bastam has so many garden with different fruits like grape, pear, nut, cherry and apple. Tomato and potato are the important vegetable of this area. Bastam is in east part of Shahrood and it has a watershed. There were some ganats and springs in this watershed long time ago but nowadays unfortunately few number of ganats are active. There are so many tube wells also in this area. Figure 2 shows the Bastam watershed.

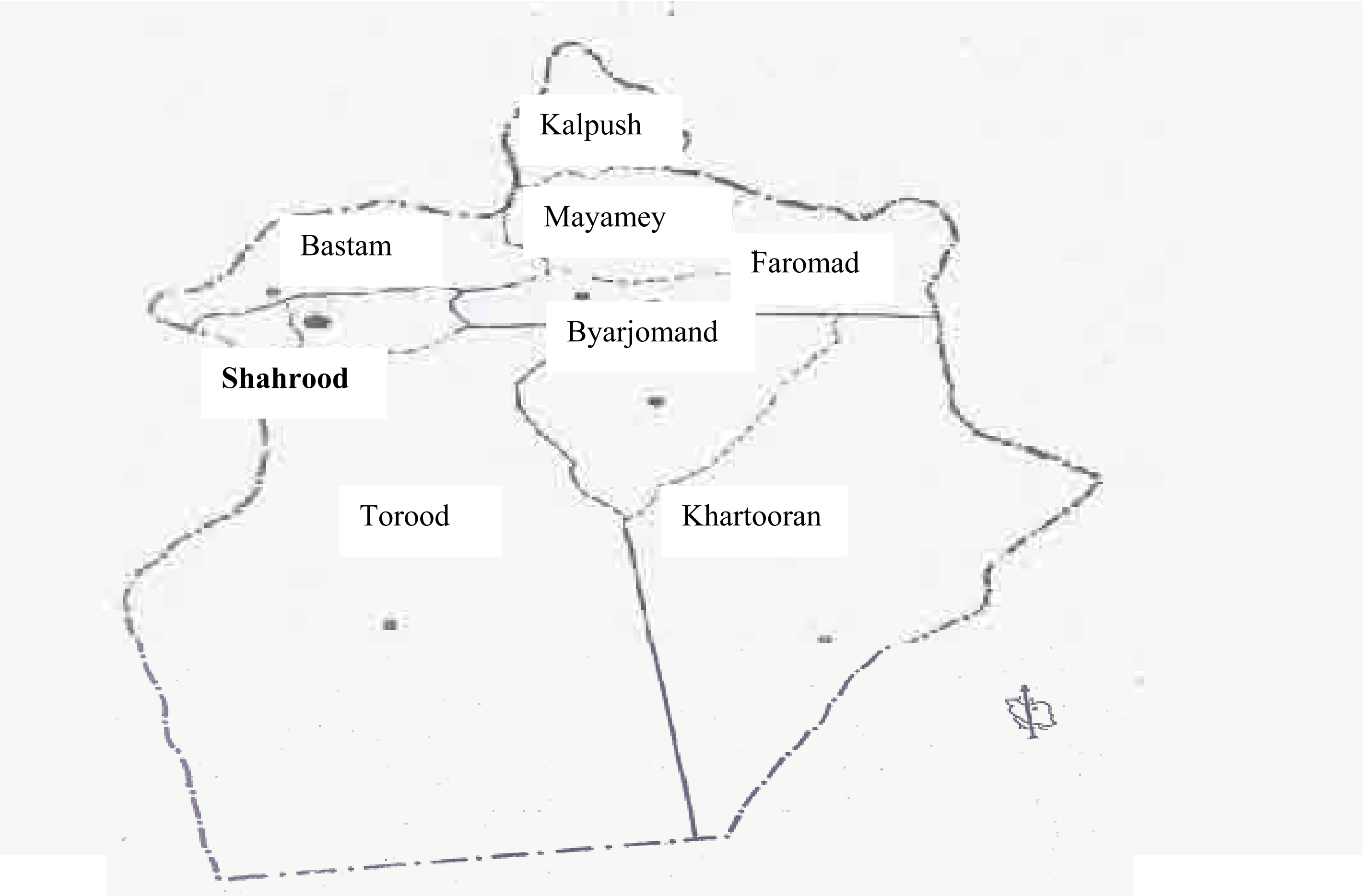

Figure 1. Shahrood map with related suburb

In this research work history of the water resources in Shahrood and Bastam plains are evaluated. The study was carried out for evaluating the water resources like ganats, reservoirs, springs and tube wells in this area. In this study at first plains are visited so many time, after that references are reviewed which are available in Shahrood Water Organization. Results of this part of study are presented in table 1,2 and 3. Table 1 shows the number of ganats, springs and tube wells in Shahrood and Bastam area. Table 2 and 3 shows discharge of these water resources.

Nowadays there are only two important ganats in Shahrood and Bastam. One of them is Shahrood City Ganat with 125 lit/s discharge. It is using only for drinking water in Shahrood. Another one is the Sadeg Khan Ganat with 52 lit/s discharge which is working for agriculture purpose and irrigating more than hundred gardens in Bastam.

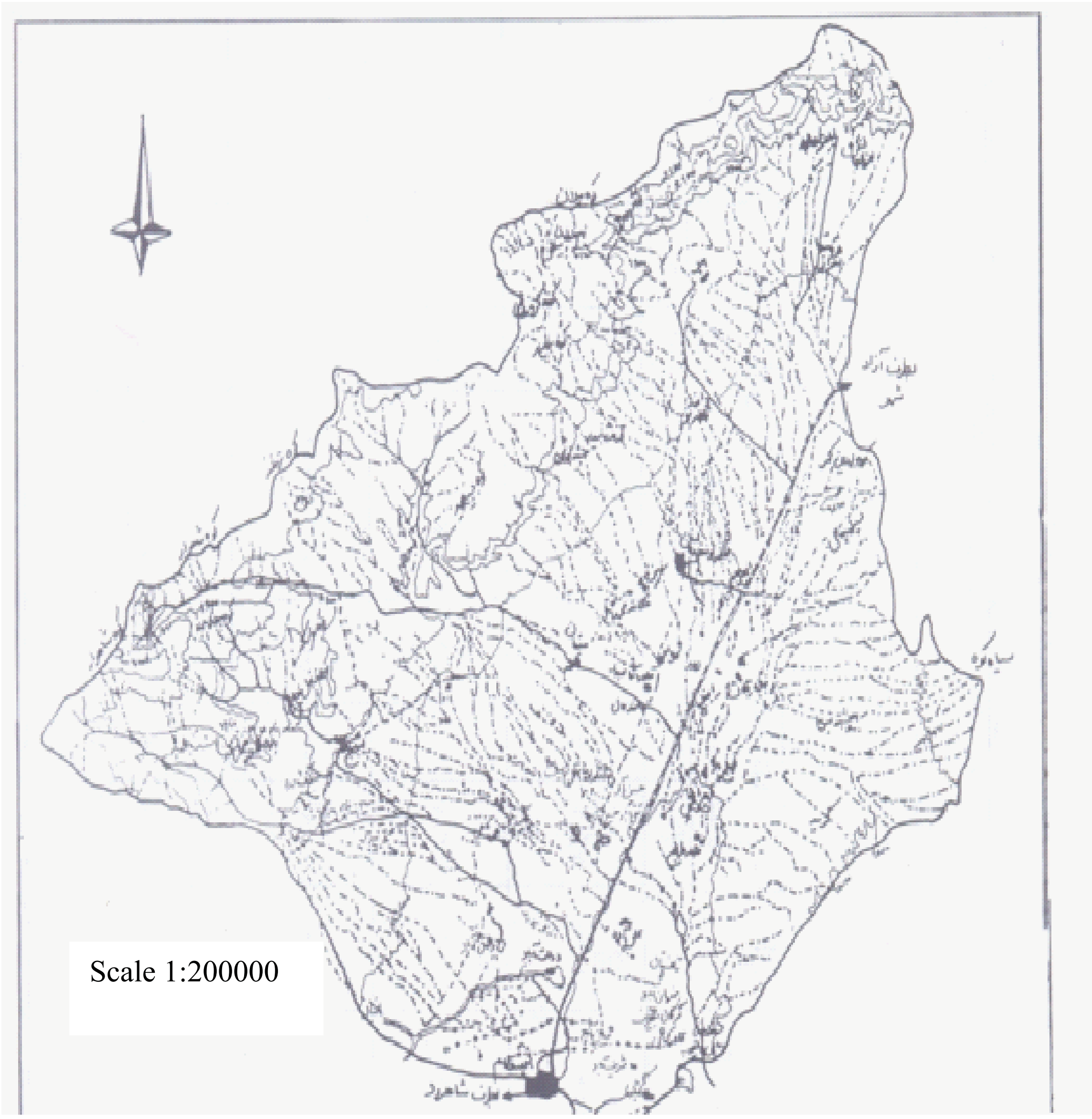

Figure2. Bastam watershed

RESULTS AND DISCUSSION

Water resources changes in two main plains of Shahrood and Bstam are presented in tables 1, 2 and 3. This tables show that water resources changes are only incase of gnates and tube wells in last 50 years and springs do not show any changing. Table 1 reveal that there were 44 ganats in Shahrood plain 50 years ago and nowadays only one ganat is working. This table shows that number of ganats are decreased more than 40 time or 98 per cent in this period and number of tube wells have been increased from 0 up to 400 in same period.

Table 1 also revealed that in Bastam plain number of ganats has decreased from 95 to 15 in last 50 years, it means 85 per cent of ganats are out of work in present time.

Table 1. Number of ganats, springs and tube well in Shahrood and Bastam in 50 years

plain	ganat	spring	Tube well	year
Shahrood Bastam	44 95	6 54	0 0	1955
Shahrood Bastam	37 89	6 54	34 13	1965
Shahrood Bastam	24 89	5 54	93 90	1975
Shahrood Bastam	5 49	5 54	250 200	1985
Shahrood Bastam	2 23	5 54	355 296	1995
Shahrood Bastam	1 15	5 54	424 375	2005

Table 2. Discharge of ganats, springs and tube wells in Shahrood

year	Discharge (MCM/year)		
	ganat	**spring**	**Tube well**
1955	14.2	2.4	0
1965	11.6	2.4	35
1975	7.56	2.3	75
1985	4	2.2	104
1995	1.5	2.2	120
2005	1	2.2	135.1
-1995	**16.6**		
-2005	**138.3**		

MCM= million cubic meter

Table 2. Discharge of ganats, springs and tube wells in Bastam

year	Discharge (MCM/year)		
	ganat	**ganat**	**ganat**
1955	-	88	0
1965	100	87	4.5
1975	90	86	8.5
1985	26	86	28.3
1995	9.5	86	54.5
2005	7.5	86	72.7
-1995	**188**		
-2005	**166.2**		

Tube wells of this area also increased from 0 up to 375. This table shows that discharge of springs has not changed in same period.

Discharge changes of water resources in Shahrood plain are presented in table 2. This table reveal that ganats discharge has decreased from 14.2 MCM to 1 MCM per year in last 50 years. It means 93 per cent of ganats water has been decreased. The tube wells discharge has increased from 0 to 137 MCM. This table also dose not shows any changing in springs discharge in same period.

Discharge changes of Bastam plain water resources are presented in table 3. This table shows that ganats discharge decreased from 100 MCM to 7.5 MCM per year in a 50 year cycle. This decreasing is 92.5 per cent. The springs of this plain also do not show any decreasing in discharge. This table also shows that discharge of tube wells has been increased from 0 to 72.7 MCM per year.

Table 2 shows that total amount of discharge in Shahrood plain has been increased from 16.6 MCM up to 138.30 MCM per year. It is showing 88 per cent increasing, however table 4 shows total amount of rainfall runoff in Shahrood area is 178 MCM, so it means only 22 per cent of rainfall is runoff and other losses. This study shows that 50 years ago potential of water saving was more than present time. Figure 3 shows the Shahrood City ganat.

For Bastam plain also we can have same interpretation but ganats and springs discharge was 188 MCM 50 years ago and present time it is 166 MCM per year and most portion of water flowing from tube wells. Mean rainfall of this plain is 160 mm and its runoff is 300 MCM, it means surface recharge is more than discharge. Study of water resources in this plain reveal that groundwater table came down few meters in recent years. It concludes that main part of runoff has not used for groundwater recharge.

Table 4. Mean annual rainfall in Shahrood and Bastam

Plain name	Rainfall (mm)	Area (km^2)
Shahrood	170	1048
Bastam	160	1876

Figure 3. Shahrood City ganat

Figure 4. water way of Yagmaey reservoir in Shahrood

Figure 5. One kind of old refrigerator in Mazaj village, Shahrood

Study of water resources in Shahrood reveal that any house in this city had personal reservoir in past (Divandary, 2000). Yagmaey house reservoir is one of the this reservoirs. Figure 4 shows some part of this reservoir. Another reservoir is Ali Akbar mosque reservoir which is big and famous to forty stair. Galeh School Reservoir and Mirza Ahmad Reservoir which is situated in Bastam are other reservoirs in this area.

Study of water resources in Shahrood also shows that there were some old refrigerator for collecting the ice in Shahrood suburb in past. Figure 5 shows one of such refrigerator in Mazaj village of Shahrood.

CONCLUSION

Final results of this research work reveal that the number of ganats and reservoirs in Shahrood and Bastam area has been decreased to minimum level in last 50 years. Nowadays in Shahrood, City ganat and in Bastam Sadeg Khan ganat are working well. This study reveal that number of tube wells has increased with high rate within 50 years. If the increasing of tube wells continues, in 10 to 20 future years amount of discharge will be more than rainfall and any kind of agricultural and industry work be will have so much problems.

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ESTIMATION OF THE REASONS OF QANAT DEGREDATION AND ITS EFFECT ON VILLAGERS' PARTICIPATION
(CASE STUDY OF SIX REGIONS IN THE KHORASSAN PROVINCE)

Mahyar Naseri Moghaddam[1], Ebrahim Mirzaee[2],
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ABSTRACT

Undoubtedly qanat could be one of the Iranian's most creative designs for sustainable use of underground water resources. Controllable application of water by qanat systems guaranteed cultivation of crops in arid and semiarid regions of Iran for more than 2500 years.

Based on the important role of qanets in the ancient lives, establishment, utilization, maintenance and management of qanats were done by all villagers and water consumers.

In recent years development of wells, and oversupply usage of water and the lack of control and supervision by the governmental authorities caused destruction, drying of many qanats and great reduction in their discharge.

Unfortunately, omission and neglect the role of qanat in the villagers' lives also affected their social aspects and communication relationships.

Researches were carried out in the *Khorassan* province, one of the origins of qanats in Iran, where six qanats were under case study. Survey on the subject was done through inquiry forms of specialist of water and soil research center of the area and the rapid rural appraisal (RRA) technique for local inhabitants.

In this study, common problems responsible for destruction of qanats and degradation factors were discussed and applicable solutions for rehabilitation of qanats and participation of locals due to improved management are addressed.

Key words: Qanat, degradation, participatory management.

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INTRODUCTION

Over 2500 years, controlled exploitation of water by qanat has guaranteed agriculture in arid and semi-arid areas in Iran. In many villages, qanat ownership is widely diffused throughout the population, and this widespread stake in the water supply system reinforces social cooperation [2]. We might dare to say the fundamental factor in qanat development and sustainability was ancient people's cooperation and participation in construction, operation and maintenance of this valuable engineering creativity.

qanat essentially consists of a tunnel and many shafts. The shafts provide repair teams with relatively easy access to tunnels when blockages occur, and a special deepest shaft is named *mother well* [4].

Farmers have participated in all qanat construction fields (including locating best sites, excavating the tunnel and shafts, and other related structures) and also in its all maintenance activities. This includes dredging, installation of clay collars and even restoration of qanat after major damages due to floods. In addition, operation of distribution network was performed according to water-rights and some managerial local rules based on their heuristic, which nowadays are known as "water participatory management". The example is bailiff's election by all villagers in order to operate distribution network fairly.

It might be said that water participatory management which has been introduced in recent decades, has been existed in Iran in a traditional way for managing qanats since about 2500 years ago. At that time each farmer had a specific water-right from qanat which he could get due to a certain program. Every thing was managed through a hierarchical system with different levels named as Bone, Varbone, Sarbone etc [5].

In recent years, many countries moved rapidly towards participation growth and development. They have planed on stimulation of water users' cooperative spirit as the most required and effective solution to water shortage crisis.

Unfortunately, in Iran, for several reasons, we have come across the reduction of farmers' participation in all agricultural fields including irrigation. The effect of this reduction of cooperation spirit on qanat as farmers' cooperation and empathizing source has been considerable and besides qanats degradation, main social and cultural problems have been rised.

In this study, common problems responsible for degradation of qanats and some of its factors were discussed. Also, appropriate solutions for rehabilitation of qanats and participation of villagers due to improved management are addressed.

MATERIALS AND METHODS

Research was carried out in the *Khorassan province*, one of the origins of qanat technology in Iran, where six regions were selected for this case study. Survey on the subject was performed through filling the inquiry forms introduced to the Water and Soil Research Center technicians working close to qanat users. The cities which the information was gathered include *Mashhad, Ghoochan, Chenaran, Mahvelat, Boshrooye* and *Kashmar*.

The major topics which were investigated are as follows:

1) Existing qanats in the area and their full characteristics, features, etc.
2) Destruction reasons of the existing qanats.
3) The way people participated in constructing, maintaining and operating of qanat in the past and present, and the trend of participatory changes.
4) The role of governmental organizations in drying out and destruction of qanats.
5) Cultural problems responsible for demise the preservation and rehabilitation of qanat.

In addition, on December 2006 a gathering was held in Mashhad to integrate the attitudes of the villagers (qanat users) in order to elevate their spirit of participation and cooperation and find practical solutions to the water crisis they are dealing with. At this meeting experts from the Water and Soil Research Center participated actively. Through brainstorming technique, solutions were introduced to optimize qanat management and performance.

Currently, the rural problems are investigated using Rapid Rural Appraisal (RRA) technique. A core concept of RRA is that research should be carried out not by individuals, but by a team comprised of members drawn from a variety of appropriate disciplines. The techniques of RRA include:

A) Interview and question design techniques for individual, household and key informant interviews,
B) Methods of cross-checking information from different sources,
C) Sampling techniques that can be adapted to a particular objective,
D) Methods of obtaining quantitative data in a short time frame,
E) Group interview techniques, including focus-group interviewing,
F) Methods of direct observation at site level, and
G) Use of secondary data sources [3].

Chambers (1980) describes the orientation of RRA as a “fairly-quick and-fairly-clean” appraisal, and as opposed to the fast and careless studies (he calls them “quick-and-dirty” studies) and the slow and excessively accurate approaches (“long-and-dirty”) [1].

In this research, during visits to qanats of some of the desert marginal areas thought exchange was done with some of the qanat owners and qanat diggers.

Qanats were chose to cover a wide range of ownership styles (from 20 owners to 400 owners) and technical features. Emphasize was on the qanats which were mostly located on the desert margin. In classifying the examined areas they were divided into two categories:

1) Areas with relatively suitable surface and subsurface resources such as *Mashhad, Ghoochan* and *Chenaran*.
2) Arid areas on the desert margin with a little amount of rainfall such as *Mahvelat, Boshrooye* and *Kashmar* in which qanat plays a vital role in villagers’ lives.

It must be bore in mind that studying the desert marginal areas are of prime importance and other areas were studied in order to make appropriate comparisons.

RESULTS AND DISCUSSION

It can be concluded from the participants' points of view presented in the brainstorming gathering, and also, from analyzing the received inquiry forms the qanats degradation and dewatering reasons are as follows:

1) Rainfall reduction and drought in recent years resulted in underground water resources reduction which eventually caused qanats to go dry. These natural causes make us wonder whether restoring and rehabilitation of qanat are economical or not.
2) Excessive well drilling and exploiting water from deep aquifers has invaded qanats territories. Also the lack of governmental supervision over well drilling in the forbidden plains, not only has decreased underground water level, but also has been the main cause of qanats discharge reduction.
3) Advancement of farming facilities and more water provided by deep wells has made it possible to farm larger areas, which further has increased farmers' expectations on the amount of yield per acre can be obtained from their land. This has lowered the true value of qanat in their mind which in comparison can provide less water for their farms. On the other hand water-rights division by inheritance has reduced the amount of water which can be allocated by each individual, and therefore, less land can be farmed through generations.
4) Extra governmental intervention in rural social organizations, and reciprocally retreat and fade of conventional rural social systems, which were based on tribal hierarchy.
5) The lack of sufficient governmental credits provided for repairing and restoring qanats. Actually, excessive governmental intervention resulted in lack of incentives of the villagers to participate and cooperate further to maintain their own qanats.

It must be pointed out that in spite of the fact that drought has been one of the main reasons for destruction of qanats in recent years, however, it should be recalled that these natural events were in play since the birth of qanat (over 2500 years ago) and never could destroy them in this scale.

By ruminating over the recent years we find out that drought, accompanied with the birth of simpler methods such as drilling deep wells with little or no governmental control over the amount of water extraction has been the cause of qanat destruction in this scale.

On the other hand, one of the major reasons which caused qanat to dry out and left destructed, are deficiency of governmental support which has led to lack of pertaining social incentives. The existence of small farm ownership systems which has been created by the inheritance water-rights also has reduced villagers' participation and cooperation and furthermore has intensified the existing problems.

Also replacements of qanats with deep wells have reduced the tendency for qanats rehabilitation. Some farmers have this illusion that a well is connected to an unlimited water source. This way of thinking has resulted in devaluing the water in their minds. Unfortunately, this attitude has not been corrected by governmental institutions and national Medias.

Having provided the pertaining budget, the government has ignored the rural systems in which qanats were maintained by participatory management of all beneficiaries. In this respect the government overlooked the effective role of villagers in this respect, and took over the qanat restoration affairs completely. In this way the government interfered in the organized, powerful, and old participatory rural system and therefore the farmers gradually had a faded role.

Whenever qanats restoration has been performed by locals and the major part of the budget has been provided by the government, the project has been successful in carrying out its mission. As an example, *Anrag* qanat in *Mahvelat* with 7 kilometers length, 80 meters deep *mother well*, and about 30 liter per second discharge, has 150 water users in a small-farm-ownership system. The qanat has been restored during five years by benefiting from governmental budget and supervision and also the participation and cooperation of villagers. At present the final stages of this plan are being performed.

The last reason but not the least is that the villagers' migration due to encountering droughts has minimized the cooperation of the remaining people in maintaining of the qanats. Where in an integrated village with a more uniform cultural background, related works were done cooperatively. Drying of the existing qanats has caused the villagers to migrate to nearby cities and villages, which has led to social disintegration.

SUGGESTIONS

Qanat can play a very important role in solving the existing water crisis. To bring this to reality some major programs that should be done are listed:

1) Informing villagers of water resources constraints and seriousness of the crisis caused by excessive water extraction and also delineating the usefulness of qanats through different methods especially via media.
2) Putting the farmers in the picture in order to maximize their participation in qanats management and restoration. Also, gradually removing the governmental supervision over qanats' management and increasing its observatory approach. The first step in this regard is to seriously involve the 30% of people's self-assistant which could be added to the 70% of the government budget. By raising the farmers participation, the role of government can gradually be transferred to villagers, and therefore, increase their participation.
3) To achieve the mentioned goals a local association related to qanats water affairs should be established. Its members can elected through the village representatives who share the qanat water. Strict supervision of the government seems essential in this regard. The relevant tasks of the association could be as follows:
   - Operation and maintenance of qanats.

- Coordinating self-assistant budget with governmental budget. Trying to reduce governmental financial role gradually, while at the same time increasing the water user's participation.
- Training young people by experienced qanat diggers and conveying the qanats' restoring and digging techniques to them.
- Updating the traditional techniques and equipments related to qanats construction and introducing modern methods and techniques.
- Gathering and editing a series of applied manuals pertaining qanat construction, restoration and maintenance.

4) Unifying farms which are irrigated by a particular qanat and facilitating the allocation of water shares by the aid of governmental subsidies to uniform farms and encourage farmers to establish a planting pattern in harmony with local conditions that eventually can increase water use efficiency (WUE).

5) Issuing heavy fines to individuals who break the rules and those who invade to water sources. Also, the need for more serious measures imposed on those who illegally use underground water resources. Putting these measures into effect by the government not only has a direct effect on water source preserving, but also identifies the real value of water in the villagers' attitude.

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INVESTIGATING OF WATER DIVERSION STRUCTURES AND IRRIGATION NETWORK IN ANCIENT TIME OF SHUSHTAR CITY TYPICAL STUDY OF DAM, BRIDGE-DAM, CREEK

Abbas Roshani nia[1], Faramarz Zalaghi[2], Mohammad Sallakhpur[3]

ABSTRACT

Mizan dam, Shadorwan bridge-dam and Dariun creek which were constructed on Karoon river in Shushtar city are from old and ancient structures that are located in Khuzestan province. In this paper their technical and engineering specifications have been addressed.

Mizan dam was constructed in Sassanid Shahpur I reign in order to regulate and to divide Karoon river water between 2 tributaries; Gargar and Shotate. this dam has 9 entrances whose buttoms are a little lower than lowest water level of the river. Dariun Creek was dug out down stream of Mizan dam in the Achaemenid Darius I reign In order to irrigate Mianab plain. Shadorwan bridge-dam was built down stream of Dariun creek by sassanid Shahpur I for 2 purposes: 1- To connect either side of karoon river. 2- To raise water level for providing necessary head so that water rivers the Dariun creek.

INTRODUCTION

Water has always played an important role in forming civilazation as the most ancient human civilizations have been formed on banks or rivers. Karoon river in south of Iran has been the origin of many civilizations. Karoon, is the greatest and the longest river of Iran. After leaving Zagros mountains' straits, it enters Khuzestun plain and then flows in Shushtar city flat land, fertile soil accompanied by plenty of water of running rivers of Khuzestun province, it has made this region as one of most important agricultural pivot points of country during the history so that it always has attracted the attention of many rulers. In Achaemenids reign. Their economy which was dependent on agricultural revenues, had made the government to increase formers' revenues and as aresult, country's revenues by developing this sector.

Digging Gargar and Dariun hand – dug creek are probable activities of Achaemenids to develop agriculture. After Achaemenids, The Sassanids attempted to construct and

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develop water installations in Shushtar and managed to create the most unique irrigation network in ancient times.

Although the purpose in constructing these installations was irrigation, their constructors achieved other great purposes such as industrial, commercial, defensive, architectural and etc.

The set of Shushtar mills comprises more than 10 mills which is considered as the greatest industrial set prior to industrial revolution. Utilizing river all around the city, digging moats, accompanied by defensive fences and adopting defensive strategic positions made this city as impregnable in some junctions of history.

- Navigability of Gargar river made the Shushtar a considerable axis at international level in commercial and trade areas.
- Utilizing water in circumferential structures for living on basis of climatic conditions by creating subterranean network under ancient Shushtar city, has formed one of the smartest aquatic architectural forms.

Shadorwan dam and bridge which gained reputation in Iranian legends, were not only one of the most fundamental part of Shushtar irrigation network, but also one of few roads for crossing the Karoon river. Probably kingdom road passed this bridge.

Considering political and economical significance of Shushtar and its water installations, castle of this city served both as control center of these installations and residence of Khuzestan's ruler.

Shushtar served as a center of this province till the past century.

The followings can be mentioned as old aquatic structures of this city:

1. Set of water falls and mills
2. Shadorwan dam
3. Mizan dam
4. Lashkar bridge-dam
5. Dariun creek
6. Gargar river
7. Khak dam
8. Gargar dam
9. Mostovfi and Bateni single – entrance bridge
10. Borje Ayyar bridge
11. Mahi Bazan dam
12. Magham dam
13. Haj Khodaei bridge
14. Suzangar spring
15. Shah ali bridge
16. Sharabdar bridge-dam
17. Dariun creek's water distributor
18. Shahi creek, dam and mills
19. Dokhtar dam
20. Dara dam
21. Chir dam
22. Amir dam
23. Chah Anjiri water tank
24. Gabri dam
25. Gargar bridge-dam
26. Boleiti tunnel

GEOGRAPHICAL LOCATION

Shushtar lies at longitude 48º 20’ east, latitude 32º 30’ north and is 150 meters high off sea level. Shushtar city is located 92 k.m. for off Ahwaz and 222 k.m. for off Persian Gulf and 831 k.m. for off Tehran, respectively.

This city is bounded on the north by Bakhtiary mountains and Dezful, on the west by Dezful and Susa, on the east by Masjed-e-Soleiman on the south by Ahwaz, on the south – east by ramhormoz. The mountains which are situated in this low city and their famous one are as follows:

1- Taft with height of 205 meters
2- Mamazade with height of 494 meters
3- Koohsiah with height of 606 meters

This city had 6 ingresses that are as follows:

1- Mafarian in north, opened facing Mizan dam.
2- Dezful gate was connected to Shadorwan bridge-dam in north – west which Dezful road passed it.
3- Adineh gate in west of city
4- Lashkar gate in west – south side, opened toward Askarmokram
5- Magham Ali gate was located over Gargar in south – east.
6- Gargar gate, opening in east side and crossing the Gargar

This city has an area of 3440 km^2 that old and historical Shushtar served as a center of it and is limited among Karoon river branches. This city is located in an island that is 2 k.m. wide and 8 k.m. long (**Figure 1**).

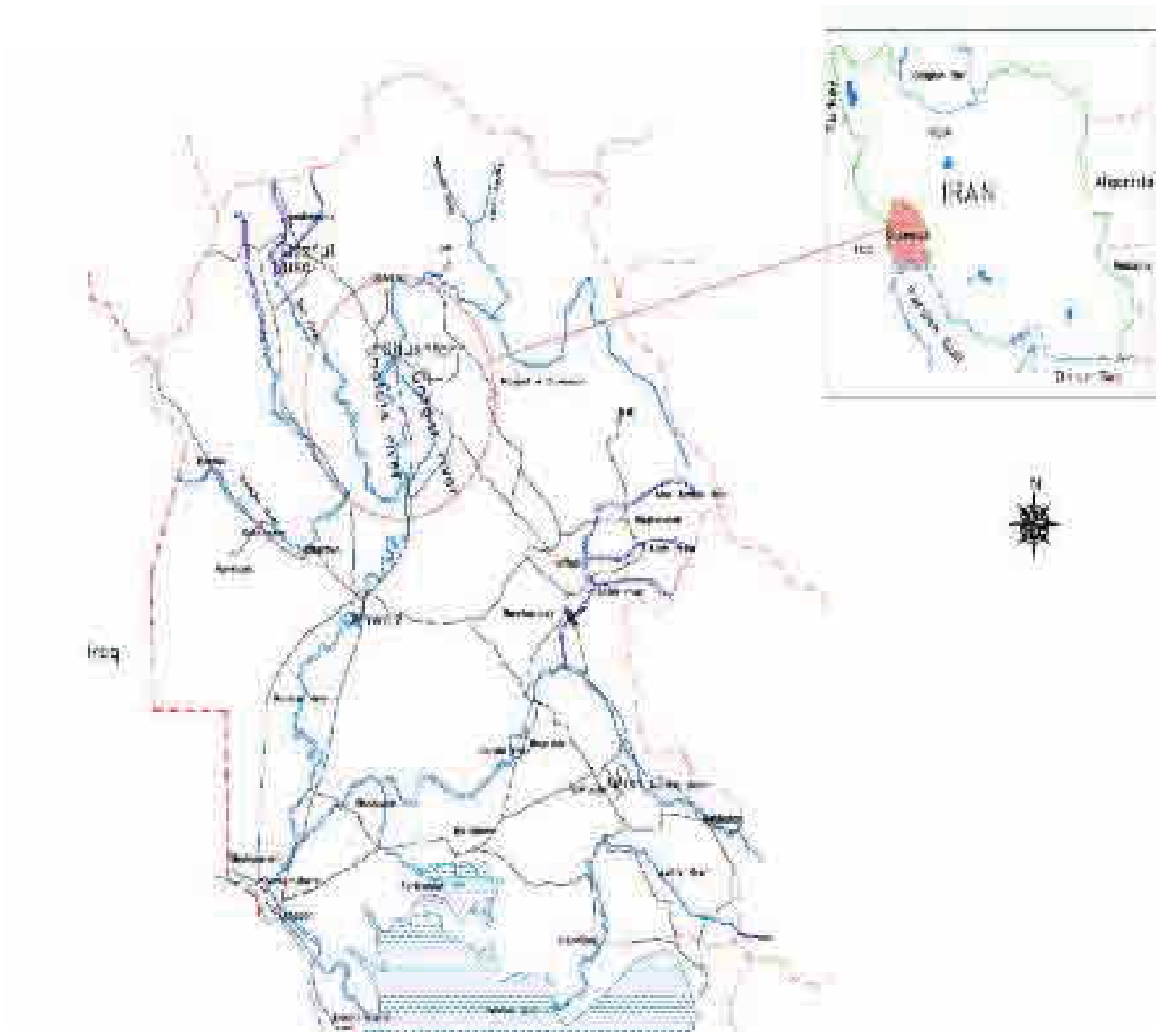

Figure 1.

GARGAR RIVER

Gargar river is an artificial tributary of Karoon river. This tributary is separated from Karoon in north of Shushtar and after traveling a distance at a place called Ghirbaz rejoines the Karoon again. Length of Gargar course is about 82 k.m. and aerial distance from Mizan dam to Ghir dam is about 44 k.m. Though some historians ascribe digging this creek to Sassanid kings, Ardeshir and Shahpur, existence of Parthian sites such as stova city, Dates digging this creek prior to Parthians, to the Achaemenids. Gargar creek transfers 2 shares of 6 shares of Karoon river's water.

Gargar creek is the biggest hand – dug in Iran. In order to prevent creeks bed to be deepened, it has been cobbled with great rocks connected to one another by metal braces.

Passing these tunnels, Moving mills' spokes creek's water car cades off inside the mills.

Considering the difference of height among afore – mentioned tunnels and compared with surrounding gardens. Digging this canal is deemed as one of engineering masterpieces of ancient Iran. This creek is known as Mosraghan in Bandahesh Book. Askar Mokram is a city which existed prior to Islam advent and after it. This city is in debt of Gargar creek for its economical briskness.

MIZAN DAM

This dam is one of high importance building in historical – aquatic Shushtar buildings that bisects Karoon tributaries: 1-Shotate 2- Gargar

The dam construction record dates Sassanid reign as its time of construction. This dam registered in national monuments list by No. 2331 (**Figure 2,3**).

According to present evidences, this dam was found in Sassanid Shahpur reign. Mizan dam is located in east – west direction, in the north of Shushtar, hear to seyyed Mohammad Giahkhar mausoleum on the location of this dam, Karoon river is bisected to 2 tributaries: 1- Shotate or Chahardange 2-Gargar or Dodange

Figure 2.

Figure3.

As some claimed the distance between this dam to Shadorwan is cobbled by hewn stones and lead braces. Since in Mohammad Ali Mirza reign, this dam was repaired, it is colled by this name. In fact, this dam divides the Karoon rivers water in 2/6 and 4/6 shares, so that 4 shares flow in Shotate course that is known as chehar dange and the rest 2 shares flow in east direction that is known as Dodange or Gargar. In historical texts, Nothing has been mentioned on the construction of this dam directly, unless in some parts in indirect ways.

MIZAN DAM ARCHITECTURE

Mizan dam has 10 watercourses 9 out of 10 opening inlets of dam are in eastern part and one is in western part. Each of the opening inlets is 215 meters long and has a specialized name. The total length of dam is 423 meters. Dams' opening inlets surfaces are a little lower than river's water level. This dam has been constructed in 2 oblique sides. These 2 sides are in forms of 2 semicircle arms. The width of water courses' opening inlets are different from one another, but the width of their pillars are all but the same.

Passing the opening inlets, 9 arcs are stretched west ward with 25° curvature and form 3 circle quarters. This stone wall stretches until it reaches kolah Farangi tower. This tower is built thoroughly by stone and mortar grout on the end of Mizan dam corner, kohlah. Farangi building is located. This tower is at the top of the hill which overlooks the Mizan dam. The afore-mentioned tower is and octagonal tower. The sides of its base have a length of 1.10 to 1.18 meters. According to some people, this tower was built as a watch tower for supervising on Mizan dam construction process. It also seems that this tower was an indicator for measuring river's water. By the end of 1971, the length of afore – mentioned tower was 4 meters. At the side facing the dam, there is a trap door that is covered by brick and stone. It seems that there used to be an inscription in this place.

In building this tower, only brick and stones were applied. The stone are of hewn sand stones. Plaster was used to caulk the stones. Tower's height from ground surface is about 7 meters. The height was more in the past, but has decreased due to passage of time. Need less to say that application of this tower was only for the dam. This tower had 4 function:

1- As a watchtower for supervising on construction process of dam.
2- As an indicator for measuring water
3- As a lantern or a guidance light.
4- As an inscription which had illustrated Sassanid Shahpur actions on it (the inscription is annihilated now)

"In Sassanid Shahpur reign, the defeated army of Roman valerianus, consisted of 70000 soldiers was captured by Iranians. Shahpur used the captives for erecting some buildings in Iran one of these buildings was Shadorawan dam in Shushtar. Shushtar located on eastern bank of Karoon river, has been considered as a principal city since Elamites and Sassanid dynasty. For elevating water level so that it reaches city's surface, they had built a dam on the river. As it is apparent, the primitive dam was not satisfactory in elevating water level. As a result, Roman captives were exploited to remove defects. Probably, in addition to labor forces, several engineers were present in Roman army. The first step was to dig Gargar river for conducting Karoon river's water. This dam, after undergoing some repairs, mow is called Mizan dam. Dam's facade is of hewn stones. These stones are joined by application of grout and metal braces which are in lead. Dam has water flows that would offload additional water. Dam is 10 to 12 meters wide. It took 3 to 7 years to build this dam. When its construction was over, Gargar river entrance was chute down with another dam. That Chutting dam is called Kaiser. This dam which has left from that time, has been constructed by big rocks which are made firm by metal braces. In order to control river's water, overflows were built on the dam. Traveling 40.23 K.m. toward south, Gargar rejoins the Karoon again. Present signs suggest digging other streams on this canal for irrigation, It seemed it was the first time in dam building history that for building a dam, a diversionary canal was built. In particular, from engineering view, considering Karoon water amount, this project was of high importance." [6]

SHADORWAN BRIDGE-DAM

Shadornwan dam is built on Shotate tributary and is one of must fundamental aquatic installations of Shushtar. This dam is registered in national monuments list by No. 78.

The construction record of this dam is related to Sassanid Shahpur. According to some evidences, it was found and constructed in Sassanid Shahpur reign. Shadorwan dam is built on main tributary of Karoon in a distance 300 meters far off Mizan dam in north – west Shushtar. At the present time, its relics has left next to Azadegan bridge. Shadorwan dam – bridge has designed as an exit sluice and regulator of water height in west end of this aquatic set in order to connect Shotate water to Dariun creek and making it possible to cross Karoon in east west main road. "It is adverted in Shahnameye Ferdousi (A legendary epic book of Iranians) that the engineer and the constructor of Shadorwan dam was a person called Branush. Shadorwan construction was finished in 280 A.D. After 3 constructional operations. In order to add to stability of dam, granite stones were applied" [6] (**Figure 4,5**).

"According, to eastern narrations, Shahpur I forced Roman empire to work on dam construction. This dam is 457 meters long and still in use to return Karoon's water to farms and is known as Kaiser dam. Probably Iranian king dam had deployed Roman captives in JondiShahpur region. Iranians emphasized high importance to Romans' skills and it is for sure that great bridge are great dam of Shushtar were built by Roman engineers." [3]

"Shushtar bridge – dam is distinctive from 2 other important bridges of Khuzestan that its main axis is not in a direct line. Roguen guesses that Shahpur bridge constructor attempted to lay the foundation of the bridge on natural rocks. Consequently, Natural oscillation of beneath stones deviated bridge axis from mainline. Shadorwan bridge–dam had 40 opening inlets and was approximately long." [5]

"Shushtar bridge was collapsed by river burst in winter of 1832 A.D. As far as I was there no measure was taken for repair the bridge any way, we had to transfer the artillery and people by raft." [1]

Figure 4.

Figure 5.

SHADORWAN DESTRUCTION PERIODS AND THE MAIN REASONS FOR THE INFLICTED DAMAGES ON IT IN THE PAST

1- Destruction by Hajjaje Yousef on account of Shaybe Khareji revolt

2- On basis of local researches, conducted by Mr. Sharafoldin and Abdolreza Farahi, Middle opening inlet destruction was done by Britain by explosives. Apparently, it was done to disconnect Shushtar from Dezful city and prevent low–paid labor force from escaping form this region and Masjede Soleiman to Dezful and other cities.

ARCHITECTURE

Shadorwan bridge-dam is built at east–west direction on Shotate tributary. Shadorwan bridge-dam has 44 big opening inlets and 43 small opening inlets.

Bridge length is some longer than river's width and is approximately 500 meters. In the construction of this dam, there are 2 arcs:

1- A convex are facing water stream and toward east direction.

2- A- concave are facing the water stream. Though these arcs are caused by river's bed, they can be considered as arc dams.

Next to this bridge–dam, there were mills which water energy moved their wheels. Construction materials applied in constructing this bridge–dam are road metals, plaster grout and ash. Bridge's foundation width is 7 meters. It water course opening inlet width is 8 meters.

The bridge height off its crest to its base is 10 meters. In constructing this bridge– dam hewn stones are applied which are connected to each other by metal braces.

There are different stories on construction of this bridge such as exploitation of Roman captives. These captives consisted of 70000 soldiers which were captured by Sassanid Shahpur. This colossal monument is considered as main principle of old irrigation network.

To construct this bridge–dam, river course was paved by arranged hewn stones. These stones were tightened to each other by metal braces.

Shadorwan mean carpet or decorated and precious layout literally. Since the distance from Mizan dam to Shadorwan river's bed is paved by arranged hewn stones, it is called Shadorwan. One of the reasons for constructing this bridge–dam was raising and quieting down the water stream by bridge dam foundation and its pillars and then to let this stream enter Dariun creek to irrigate farms.

DARIUN CREEK

Dariun creek was dug out in Achaemenides Darius I reign. The purpose for digging this creek was to irrigate Mianab plain of Shushtar.

This creek is registered in national monuments list by No. 4141.

Some historical texts ascribe digging this creek to Achaemenides Darius I, that dates 500 B.C. Dariun creek is the second greatest hand – dug canal in Shushtar that irrigates those farmlands which are situated between Shotate and Gargar, tributaries due to height of these lands. Dariun is named after Darius I. This creek is the only Shushtar aquatic structure which still possesses its original name.

This creek not only supplies farmers sufficient water, but also through some tunnels conducts water to houses' basements. Although several historian recognize Shadorwan bridge–dam as of Sassanids aquatic structures, considering Dariun creek existence in Achaemenides and the position of Dariun creek basins at a higher distance off water level in water Shortages time, the existence of this bridge – dam can be verified definitely in Achaemenides reign.

It is for sure that this bridge – dam was reconstructed in Sassanids reign (**Figure 6,7**).

In recent years, Dariun creek has been constructed by power department. Dariun creek by possessing various sluices, extremely accurate canals, water distributors, paved creeks and bridge was dug out for different complex purposes such as irrigating Minab Island, supplying potable water of Shushtar and providing specific accessibility to Salasel castle.

Figure 6. Turn out of Dariun creek

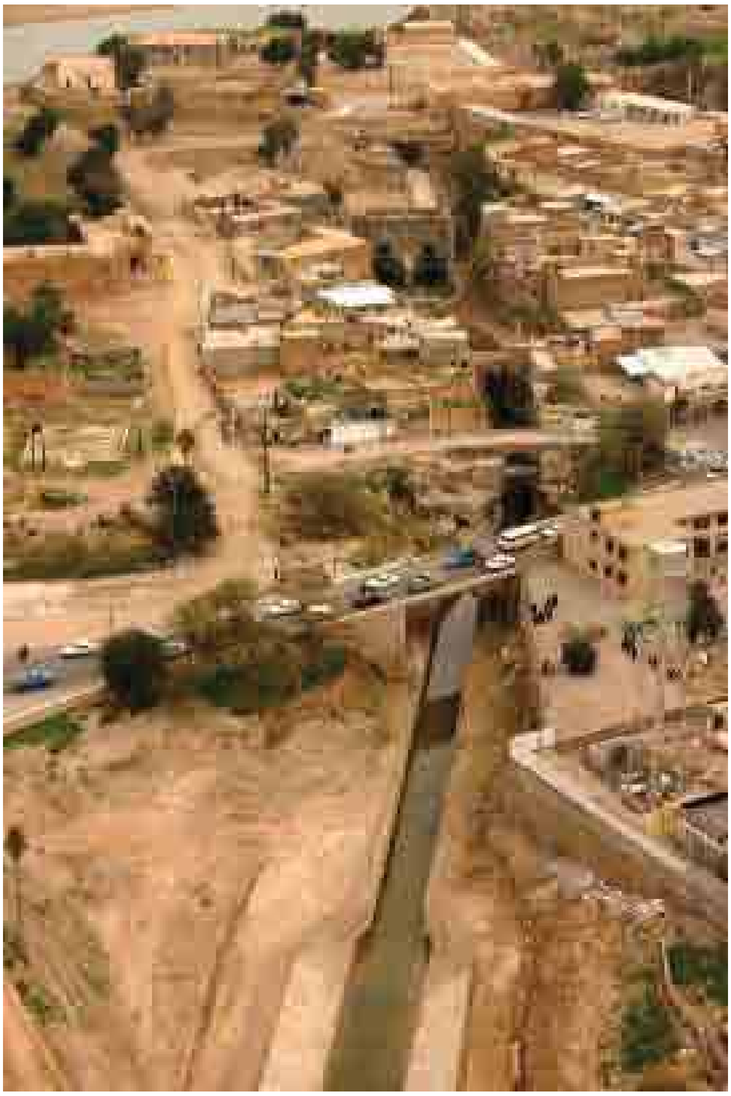

Figure7. Dariun creek

HISTORICAL TEXTS ON DARIUN CREEK

“About 300 meters at upper position of Shushtar bridge – dam, beneath Salasel castle, 2 tunnels have been dug – out which join one another after traveling 100 meters. These tunnels form Dariun creek. Another name of this canal is Mianab or Darabian.”[5]

Ravelinson mentions in his travelogue on this creek as follows:

“It’s total length is 273 meters and it’s total width is about 14 meters”.[1]

To make irrigation of south Shushtar farms possible, at and upper distance off Polsangi and at a lower distance off Kaiser dam, a canal has been dug out in main branch.

Herodotus mentions Karoon river as Khuaseps and says “From Shaushtar dam, an area of 60 K.m. long and 36 K.m. wide is under cultivation that yields various crops the distance from this dam to Shushtar is 9650 meters.

DARIUN CREEK ARCHITECTURE

Dariun creek basins which start flowing off beneath the Salasel castle, comprise 8 basins. Some of these basins have been blocked during successive years. Beneath Salasel castle, some stair cases were devised to use water so that in siege times, which castle doors would be shut down, they could access water easily.

8 afore–mentioned canals turn into two big canals leaving the castle, they join again and make a big canal that is conducted in format an open canal through Mianab plain. With the castle, there were various bath room which spent Dariun creek water using clay water pipes.

SALASEL CASTLE

One of the most important parts of every ancient city which was involved in forming the initial core of every ancient city is its stronghold. Every city's stronghold is settlement of king or local governors considering historical importance of Shushtar as capital of province this city was very important. Besides political centralization, Shushtar stronghold was a base for supervising on the efficiency of aquatic structures through history, name of Shushtar always reminds us of Sassunid Shahpur I. Seemingly, during his reign, Shadorwan bridge – dam and the castle were reconstructed.

In addition to supplying castle resident water, Dariun creek irrigated Mianab plain which was a very important agricultural pivot point in that period. Within the castle, there were many staircases. Some of these staircases led to rocky rooms which were situated under the castle on the river bank this rocky rooms provided the castle with a pleasant climate in the summer. (**Figure 8**)

Figure 8. Salasel castle abow the turn out of Dariun creek

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ARTIFICIAL RECHARGE OF UNDER GROUNDWATER RESOURCES RESULTED FROM PERFORMING WATER SPREADING PROJECTS (CASE STUDY: KHORASSAN-KASHMAR)

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ABSTRACT

Man has always faced different water problems in different ways.while in Iran and other parts of the word we face drought and water shortages, there are certain places around the world where flooding is the main problem. However, there are certain regions in the world, like Iran, which usually face with two problems, drought and flooding simultaneously. Environment protection and scientific organizations search for the optimal use of environmental resources including soil, water and resources including soil, water and plants which should be in balance with each other. The role of rainwater catchments systems is more sensitive in its nature which involves the conservation of water, soil and grown water supply. It is due to this fact that we should keep man's three important environmental resources including water, soil and the plants in harmony. Safeguarding their optimal and continuous utilization, the floodwater spreading systems are among the most efficient rainwater catchments systems. These systems, in comparison with other systems for floodwater harnessing are considered the most efficient. Their implementation is not only much more economical but they also provide us with new possibilities for crop production. The most important feature of these systems is that they will provide the land for creation of pastures and artificial forests in arid lands and deserts.

Key word: Aquifers – Soil – Erosion- Artificial recharge- Groundwater

INTRODUCTION:

Using and controlling the floodwater in many parts of the world have been traditionally developed in many parts of the world specially. These parts in which the amount of percioitation is not enough for agriculture. it goes back to more them 3400 year B.C .

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The method of using floodwater, depending on different circumstances differ from each other one of the most important methods, having several goals, in the water spreading method. This is the best and the native knowledge and modern together.

The artificial recharge is one of the best method for improving underground water resources and Qanats. The goal of this research is to evaluate the effect of such projects on the condition of underground resources in Kashmar.

Aquifer management (AM) is a variation on the same theme: "where possible, recharge the empty aquifers in wet years and optimize the water use for sustainable production and development ".

AM is defined as the science and art of maximizing the productivity of aquifers by whatever reasonable means, and optimizing all of the resources which somehow bear upon the continused usefulness of aquifers. Therefore, any activity on the basins of aquifers, on the debris cones, and wherever artificial recharge of groundwater (ARG) is performed, the means and reates by which water is extracted from the aquifers, and the way the water is used downstream, has to be performed in such a manner that the continued operation of the aquifers is ensured .

Water is the most important factor for life.Food chain and social-economical activities is related to it.Water distribution between oceans and dry lands is related to hydrological circle.(Mutiso,2003).water shortage population growth in arid and semiarid region is caused some problems.Ground water is an important for water supply because of limitations in surface water use.Improper recharge of aquifer effected ground water table and downing it.One of suitable method in artificial recharge is use of seasonal flow.History of ground water recharge is more than one thousand years(jakel&Heinzman,2003). Natural and artifical recharge is two main methods in aquifer recharge. Rainfall is the main source of natural recharge and all aquifers are affected by it. But in artificial recharge,water is infiltrate to a impervious formation(Heydapoor,1990).this method is based on structural work and ground water table is increasing,so it requires precious design and programming. The main advantages of recharge are:prevention of water wasting,improvement of ground water quality,restore origin aquifer conditions Alter ground water flow direction in order to prevention of pollution resources,cost minimizaing in relation to surface storage reservoir,eliminate evaporation losses in surface water reservoir and decreasing of pollution risk in surface reservoir (majead,2000).A research in dry soil of oman is showed that efficient of aquifer recharge is increasing with soil moisture content,water level of surface water and time of infiltration (Gerhard & frana,2002).

Aquifer recharge is releted to river canal in dry land and depend on direct recharge with rainfall or in filtration through cracks.(kearns and Hendrickx,1998)In surface recharge infiltration and percolation factors is very important,1998)In surface recharge infiltration and percolation factors is very important.physical and chemical characteristics of ground water is a adapting with aquifer characteristics over the time.Topography conditions,surface soil type,General slope,land volume and kind of water are affected in type and amount of recharge (Attarzadeh,1974).Also for evaluation of aquifer recharge,simulation models of ground water such as MODFLOW can be used (Thomas,2003).

Ground water dam is a suitable rechnique for water supply,prevention of water wasting and artificial recharge of ground water.Ground water dams may by of two types.sub-surface dams and sand storage dams.The main method for construction sub-surface dam is in an excavated trench in a valley or river bed.

Dam with can be decreasing with use of construction works and decreasing cost.Generally ground water dam constructed in the end of the dry season,because of low flow in these periods and can be pumped to out.These dams hare multiple use.For example for prevent of sea water percolation in ground water,after several evalution,are used of a subsurface dam in an island which located in northern of Okinawa in japan (jinno and et al,221).Several sand storage dama constructed in kenya;216 dams constructed in the rivers of the kitui region that covered 600 km area unit April 2001 .These dams are affected local communication .For example,a sand storage dam is constructed in kiindu river basin in 1998 . Groundwater level before of construction is 12 feet that reaxhed to 4 feet after constructed,while were affected by drought.Also capability of all dam were not good(Hoogduin and etal,2004).

SAND STORAGE DAMS:

A sand storage dam impounds water in sediment caused to accumulate by the dam itself.Filled pond with sand is General kind of infiltration equipments.Sand layer do mechanical and chemical treatment.Particles accumulation can be decreasing infiltration and some problems appear (Heydarpool,1990).Usually the height of sand storage dam is among 1 to 4 meter(Nillson,1988).In the following suitable ohysical conditions and appropriate critetia for site selection and construction of sand storage dams have evaluated.

MATERIALS AND METHODS:

Water shortage and its resulting problems, is the matter which has the direct relationship with man’s environment and iss wise element-man. Intensifying of the problems caused by water shortage, drought and floods together with the increase of population and expansion of urbon areas have been the real reasons to carry out a multi-purpose effort, all around the word to find practical alternatives in this relation. Infact, these continues effort and the modern innovations and up to date knowledge and techniques to surmount the problems resulting from water shortage and optimization necessity of the existing water resources, show the improved path of ways and methods which have been common in different places or some of them have been forgotten, gradually . with passing of time and increase of population along with increase of food and water demands the thought to making use of floodwater in high volumes where controlled was not possible by simple methods and small measures . Man in search of water by benefiting of experiences of floodwater farming gained access to flood spreading techniques .collection and transfer of significant volumes of flood waters and spreading them in low-sloped farms which have high penetration and suitable water passage coefficient is necessary for this method .

In this method, the goal is not limited to making optimum use of water but in addition to supplying water for farming or conservation of rangelands and establishment of tree cultivated lands is amendment of farms by spreading small suspended grains in flood waters and artificial recharge of groundwater are of the important objectives.

For this reason to make use of this method usually the existence of conponds and larg grain alluvium plains which have the necessary ability to store water and make use of it in drought periods by well excavation is provided .these are of the major points which should be considered . this method which is called ground water artificial recharge in iran in regions where the watershed areas due to various reasons have the ability of producing surface runoff water in larg volumes and the climatic conditions make possible the plant coverings in short term and in some case in long term (due to insignificant reason the annual rainfall and its unsuitable distribution) can be used as an efficient method .results gained from this study shows that Iranians throughout history and in different conditions have used this method in some way for different objectives .today in different regions, this method is used in various ways . The most common are as follows:

- Deep water method in pieces of land surrounded by sand walls having excess water overflow for each piece.
- Spreading of water in singular canals known as meskats .
- Spreading of water in wide canals with high sand dunes at the water foot know as liman.
- Floodwater spreading in leveled terraces on coneponds and alluvium plains known as oases.
- Produced floodwater spreading from unproductive farms in constructed leveled terraces on plains.
- Floodwater spreading in coneponds and large grain alluvium with construction of floodwater spreading canals by using sand dunes construction in the sections without water.

Of the methods mentioned, floodwaters spreading on coneponds and alluvium plains are more common than other methods.

Results:

Floodwater spreading is the best method and will have maximum multipurpose usage of floodwaters including:

1. Economic control floodwater, reduction of its damages and proper management.
2. Proper and low cost recharge of aquifer for optimum precipitation utility.
3. Amendment of unutilized coarse alluvial basins to ranglands and forests.
4. Amendment of bare and desert lands to new cultivated lands.
5. Prevention of sand moving by depositing of adhesive fine sediment and improvement vegetation cover.
6. Rehabilitation of bare lands and prevention of desert incursion.
7. Making occupation.

8. Increasing of agricultural products and improvement of natural resources economy.
9. Optimization of environment and development of reclamated forests and ranglands .
10. A planned and strong movement against weather altrations and drying climate.

PHYSICAL CONDITIONS FOR CONSTRUCTION OF SAND STORAGE DAMS:

1- CLIMTE

The need to dam groundwater for water supply purposes is caused basically by the irregularity of rainfall would generally be sufficient to cater to the needs of people and agriculture,but here the seasonality means that during some parts of the year water is not available.

2- TOPOGRAPHY

The topographical condition governs to a large extent the technical possibilities of constructing the dam as well as achieving sufficiently large storage reservoirs with suitable recharge conditions and low seepage losses.

3-HYDROGEOLOGY

Suitable aquifers for construction of subsurface dams are riverbeds made up of sand or gravel.In –situ-weathered layers and deeper alluvial aquifers have also been demand with success.The specific yield of such water-bearing strata may vary from 5 to 50 percent depending on grain-size distribution,particle size and compaction.Hydraulic conductivity values are more sensitive to the type of material constituting the aquifer.

4- SEDIMENT

The accumulation of sediments upstream of a sand-storage dam is the find result of a series of physical processes,which will all influence the hydraulic characteristics of the sediments.The parent roch in the catchments is the basis weathering orocesses disintegrate the roch and soil particles.Are detached by erosion,transported by water and finally deposited in the storage reservoir.

Hydrological and hydraulic aspects of sedimentation directly are relevant to the storage of water in sand-storage dams.

5-WATER FLOW

The surface flow of water in the stream under consideration will determine the design of the dam in terms of stability and height,as well as govern the sedimentation process in the reservoir.An analysis of surface discharge data in the actual river or similar rivers in the same area would make it possible to arrive at design flows.

6-BEDROCH FOUNDATION

Ground water dams should as far as possible is anchored in solid roch.This generally gives the best stability and it makes it possible in most cases to control seepage below the dam.

Results:

Floodwater spreading is the best method and will have maximum multipurpose usage of floodwaters including:

1. Economic control floodwater, reduction of its damages and proper management.
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7. Making occupation.
8. Increasing of agricultural products and improvement of natural resources economy.
9. Optimization of environment and development of reclamated forests and ranglands .
10. A planned and strong movement against weather altrations and drying climate.
11. Actualization of public participation in various aspects for development, reclamation and conservation of natural resources.
12. Making serious belief about socio-economic development on the basis of agriculture.
13. Revival of sustainable agriculture development and non-oil economy in the way of Islamic revolution ideals. These are also the explicit desire of the great leader of Islamic revolution, the agendum of government and Iranian Moslems wish.

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Photo 1: Planting of trees in floodwater spreading areas

Photo 2: floodwater spreading for artificial recharge of groundwater

Photo 3: soil erosion and runoff control by floodwater spreading project in Kashmar

Photo 4: floodwater spreading on aquifers project.

WATER RESOURCES MANAGEMENT TECHNOLOGIES FOR BARANI AREAS OF PAKISTAN

Engr. Dr. Illahi B. Shaikh & Engr. Qazi Tallat Mahmood Siddiqui[1]

1. ABSTRACT

Pakistan with a Geographical area of 796,101 square kilometers possesses a large river like Indus, which alongwith its tributaries namely Chenab, Jhelum, Ravi, Kabul and Sutlej, forms one of the mightiest River System of the world. The River System comprises of 19 large river headworks, 45 independent irrigation Canal Systems measuring 64,000 kilometers, some 1.6 million kilometers of water courses and 94 large dams of height 15 meter and above including 3 super storage reservoirs. Water resources development (Surface & Groundwater Reservoir, Canal Network and Drainage System) plays a vital role in growing economy of the country. Agriculture, being the main source of crop production and necessity for the existence, directly depends upon the availability of appropriate quantity and quality of water in proper time. The fertility of land and production of crops is badly affected due to the unavailability of suitable water in arid area and standing of surplus water in the waterlogged area.

Barani agriculture contributes about 10% of the total agricultural production of Pakistan and depends on rainfall for its water. Most of the rainfall occurs during monsoon season from July to September. In the context of crop production, barani lands have often been underestimated. However, bumper crops especially wheat, sorgum and barley have been produced in these areas, which reveal a high potential for crop production. Water is the only limiting factor for agriculture development in these areas. The occurrence of rainfall in the rain-fed areas is erratic and its spatial and temporal variation is high. Due to the uncertainty of rainfall, farmers normally use less input to reduce the risk of loss in the event of drought. Nevertheless, there is high potential for the development and management of water resources and therefore, adopting proper water resource development and management practices could increase crop yield.

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Paper discusses in detail various water resources development and management technologies at length which are being practiced in Barani (rain-fed, arid /semi-arid) areas of Pakistan.

2. BACKGROUND INFORMATION

Only about 3 % of the world's total water resource is fresh (non saline) water, of which roughly one-third is inaccessible. The rest is unevenly distributed. In many areas, the existing water resources are increasingly contaminated with wastes and pollution from industrial, agricultural and domestic sources. Over the years, rising population, growing industrialization, and expanding agriculture have led to a rising demand for water.South Asia is one of the most densely populated regions of the world. It houses roughly one-fifth of the world's population, and this share is likely to increase to one-fourth of the total world population by the year 2025. The economies of the countries in the region are heavily dependent on agriculture.

Pakistan with a Geographical area of 796,101 square kilometers possesses a large river like Indus, which alongwith its tributaries namely Chenab, Jhelum, Ravi, Kabul and Sutlej, forms one of the mightiest River System of the world. The River System comprises of 19 large river headworks, 45 independent irrigation Canal Systems measuring 64,000 kilometers, some 1.6 million kilometers of water courses and 94 large dams of height 15 meter and above including 3 super storage reservoirs. Figure 2.1 and figure 2.2 show the Indus River Irrigation System map and Schematic Diagram respectively. In the case of Pakistan, water has played a very significant role in the economic development and will continue to be a driving force in its continued development into the future. Agriculture is the largest sector of the economy, with primary commodities accounting for 25% of GDP and 47% of total employment, and contributes more than 60% of foreign exchange earnings.

Pakistan is blessed with one of the largest integrated irrigation network in the world. The Indus Basin Irrigation System commands an area of 17 million hectares (42 million acres). The Indus River and its western tributaries on average bring about 175 BCM (142 MAF) of water annually and the average annual canal withdrawal is 128 BCM (104 MAF). The System has three major reservoirs, 19 barrages, 12 inter-river link canals, 45 independent irrigation canal systems and more than 1.6 million kms of water courses. The total length of the canal system is about 64,000 Km.

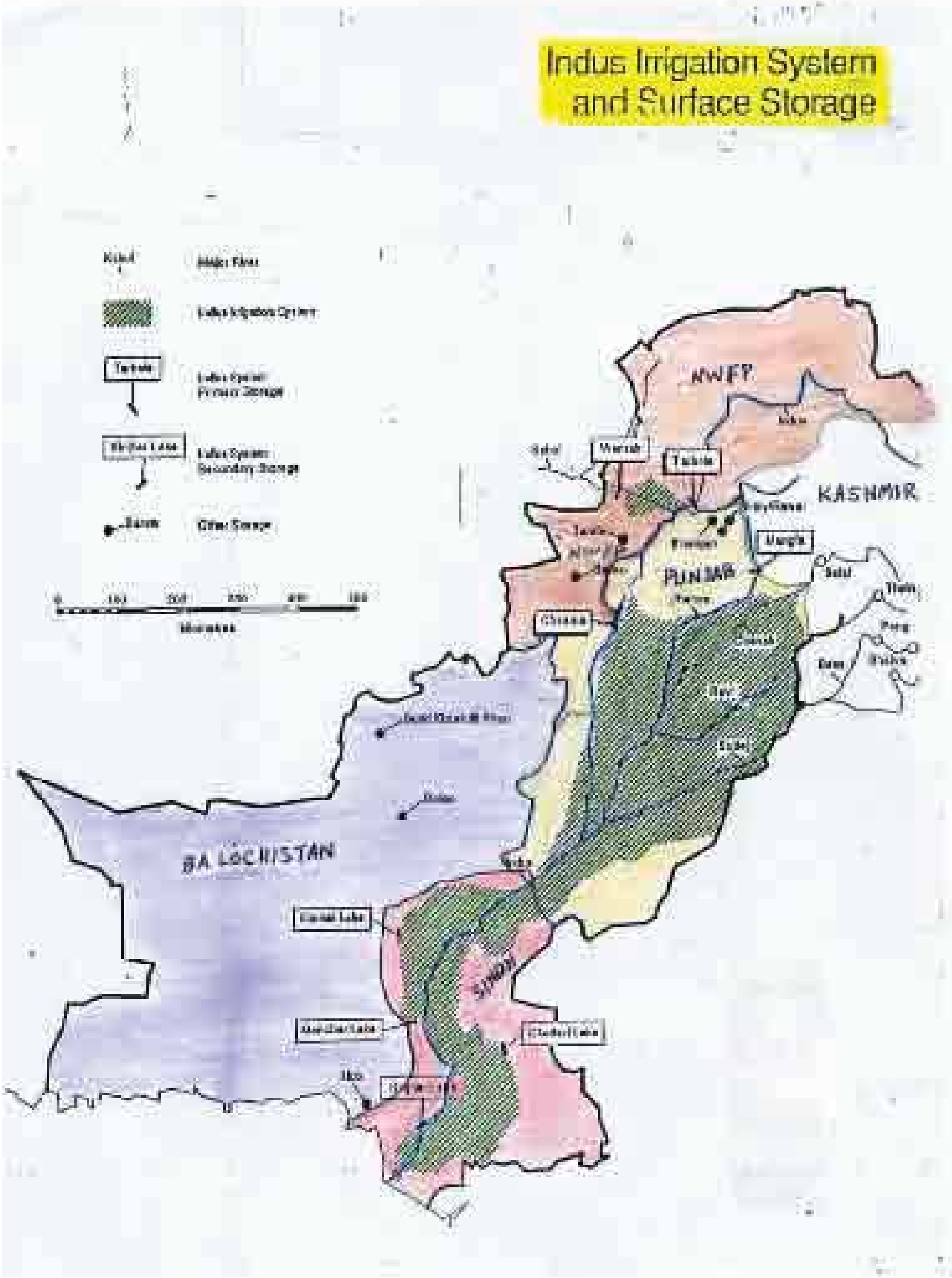
Indus Irrigation System
and Surface Storage
NWFP
KASHMIR
PUNJAB
BALOCHISTAN
SINDH

Figure 2.1

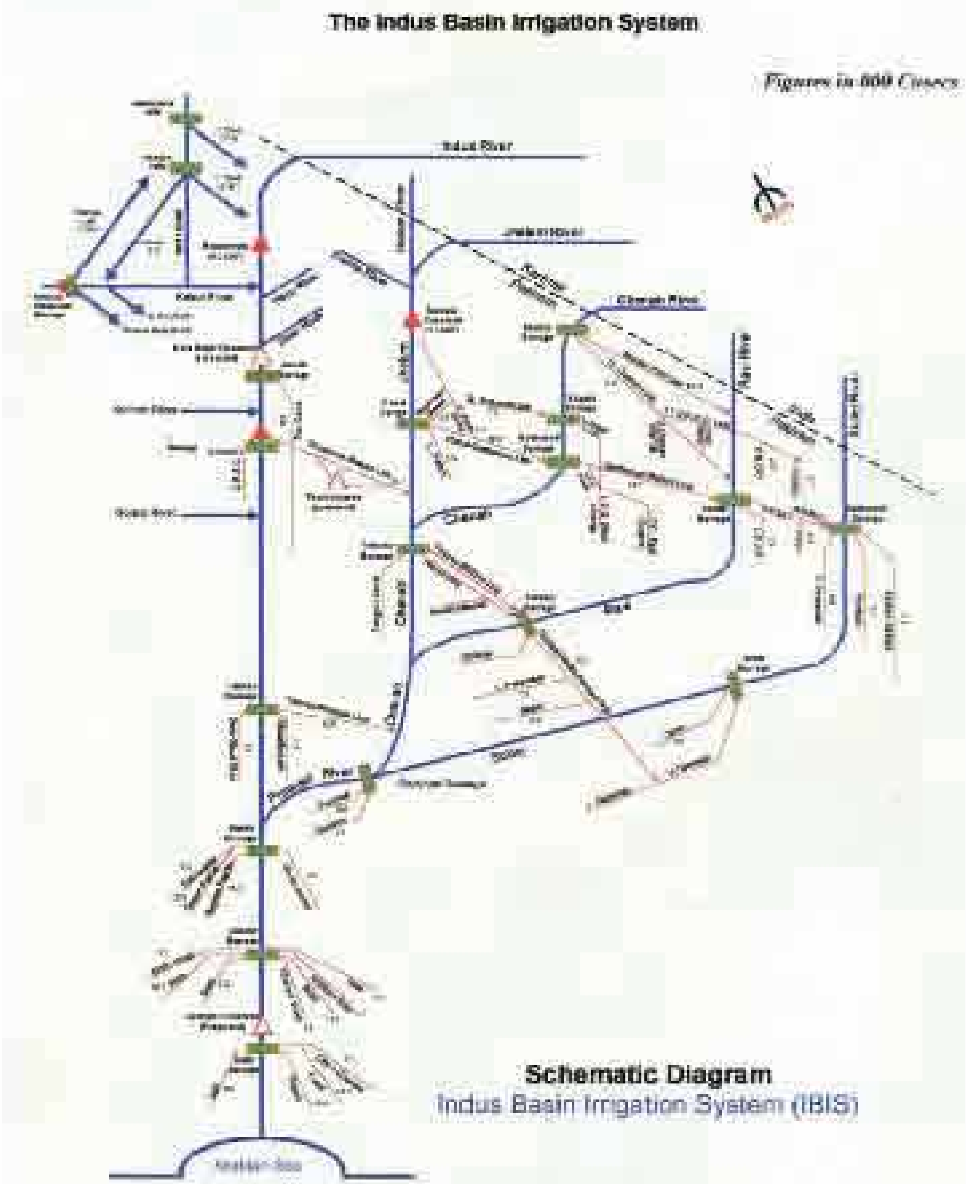

Figure 2.2

Pakistan is a country of over 141milion people, which is expected to grow about 221 million by the year 2025. The most pressing need over the next quarter century in Pakistan will be the management of the rapidly increasing population and provision of basic amenities. The increasing population will have a major impact on food and fiber requirements. Irrigation is the single largest sector of Pakistan's economy. The principle crops include wheat, rice, cotton, sugarcane, oilseeds, fruits, vegetables, pulses. The overall yield per hectare of most crops is far below their demonstrated potential.

Irrigated agriculture yields can be increased through use of improved technology and better management of the highly complex agricultural management system.

As the population continues to grow, Pakistan is now essentially at the limit of its water resources and is becoming a water scarce country. There is a strong and growing need to manage this precious resource more carefully and efficiently to ensure water for all on a sustainable basis. In order to effectively use water to meet the future demands for food and rural development, there is need to evolve strategies for development of water resources, management and conservation. A good proportion of the water which will supply the additional needs of the future must come from conservation, the food needs of the future could only be met through combined efforts in water conservation, additional storages and most importantly through increases in crop yields.

Pakistan falls in arid to semi-arid region of the world. The rainfall is neither sufficient nor regular, to meet the growing needs of agriculture. About 70 per cent of the annual rainfall occurs in the months, of July to September. The topography of the area forms mainly Indus Basin, Cholistan and Thar Deserts and small basins of Balochistan. The major source of irrigation is surface water mainly consisting of flows of the Indus River and its tributaries. The months of peak-flow are July to September during the monsoon rains. There are mainly two crop seasons. The flows during the Kharif (summer) are 84 % and during Rabi (winter) season are 16%. The alluvial plains of Pakistan are blessed with extensive unconfined aquifer, with a potential of over 62 BCM (50 MAF), which is being exploited to an extent of about 47 BCM (38 MAF) through private and pubic tubewells.

Barani agriculture contributes about 10% of the total agricultural production of Pakistan and depends on rainfall for its water. Most of the rainfall occurs during monsoon season from July to September. In the context of crop production, barani lands have often been underestimated. However, bumper crops especially wheat, sorgum and barley have been produced in these areas, which reveal a high potential for crop production. Water is the only limiting factor for agriculture development in these areas. The occurrence of rainfall in the rain-fed areas is erratic and its spatial and temporal variation is high. Due to the uncertainty of rainfall, farmers normally use less input to reduce the risk of loss in the event of drought. Nevertheless, there is high potential for the development and management of water resources and therefore, adopting proper water resource development and management practices could increase crop yield.

3. TECHNOLOGIES FOR BARANI AREAS OF PAKISTAN

3.1. SMALL /MINI DAMS:

It has been estimated that about 11 BCM (9MAF) of water is lost annually as surface runoff from the Barani regions. If 50 % of this could be retained in small/mini dams, water equivalent to more than half the capacity of the Tarbela dam reservoirs could be stored. There are many potential sites for the construction of small/mini dams in northern areas of the country as well as in Pothowar region. The government of the Punjab has constructed 31 small dams in the regions.

Besides supplying water for irrigation, these dams have many indirect benefits. They help recharge the groundwater, provide water for domestic and municipal purposes, control soil erosion, control floods in hilly and plain tracts, help to develop fish culture and also provide recreational activities.

However, there are several issues relating to these dams which still need to be addressed, such as development of command area, low water conveyance and application efficiencies, reduction in reservoir capacity due to sediment deposition and vegetation growth, evaporation and seepage losses. Reports compiled by International Water Management Institute (IWMI) and National Engineering Services of Pakistan (NESPAK) reveal that presently only 23% of the stored water is being utilized with a cropping intensity of 60% against projected figure of 130%. With no salinity and groundwater problems, good climate for production of high value crops and proximity to markets, this area should increase its share in agriculture production using high efficiency trickle or bubbler systems. It is interesting to note that small/mini dams are being constructed by many progressive farmers in the Pothowar Region and they have proved to be successful in generating income comparable to that of farmers in the canal irrigated areas.

3.2: DUG WELLS

Large scale water resource development through mini and small dams involves large capital investments. Moreover, these reservoirs need special attention in terms of operation and maintenance. Since these dams are mostly public owned, disputes over water rights and sharing maintenance cost also arise. Small- scale on farm water resources development and management activities however, can play an important role in increasing the income of the farmers. The individual farmers or a micro community owns these systems, therefore they make best use of the water resources available and the problems of disputes over water are also eliminated.

The Barani Master Plan reports that there is considerable potential for development of open wells in the cultivable lands of the Pothowar Plateau. The aquifers in the Plateau are generally in sandstone formations with low transmissivity values. It is considered that dug wells up to 20 m (66 feet) deep can safely yield 3-6 liters/second (lps) water to irrigate small fields besides meeting domestic requirements. However, the design of such well needs to be based on aquifer transmissivity and recharge characteristics of the aquifer. The development of a typical dug well can provide water for about 2 ha (5 acres) of flood irrigated 4 ha (10.0 acres) of sprinkler irrigated or 6 ha (15.0 acres) land with low-pressure drip, typically for high value orchards.

3.3 PRESSURIZED IRRIGATION SYSTEMS

Due to the scarcity of water, merely 25% of total rain-fed area is under cultivation. The farmers use obsolete methods of irrigation resulting in poor application and distribution efficiencies. In most of the area, the land is highly undulated and precision land leveling is therefore, not a feasible economically justified option. Under the prevalent topographic conditions, gravity irrigation is also not possible in these areas. Therefore, it is of utmost importance that the scarce water resources in the region are utilized most aptly and efficiently with minimum losses.

3.4 SOIL AND WATER CONSERVATION PRACTICES

These technologies include contouring, strip cropping, terracing, improved tillage practices and construction of soil and water conservation structures. A brief description of each follows.

a). Contouring:

In contouring, tillage operations are carried out as nearly as practical on contours. On gentle sloping lands, contouring reduces the velocity of overland flow. If ridge cultivation is practiced, the storage capacity of furrows is increased, permitting the storage of large volume of water. It has been shown that contour cultivation of a good piece of land with grass can reduce watershed runoff by 75 to 80% at the beginning of the season.

b). Strip Cropping:

Strip cropping consists of a series of alternate strips of various type of crops laid out so that all tillage and management practices are performed across the slope or on the contours. Strip cropping is not a single practice. Rather it is a combination of several good farming practices such as crop rotation, contour cultivation, proper tillage operations and stubble mulching.

c). Terracing:

The cultivated lands of Pothowar tract are undulating. Land leveling is not only costly but also puts the soil at the risk of erosion. Terracing involves constructing broad channels across the slope of rolling land. The function of terracing is to decrease the length of hillside slope, thereby reducing sheet and rill erosion, and preventing the formation of gullies. Terraces not only check erosion but also increase retention of rainwater in the soil for next crop.

d). Good Management Practice:

Where erosion can be controlled by stubble, vegetation or other means practices that reduce surface runoff, diminish erosion and improve moisture reserves in the soil are proper bunding, leveling and deep ploughing. Deep ploughing helps hold water so that most of the water infiltrates into the soil, while leveling ensures the equal distribution of moisture over the whole field. Each millimeter of saved water could increase yield of wheat by an average of about 10 kg/ha. The adoption of these conservation practices for a kharif season increased crop yields by 14%. However, for light-textured and sandy soil, Rain-Water harvesting technique can increase surface runoff and collect it at appropriate places to meet domestic, livestock and agricultural needs.

4.0 CONCLUSIONS

There is high potential for the development and management of water resources in the Barani (rain fed/arid) areas of Pakistan. These areas have a strong legacy of ancient water application and conservation techniques which have now been blended with modern trends. Adopting proper water resources development and management practices could considerably increase the crop yield in these areas.

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WATER & IRRIGATION IN JOLFA

Sajjad Hosseyni[1]

ABSTRACT

History tells us about an old Jolfa in north- east of Iran. Jolfa is a village of Marand, a town in Azerbaiyjan, near Tabriz. It is understood from these reports that people of this region had had many problems in supplying water. Although they lived near the Aras river. They used water of fountains wells and subterranean canals.

Why the people of these areas used small rivers, streams, wells and subterranean canals as their water supply, while the great river of Aras was just to their north. To answer this question we need to know geographical conditions of the region: Because the valley is so deep that only modern technology can make it possible to use the river's water for farming purposes.

Water is so important to the people of Jolfa that they consider it as the symbol of light, and respect it as a holy element.

Maybe if people of Jolfa and Gargar did not have the water problem, water would not be so important in their customs. Only those who face water shortage need to pray for rain, so, respecting and praying for rain shows the need that the people of this region feel for water.

Construction of the canals was done through cooperation of the natives. Some people did their best to build the canals and then all people could benefit from the result.

One of most important affairs in water management in the region was its distribution water has been so important to the natives that many quarrels have happened over it. They usually disused the affairs in mosques. They talked each other until they com to an agreement yet sometimes discussions could turn into quarrels.

JOLFA HISTORY & WATER PROBLEM:

History tells us about an old Jolfa in north-east of Iran. Jolfa is a village of Marand, a town in Azerbaiyjan, near Tabriz. The oldest words on Jolfas history come from "Vaq Name-ye Rabi Rashidi". In this historical text there are many references to the water problem of the region.

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The “Vaqf Name “tell us about the geographical location of the village and also about what exists in the area, including: subterranean canals, streams, farms, gardens and watermills. It says that Jolfa had once belonged to Amir Jamal al Din Mohammad Kermany. But then it is sold by his heirs. (Khaje Rashid al Din Fazl allah Hamedany, Vaq Name-ye Rabi Rashidi, p 258).

According to the information given by the Vaqf Name, using surface and development of the region. Residents of Jolfa at that time used these water supplies for drinking, farming and also putting mills in to work.

In Safavid period we find Jolfa to be an Armenian town in which silk business is very popular. But during Shah Abbas s wars against Ottomans he fallowed scorched earth policy and burnt many farms in Azerbaijan and in Jolfa as well. Which the destruction of Jolfa, its Armenian residents were moved to Isfahan. (Iskandar Beig Monshi, Tarikhe Alam Araye Abbasy, pp 1308- 9).

The Safavid king built a new Jolfa beside Zayande Rood river and resided Armenian region of jolfa, south of the Aras river,there were muslim residential areas named Alamdar and Gargar which are mentioned in some sources lik Alam Araye Abbasy and Zeile Alam Araye Abbasy.

Jolfa experienced one of its best periods during the Safvid era and there are many reports on the Safavid Jolfa.

It is understood from these reports that people of this region had had many problems in supplying water. Although they lived near the Aras river. They used water of fountains wells and subterranean canals.

Sharden says that Shah Abbas, as a part of his scorched-earth policy, had poisoned the fountains in Jolfa (Sharden, Sharden’s itinerary, vol 2, p 394).

This implies the importance of fountains in people’s life in the area. Sharden also writes:” According to Armenian traditions the old Jolfa had had four thousand gardens, houses and other buildings, but even if we consider the present ruins, this number will not even reach half of what is said, and to this we should add the fact that most of these ruins had been shops or sheds which were built in the mountains, and were mostly used for flocks. I can’t think of any place in the world more barren then the old Jolfa, there are no trees, and no plants there; actually there are many fertile lands around this town, but they may not be seen from the town which is located in a stony, droughty, area’(ibid, p. p 392- 3).

It’s a surprise that Sharden describes a town near the Aras as a droughty region. One can just infer from these reports that people of this area didn’t use the river’s water or they made so little use of it that it wasn’t worth reporting. However, Shah Abbas’s scorched- earth policy could be an additional cause of the bad conditions in the area.

After that the old Jolfa remains as a ruin till the rise of Qajarids. But a tow kilometers further Muslims were living an active life. They lived in places like Gargar and their main jobs included producing wool and cotton, spinning and weaving, just like the old Jolfa. Although there wasn’t a town of Jolfa anymore, but the name, which means weaving, still suited the region.

August Benton, about the riverside village of “shujae”, in Fath Ali Shah’s period,writes: ”The poor village of Shujae was located at the foot of some droughty, sandy hills, about two farsangs away from he river(Aras) “ (August Benton, August Benton’s Diary, p. p. 65- 6).

This shows that the village of Shujae, like many other villages in the region, supplied its water from fountains and wells not from the river. Benton also talks about fertile fields of Gargar, which is also called “Darre Dooz”(Darre Deez or Daraq Dozd), and had many subterranean canals, and also a river with the some name which made it so fertile. The field was used for planting various plants such as wheat, cotton, etc. There are some documents from Fath Ali Shah era which show us that people traded the water of the mentioned river.

That how Jolfa is described in report, depends on the time of the year when they are written. Springtime reports talk about rainfalls and freshness of the region. But reports written in summer and fall describe Jolfa as a droughty area. Nasser al Din Shah’s diary in his travels to Europe are springtime reports about rainfalls and freshness of the region (Nasser al Din Shah, Nasser al Din Shah’s second tour to Europe, p. 27) But the report by Brogesch, ambassador of Germany in Iran talks about the drought of the area. (Heinrisch Brogesch, A trip to soltan’s court, p. 123).

Nasser al Din Shah in his second tour to Europe also mentions the existence of many mills in the field of Darre Dooz ”On both sides of the road Gargarians have built many mills “ he says(ibid) And a few years later in his third tour to Europe he report :”We saw the mills we had seen the previous time again and also some other mills were added to them this time “(Nasser al Din Shah, Nasser al Din Shah’s third tour to Europe, p. 35).

These mills had most probably worked by water power of the Daraq Dozd river.

To use the water and manage the problems, people of the region worked in groups and cooperated with each other. Because it was no easy job to do individually. There are many documents, remaining from that time which proves the idea:

One of these documents is a command from Qahraman Mirza,Abbas Mirza’s son, to Haji Abdi Khan Yavar Alamdary governor of Gargar (23 rd Bulletin of center of documents north-west of Iran, p. 11) According to this, the natives had had an active role in constructing the canals. In fact, the water problem had been so important that had made the natives forget about their, still famous, old arguments and had forced them to cooperate in order to overcome their common important problem.

Another matter which could be inferred from the document is the high prices of constructing subterranean canals at the time. The costs are so high that the governor of Azerbaijan asks the government to delay the taxes.

GEOGRAPHY OF JOLFA WITH EMPHASIS ON WATER PROBLEM:

An important question about history of irrigation in Jolfa and Gargar areas, is, why the people of these areas used small rivers, streams, wells and subterranean canals as their water supply, while the great river of Aras was just to their north. To answer this question we need to know geographical conditions of the region:

Jolfa is located near the Aras river in deep valley and is surrounded by high mountains of Iran and Caucasia. The Aras river flows from west to east in such a valley, too. But only areas near the dom of Aras can use its water. Because the valley is so deep that only modern technology can make it possible to use the river’s water for farming purposes. (Behrooz Khamachi, gazetteer of east Azerbaijan, p. 302)So it had not been possible to exploit the river’s water in Jolfa either. Also the fact that the Aras river is a frontier river makes it possible to use its water for some small fields near it.

Because of the high mountains around it, Jolfa is warm and unpleasant in the summer and temperate in the winter. These mountains also prevent Mediterranean currents from affecting the region, so Jolfa has a poor vegetation. (ibid).

Jolfa is one of the warmest areas in northwest of Iran and its temperate is usually higher than other areas of Azerbaijan.

All these factors are combined to make water shortage the main problem for the residents of the region. A problem which has existed from long ago, according to historical evidences.

So, people of Jolfa had to find away to gain water. The geography of region has provided some solutions to this problem, too. One of them is the high mountain of “Kiyamaki dagh”.

This is the highest mountain in the region. It is surrounded by “Zoonooz” to its south, “Hadishahr”(Alamdar – Gargar)to its north, the village of “Dizmar” to its east, and mountains of “Darre Deez”(Darre Dooz)to its west. Because of its temperature, fine weather, enough snow and rainfalls, and green, fresh fields around it, many villages have been built around it. Nine months of the year the mountain is covered with snow and thus it is the main source of many rivers in the region. (ibid, p. 443).

It also is the main source for underground water supplies and, so, solves the water-problem to some extent. But it, still, is highly dependant on human activity to solve the problem.

And people of the region have shown, since long ago, that they can well-develop and manage existing water supplies.

WATER IN NATIVES CULTURE:

Water is so important to the people of Jolfa that they consider it as the symbol of light, and respect it as a holy element. On the last Wednesday of the year, people of Azerbaijan had had special customs to praise the four elements (water, soil, air, fire). But, nowadays, fire is the only element present in the ceremonies. But some decades ago a great deal of attention had been paid to water and it had had some special customs. For one of these, people, especially young girls, would go to rivers and fountains and drink water from them, in order to have good luck in the falling year. People also jumped over water, like what they do about fire now.

Maybe if people of Jolfa and Gargar did not have the water problem, water would not be so important in their customs. Only those who face water shortage need to pray for rain, so, respecting and praying for rain shows the need that the people of this region feel for water.

JOLFA AND CONSTRUCTION OF SUBTERRANEAN CANALS IN THE PAST:

Construction of the canals was done through cooperation of the natives. some people did their best to build the canals and then all people could benefit from the result. The canals were usually built in a period of 16 days, and for built these canals 16 or 32 people worked together. In earlier times there had also been periods of 21 days.

The construction needed 3 experts. They were called “Kankan”, “Loooganbarchi” and “Charkhchi”.

Kankan was an expert in digging. Looghanbarchi gathered the soil in a bucket, and Charkhchi was the one to take the soil out of a well.

Before construction, they studied the place to estimate the number of wells needed for taking water where they wanted. Then they would begin digging.

In addition to digging many wells and connected these wells through some canals and then strengthened them by stone revetments. The best Kankan is called “Moganny”. They are so good at their job that with a short study on a blocked canal. They can exactly show the point where it has collapsed.

Kankans and other subterranean canal constructors demanded high prices to work in canals; because of this, canal owners called upon them only once in 10 to 15 years to clean the canals.

WATER DISTRIBUTION IN OLD JOLFA:

One of most important affairs in water management in the region was its distribution water has been so important to the natives that many quarrels have happened over it.

Water distribution was controlled by some experts called “Mirab” or “Dashtban”. They distributed water all over the region and got money or some farming product as their income.

People had to obey some rules in using the water of canals, rivers or pools. For example, they could use pool waters only from morning to evening after sunset it was forbidden to use the water so that the pool could be filled again till morning for the next person.

They usually disused the affairs in mosques. They talked each other until they com to an agreement yet sometimes discussions could turn into quarrels.

NAMES AND LOCATIONS OF SUBTERRANEAN CANALS:

An interesting thing about the canals is how they get names. Sometimes canal takes its name from its location and also sometimes, it gives its name to its location. The subterranean canals in Jolfa usually belong to the latter. There is a canal in Jolfa which has given its name to the village in which it is constructed ("Taleb Goli"). This show the unbreakable connection between the canals and country life.

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HISTORY OF WATER DISTRIBUTION IN THE ZAYANDEHROOD RIVER AND SHEIKH BAHAIEE'S SCROLL

Mahmoud Pirpiran[1]

The Zayandehrood River of Isfahan originating from Zardkooh Bakhtiari Mountain to Gavkhooni Lagoon with an approximate distance of 400km is a vital vessel to Chahar Mahal-o-Bakhtiari region and Isfahan province. Naturally, severe seasonal tolerance of this river has been a great dispute in the social tensions of the region before building Zayandehrood Dam and water transfer tunnels. During its long history, the river has granted water rights to inhabitants near it; systematizing, balancing, monitoring, and distribution of water have been inevitable and inseparable parts of the regional policies.

Several factors have naturally existed in water distribution disorders of this region the most important of which are as follows: water shortage especially for the agriculture sector with regard to Isfahan's dry climate, coincidence of the river's low-water season with users peak time of requirement, the access possibility for upstream inhabitants and lack of such possibility for downstream inhabitants with regard to lack of the possibility to continuously monitor and control the utilization networks, the interference of big landlords, and the influence of tyrannical rulers of the time.

What is understood by studying the history of water distribution in this area is that using the river water would have led to numerous disputes and quarrels and that specific order would have been enacted by headmen of the riverside villages during historical periods; this order was subject to muddle with seasonal water fluctuations as well as the rulers' instability. The scroll attributed to Sheikh Bahaiee is one of the best historical written documents on water distribution management drawn up and edited 400 years ago; it has noticeable cultural aspects and hereditary capitals in particular. This is the only written document to which water distribution generals have been referred in this paper. Its first page is exactly presented here due to the writing eloquence and the vocabulary used.

"In The Name of He Who is The Most High.

To: His Majesty Shah Tahmasb, the Great, and the Precious. According to your Majesty's royal order regarding some conflicts risen in the villages and water shares of the Zayandehrood River, please kindly assign some trustees of your powerful government along with some trustworthy aged men verified and approved by Their Highnesses state accountants and headmen and patriarchs of the common districts in order for every village and farm's share and allotment to be specified in each district in accordance with their capability and capacity without any deception and false intention

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and to be necessarily registered in the logs to refer to later on; and as 'Jay' is located in the middle of the irrigated districts of the blessed river, it has been appointed from old times that a trustworthy headman of any district takes on the watering works of that district. His Royal Highness is requested to order the same again for the present time.

Please also kindly order your respectful agents and registrars, headmen and patriarchs of the said districts, water distributors, supervisors, waterway chiefs, and workers of the blessed river to consider every district's water right as per the instructions in this scroll without any violence and away from the reprimands of His Majesty's powerful government forces and to keep their word. Written on July-August, 1500.

According to His Majesty's order and signatures of state accountants and confirmation of headmen and patriarchs, the distribution resolution of the blessed Zayandehood River of Isfahan among farmers of the said districts for the duration of one Hijri Shamsi year is as follows:

Every village of Lenjan and Alenjan gives ten thousand kilos of rough rice to the Rei'e Office, plants 33 acres of rough rice and if extra land is planted, farmers of 'Marbin' and 'Jay' districts are allowed to plough the same. In every watering year, inhabitants of Roudasht have two times excluded from the subject and when there is drought from the 78th night of Nowrooz which is the half of Gemini up to fifteen days, in this way that on the 78th day a messenger is appointed at the main origin of waterways and before dawn, all waterways from 'Polkalleh' to the end parts of 'Bara'an' waterways is dried until the 10th day and after 5 days of shares distribution (Sarkardeh) if there is a big damage to local seedlings, a slight irritation shall be done on the 6th and 7th day and the second "Vanesh" (see below list) which is soiled water shall be dried and then share-distributed according to the first Vanesh instructions. As 'Fady' waterway is flowing through the town, irritation adequate for three or four millstones shall be done and regarding 'Nyasarm' waterway of 'Jay' , as some respectful quarters are drunk from that and it is a main canal, the resolution is that one day before the Vanesh of Roudashtain, the water distributor marks its Shourabeh (see below list) and hands it over to the headman, the waterway chief, and the messenger to keep an eye on it till the end of Vanesh and not to violate. They shall keep Bara'an inhabitants for five days and then let them in."

The vocabulary used in the writing of Sheikh Bahaiee's Scroll is extracted from the local culture and common irritation words of that era which are exactly used in the scroll. Some of them are listed below for their historical eloquence and hereditary aspects:

Waterway chief (Madisalar): A man who has the responsibility of supervising water distribution in initial main distributions.

Messenger (Ghased): A man who is appointed at waterway origins by the irritation office.

Water distributor (Mirab): A man who is chief of the river and divides the whole shares among districts.

Chief watch (Sarkeshik): equal to water distributor.

Alj: a stream branched from a waterway.

Waterway (Madi): local term for a large stream.

Lat: the point of water distribution in waterways.

Jolbandy: Blocking the course of water by means of motes and stalks.

Vanesh: dedicating some shares to one stream at times when there is little water or when the water is not transferable.

Sarkardeh: Distributing the river water to waterways according to their shares.

Vareh: Blocking the course of water by means of stones, mud, etc.

Shourabeh (salty water): when a waterway's entrance is blocked, the remaining water inside is called Shourabeh.

Gelandaz: land on the sides of a waterway for its silt clearing.

Studying the generalities of Sheikh Bahaiee's Scroll shows that an amazing knowledge is applied in it. The important aspect is that it is drawn up in accordance with the regional environmental characteristics, farming diversity along the said course, and users' previous known principles. The text of the scroll is executive so that the executor can infer his orders from that.

In this scroll which is written with respect to Shamsi days, one Shamsi year has been considered 360 days and water distribution is not implemented in the first 75 days because of water adequacy. The last 120 days which coincide with the cold season and stoppage of farming activities are also overlooked; the remaining 165 days are considered in water distribution and the scroll's shares that are divided into 33. Districts of this course having water right are 4 general districts called Lenjan and Alenjan, Marbin and Jay, Kararaj, Bara'an and Roudashtain. Except for Kararaj that has 3 shares of the river water, the other districts have 10 shares making 33 shares on the whole. In other distributions, main shares are divided into subsidiary shares with regard to the districts conditions, forming a sum of 275 shares which are in return divided into other subsidiary shares making a grand total of 3098 shares.

After the distribution, considering the districts' need to water naturally influenced by crops type, days of allowed use with specific alternation are executed. As mentioned at the beginning of the scroll, headmen of Jay district who are located in the middle of the river's course, have the responsibility to supervise and execute the contents of the scroll.

Waterway chiefs and water distributors of Jay district take action to close or open water right canals by utilizing workers (water distributor's servant) of the other district. Another part of the scroll denoting its instructions in this regard is presented below for its clear wording:

"The resolution is that one day before 'vanesh' , the water distributor shall call the messengers of Marbin and Jay together at the bridge of Falavarjan and shall give them the chief-watch share of Alenjan and Lenjan and shall appoint the water distributor's servant of each watch, stood at the waterway, to gather grass and shall appoint the messenger of Nyasarm waterway for Marbin watch and he himself shall leave for Ashyan quarter. Before dawn, the servant of each watch shall close all of his waterways so that two hours passed from sunrise, all waterways would be closed. After water spills over the sides of Falavarjan bridge, the servant of Marbin watch shall close Marbin waterways and the water distributor shall seal the closed waterways from Polkaleh and shall go down to the gate of Nyasarm waterway of Jay. After water reaches Nyasarm waterway gate, as long as the time needed for grinding one thousand kilos of flavor in Mo'menagha's millstone, the water distributor shall go up and seal every waterway according to the known shares he has and then he shall go to the watches until morning of next day when it is time for water closure. Every opposing waterway shall receive self-closure and shall carry its own remaining water so that there is adequate water in Lenjan and Alenjan to reach everywhere. If it is little, the habitants do 'vanesh' for five days in the way that after Jay's Marbin 'vanesh' they flow it toward Ashyan to reach every waterway. After that, it flows to Alenjan for 4 days and then 2 other days for Lenjan and then Jay and Marbin's 'vanesh' according to the said instruction. If it is not so little, they distribute it to the waterways according to the shares so that it reaches all the chief-watch waterways. The water distributor must consider Alenjan's rough rice when giving water rights of Marbin and Jay not to plant further to the agreement. As the waterways of 'Kooshk' and Ghartaman of Marbin are covered by Alenjan's watch, it is drunk by Alenjan's water. In return, Shahababad and Darjazin's waterway covered by Marbin's watch, is drunk by Marbin's share.

In the first day of 'Jolbandi' when closures are to be built, all of waterways of Lenjan and Alenjan and Marbin are dried for 3 days so that water may reach the waterways of Jay. Then all the waterways are dug so that self-distributed water comes back. A messenger is hired from Marbin and Jay for 20 days who shall sit on all waterways to prevent from making further branches until the time of 'vanesh' of Roudashtain's soiled water. If at any time, water is too little to irrigate crop seeds of Marbin and Jay, on the 15th day of Scorpion as much as 30 or 40 millstones of extra water shall go to Kararaj and Bara'an for planting and after 5 days water shall go under 'vanesh' . As the remaining water of Kararaj is adequate for the summer crop, it has no specific 'vanesh' except for 'vanesh' of Marbin and Jay that if there is sufficient water, the water distributor helps them by giving some water at the time of Roudashtain 'vanesh'. The distribution resolution for the messenger of every district and quarter is mentioned below; all districts of a village shall pay 1500 Dinars and those out of the resolution have to pay 350 Dinars for every acre to the water distributor."

Although Sheikh Bahaiee's Scroll ended the anarchy of the Zayandehrood River's water utilization to a remarkable extent, during next times the anarchy went on especially when Isfahan was subject to brutal invasions of some rulers who interfered in water distribution and possession based on their personal tastes. However, after the Constitutional Revolution owners of villages asked for water distribution according to the scroll. They submitted too many objections and complaints to the governments of the time. Finally in 1927, holders of water right who were about 500 people held a meeting at Mirza Taghi Bonakdar's garden and approved the implementation of the scroll. From that date on, affairs of the river were carried out under the supervision of Mr. Nourodin Khan Ostovan who was a high rank officer in the Ministry of Finance. After him, the Waters Office represented by Mahmoud Khan Faroughi, the late and Shokrolah Khan Shirani directed the works respectively.

When the Civil Status Registry was established, people required their shared to be registered and with the agreement of Ministry of Justice and Ministry of the Interior, it was supposed that in notices and ownership documents the sentence "water right according to rules of the district" be mentioned.

In 1941, the Waters Office was transferred to the Agriculture Department by the approval of the Governor General. All the documents were handed over to the new office. From that date on, 33 representatives were selected based on the 33 parts of the river's water in the scroll. They took on ordering and distributing works. Among them we can name Mr. Karim Keshavarzi, General Manager of Isfahan Agriculture Dept., who worked as the river chief while keeping other duties. He has always been accepted by people.

After building Zayandehrood Dam and its start-up in 1970 and increasing quantitative and time capabilities of water, the system of water utilization based on the scroll was implemented quite free of any problem. It was partly influenced by farmers' expectations change and increase to the utilization system. Those who did not have water right enjoyed it in months when they had no water share. In area where cultivation improved, farmers possessed the right by referring to technical and scientific documents. This process is still ongoing with establishing modern irritation networks on the downstream of Zayandehrood Dam.

RESOURCES:

1. The Zayandehrood River from the Origin to the Lagoon, Dr. Seyed Hassan Hosseini Abari,
2. The Zayandehrood river of Isfahan, Mr. Mohammad Mahmoudian.

INTRODUCING ONE SAMPLE OF IDIGENOUS KNOWLEDGE OF QANATS WATER CONTROLLING IN YAZD PROVINCE (MORE DUAL-PURPOSE CULTIVATION FOR AQUIFER MANAGEMENT AND PRODUCTION)

M.A.Dehghani[1], M.R.Kaki[2], M.Abolghasemi[3]

ABSTRACT

Farmer of yazd province have innovated some scientific and worthy methods for water controling , because of its shrotage. This indigenous knowledge is the cause to keeping of rural areas, for example there had been created barrier and canals to convey water form seasonal rivers to marginal lands.

This subject was studied in Sanige valley , yazd . there are 22 inhabited villages so that in 12 of them , this methed has been used with dual – purpose cultivating in spring and qanat aquifer recharge- in this study the cultivation and qanat aquifer recharge were surveyed in 12 above samples . At the result the villagers were building small barriers across river and conveying water to the wide lands for the cultiration in the spring in previous years.

In this utilizing additional to producing product , the down aquifer recharge was also considered , sloping and permeable lands have been cultivated as circular Qolam (morei) with encourage owner and share farmer in spring season. in this way the lands dominant over qanat aquifer will be recharged and it will help water introducing along the summer . In fact there was a kind of water controling through the cultivated strategy that has caused continuation of qanats and fountanis.

Key words: aquifer management, Idigenous Knowledge , agricultural , village , permeability , cultirated strategy

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INTRODUCTION

Farmers' coexistence with extra arid climate in central areas of Iran is an interesting topic. Precipitation is low in this area. While mean annual Precipitation is about 100mm and it has a irregular distribution but the annual evaporation is about 3000mm and air humidity is less than 15% , in addition blowing hot and dry winds makes bad conditions for farmers, nevertheless the farmers have made thousands big and small villages according to their ancestors' wisely manners. These villages have remained for several years.

The cause of remaining people in such difficult condition is that they have learned to make the most of water. There were some group interview with selected villages correspondents to knowing the manner of coexistence with water shortage and dry conditions. In this way many manners were introduced so that one of them is method of subterranean waters improvement and store water under the ground to use it during the water shortage. Water supply resource in such villages is qanat that is connected to subterranean water resources and gradually makes it discharge in piedmont plains due to the geological conditions and shape of earth there would be changeable water discharge during the year. Qanat water would increase in winter and spring seasons, but it decreased at the end of summer (table no. 1), the villagers to face with excess water during the winter but with water shortage at the end of summer. In the studied area the villagers have solved this problem with irrigation and cultivation management in land over look the qanat.

Dehghani et. all have reported the fluctuating of qanat water discharge in this area from average of 43 liters per second during the spring to average of 1.32 liters/s at the end of autumn. This fluctuating has become an important difficult in piedmont and mountainous regions during recent years. The authorities of selected villages explained that farmers for solving the problem combined farming with aquifer and through cultivate on up lands in spring season could increase the qanat water in the next months.

Similar to this method has been reported in Sistan and Balochestan by Henry Goblo(2). So that Iranian ancient people caught extra water in pools named "Gabr Band" during the spring. The water permeated through the soil and increased qanat water of down lands in the next months.

In fact the people of desert-dweller stored extra-water in different forms on the ground during the spring, then gradually used it through the qanat in dry season. The villagers had a good experience in method of water-supply and its circulation. The selection of soil type and distance between place of water permeation to qanat recharge reservoir, also the time of its impression qanat discharge is important and depends on people's experience these methods include cultivation management aim to aquifer management, recharge into soil directly through the "Gorabs" (fig.no.2), water transfer through the rich basin to poor one, diggings subterranean conduits aim to recharging water into qanat aquifer and creating terrace villages along the valley (fig.no.3) aim to drain the upper plantation then the water was utilized in an area.

MATERIALS AND METHODS

The study was carried out in area of 5960 Km2 in Taft city limit, Yazd; there were selected 473 habitable villages as statistical universe and 10% of them were as statistical sample villages. At least 3 local authorities were selected from every sample village to interview.

The interview was done in from of semi-open. Their group suggestions were recorded as different experiences. Behaviors were deeply investigated before interview. Many behaviors were observed about farming especially water and soil conservation. In this article you will see only a sample of behavior concerning to water supply and to regulate its circulation. Since these suggestions are offered collectively and its date and effect can be observed there, thus they are assured and believable. Sociologists such as Dani have introduced this study much reliably.

RESULTS AND DISCUSSION

The results showed that arid zone inhabitants of Iranian central plateau used an effective method to adjust water shortage. This method included artificial recharge of qanat aquifer in different farms.

One of the methods of aquifer reinforce is combined agriculture with aquifer management.

This was done in form of cultivating on up land of qanat aquifer in spring season. There is usually extra water in mountainous village valleys during the spring. Qanats are dug in path of these valleys alluvium. This alluvium is qanat aquifer. The villagers selected up land and conducted extra water there, then they were temporarily cultivating to reinforce qanat discharge (Fig.no.1). Sometimes crops failed because of short period of extra water flow. But the farmers always use this method since they sought artificial recharge of qanat aquifer not to get a good crop. Varied value was selected on the basis of material and depth of alluvium, area slope, the time of decrease of qanat water and distance of cultivation to first well (Mathar chah). The farmers were experienced in selection of distance and the other mentioned parameters for mountainous shallow qanat with 20m depth this distance was 3 kilometers. If there wasn't any natural limitation, they would select this distance according to alluvium material and texture until the drain of plantation effect on qanat discharge. This dual purpose cultivation carried out in sloping land and hillsides in form of terracing or by the side of the small channels. They called it "Mor-ei-kary" and usually cultivated wheat, barley, pea and lentil in channels Mor-ei cultivation caused recharge water in sloping land that was in the distance one kilometer of qanat. This strategy has regulated the qanat discharge fluctuating and caused to stability form and village, the terraces where cultivated wheat were irrigated regularly before cluster growth.

In addition to combine cultivation that was explained, there were dug several hollows in suitable distance for catching extra water during the spring. Water gradually permeated in aquifer and would increase the qanat water later. These reservoirs called "Gorab" there was one or several Gorab for every qanat that helped the artificial recharge. Areas of Gorabs were from 100m2 to one hectare and were at 1-3 Km distance of qanat. When two sub-basin were beside each other one was rich and the other poor. By making some channel could transfer water from rich basin to poor one, thus they produce a water balance in the region.

The authorities showed some under ground channels in rural districts of Sanij. These channels are made only for artificial recharge of aquifer .When the surface of aquifer was impermeable, water transferred into the aquifer through the channels.

Finally, people of desert-dweller had a wisely behaviors for water supply and circulation. Through these behaviors villagers could endure the most severe conditions such as drought.

Nowadays unfortunately the beautiful and coexist with environment behaviors are being forgotten. This forgetfulness is one of reasons for destabilize agriculture in villages. It is necessary that responsible organizations collect the indigenous knowledge and current behaviors in every region as soon as possible and combine them with modern behaviors utilizing for stability development.

Table no.1- discharge fluctuation in qanats of Sanij rural districts

Village name	Mean qanat discharge during April Li/s	Mean qanat discharge during September
Dashtak-e- Olia	35/5	1/44
Dashtak-e- sofla	41/1	2/23
Bagh-e-Khatoon	33/1	1/7
Ghala-Khan	27/5	1
Sadegh Abad	32/5	0
Koreh	62/4	1/5
Navabi	71	1/4
Mean	43/3	1/32

Key Speakers

International History Seminar on Irrigation and Drainage

WATER MANAGEMENT - BASIS FOR THE DEVELOPMENT OF SETTLEMENTS SINCE PREHISTORIC TIMES?

Dr. Henning Fahlbusch[1]

Water characterizes the "blue planet". It is the basis of life, the life of plants, animals and mankind. The water is unequally distributed on the earth in the framework of the hydrological cycle locally as well as temporally. And when we consider the meaning of water for humans in history the discussion must focus on water itself. The engineering structures and technical elements are nothing but a necessary consequence for the management of water resources.

AVAILABLE WATER SUPPLY AND WATER REQUIREMENTS

The water that is available for living precipitates to earth as rain, dew, snow etc. Partly it percolates into the soil and seeps to the underground water. Another part will be collected on the surface in puddles, ponds or lakes or it flows in rills, brooks or rivers towards the sea. Surface water and ground water are the only natural resources available for use by living beings because the part that evaporates is not usable.

Plants are locally fixed and therefore depend on the locally available supply. Animals and humans on the other hand are mobile and can move to where the water is available. This behaviour probably dominated the early humans such as nomadic hunter-gatherers, but we still observe this phenomenon in the case of Bedouins.

However, after the humans settled down the need for a regular supply of water grew. This was possible easily from perennial rivers or lakes and/or at some places from springs. When there was sufficient or even abundant water cultures could develop, as for instance in the river valleys of the Nile, Euphrates/Tigris, Indus, or Hoang Ho. These cultures which depended on the water in the rivers are therefore often called "hydraulic civilizations".

Since early times humans were confronted with the natural hazards of droughts and floods. Both threatened people, as we can read not only in the Bible but in many other reports from various parts of the world. And people had to overcome both these situations. To achieve this structural measures were necessary which were more or less copied from nature and then developed and improved. Nature was the teacher in antiquity. In the following text measures for the supply shall be dealt with first, and afterwards those for flood protection.

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In the beginning, water requirements were confined directly to the supply of drinking water for humans and animals. After people settled down and developed a more complex society, water requirements increased to include also hygienic and ritual washing, water games, cooling and the use of water power as well as navigation. Often the local water supply became insufficient for these various purposes and the need for water resources management developed.

WATER RESOURCES MANAGEMENT – TRANSFERS

With regard to the supply of water there are in principle two problems: one of quantity and one of quality (hygiene, salt content, bitter taste, temperature etc.). The problem of quantity was regarded as more important. As already mentioned, from the beginning humans used surface or spring water for their supply. The latter was certainly better from the hygienic point of view, but its quantity was, and is, generally limited. Thus underground water could only be made accessible by wells, and this was already done very early on.

When water requirements exceeded the locally available supply there are only two manmade measures available to meet the demand: temporal transfer and local transfer, or a combination of both these methods. Local transfer of water involves its transport in aqueducts from the origin to the place of demand; whilst temporal transfer involves its storage in times of surplus to be used at times of insufficient supply.

Nature was the model for the builders of storage facilities as well as for aqueducts. Both types of transfers have already been used since very early on. The builders constructed the necessary hydraulic structures only after thorough studies and analysis of the local natural conditions to which they were excellently adapted. Their improvement was surely based on the principle of trial and error.

THE SUMERIAN MYTH OF CREATION

A Sumerian myth of creation, which can probably be dated to the 3rd millennium BC (Bagg 2004) shows, that already more than 4000 years ago the climate in Mesopotamia was arid or semiarid because agricultural production already depended on irrigation. To achieve this, the backing up and storage of water, as well as its conveyance, were common practices. The translation of the relevant text by Pettinato reads:

… nobody cleaned the small canals;

Nobody removed the sediments from them;

Nobody irrigated the good fields;

Somebody, who dug irrigation ditches, was not available;

…….

…. Ninurta, the son of Enlil, did great things:

He built a big mass of stones in the mountains;

….

He constructed a barrier at the horizon;

….

The stones struggled with the powerful water;

Now the water of the mountains will not flow down to the valley any more;

(the waters) which were scattered he collected,

(the waters) which were lost in the mountains

he collected and pitched (them) into the Tigris,

early flooding he poured onto the fields.

………..

Engineers cannot comment on this translation. But the interpretation of Pettinato is logical that the text says, that the god Ninurta collected the water of the Tigris by means of a huge dam which stored it and thus tamed it. The stored water was used to overcome droughts. The need for temporal as well as local transfer was obviously common knowledge at that time.

TEMPORAL TRANSFER BY MEANS OF DAMS AND CISTERNS

The oldest dam of the world known to us was obviously constructed in the same epoch in which the quoted Sumerian myth of creation was written. It is a dam 5 m in height and 80 m in length at Tel Jawa in the desert of northern Jordan (fig. 1). The dam was constructed from two walls made of basalt-stones and a core in between of ashes and soil. Together with three additional ponds the whole system could store about 42000 m^3 of water (Vogel 1991). The discharge after the heavy wintry rainfalls in the catchment area of the wadi was stored there. This was the source of the water supply for the people of Jawa in the desert.

Figure 1: The old dam at Jawa

The example of the dam at Jawa shows that it was already possible to construct high, long and obviously expensive dams during the bronze-age. However, such a big thoroughly planned structure was surely not constructed as a new design but would have been the result of a long development process. But this we do not know. How was it initiated?

When Darwin proposes that the human embryo repeats the historical development of the human species, it can be supposed that children might also perform the cultural development of mankind. Every child coming to a brook immediately starts to play there. And when playing he will start to back up the flowing water. Is it instinct?

Surely the first dams were of low height and of short length. They could not be confirmed archaeologically yet. But surely they did exist. But in the course of centuries and millennia they would have been demolished by nature and men.

The various types of dam construction were improved in the course of time, especially by the use of ashlars. Small valleys were closed at very many places in order to create basins for the storage of water. In Petra (Jordan) for instance small walls can be seen in narrow side gorges (fig. 2) when one walks through the main gorge, the Siq, into the old Nabataean capital. Behind these walls water was trapped and stored and at the same time the threats of floods decreased.

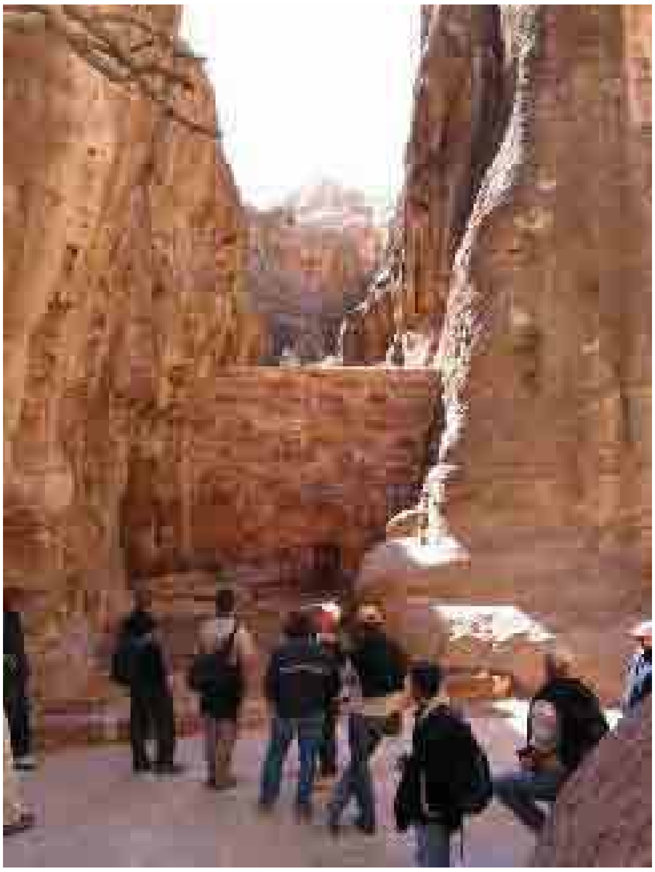

Figure 2: Reconstructed dam in a side gorge of the Siq in Petra (Jordan)

Water in open ponds stored by means of dams is not perfect from the hygienic aspect. Pathogens can easily develop there. This is not the case in closed, covered cisterns because of the darkness and the lack of organic material for the supply of bacteria. Additionally, the water in cisterns remains cool in summer in comparison to that from open ponds which are directly influenced by the sun. This is a very valuable advantage in quality as well as diminishing evaporation.

Cisterns were often directly cut into the rock and sealed by means of plaster to prevent seepage losses. Rainwater was then diverted into them and stored there. If the volume in the cistern amounted only to a few cubic meters, probably only single estates would have been supplied from it. Later people managed to construct large cavities with a volume of more than 100 m³, including the sealing of large clefts or caves in the rock in order to create huge underground storages. Examples for that can be found for instance in Beidras (Jordan) or at ancient Sepphoris (fig.3) in the Holy Land.

Figure 3: Cave used as huge cistern in antiquity at Sepphoris (Foto: Tsuk)

LOCAL TRANSFER BY MEANS OF AQUEDUCTS

The oldest long distance channels known to us are also already high quality engineering structures. The 54 km long Menua-canal in southeast Anatolia (Garbrecht 2004) as well as the 55 km long Jerwan-canal (Garbrecht 1985) in Iraq of today conveyed water mainly for irrigation. The discharge of the Menua-canal (fig. 4), of up to 8 m³/s was limited by the output of its spring. The discharge of the Jerwan-canal was probably much larger then 10 m³/s as its water was taken from the Gomel river. The discharge of these aqueducts far exceeded that of the famous Roman aqueducts. In one of its largest, the Aqua Claudia of Rome, not more than 1.5 m³/s flowed into the capital.

It can certainly be assumed also for the structures of the local transfer that such “world records” had not been created ad hoc but were the culmination of a long process of development. But we do not know the details of this development, probably because all the elements of the early small structures have vanished in the course of time.

Besides some written sources like the text quoted above, sometimes traces are found already in prehistoric times of the human ability to direct water to a goal in a planned line. Such an example is the irrigation project of Tel Hujayrat-al-Ghuzlan near Aquaba in Jordan, which can be dated to the first half of the 4th millennium BC. Here artesian groundwater came to the surface most probably under the specific hydro-geological circumstances in a number of spots in a field of springs. Traces of calcareous crusts on the stones, so called sinter, prove that indeed ground water was used here, principally to supply the humans and their animals. Additional water however was diverted into a vast system of terraced fields for irrigation by means of conducting walls which were made of unhewn stones set into loam. The size of this system indicates that here agriculture was done on a large scale and was the source of the prosperity of the settlement (Grottker/Heemeier 2006). This in turn supported the further development of the hydraulic system.

Figure 4: The modern Menua-canal. Above it at the slope the retaining walls of the old structure can be seen (Foto: Garbrecht)

FLOOD PROTECTION

On initial consideration, flood protection seems to be unimportant in the arid region of the Near East. However, this is not true, at least not for Mesopotamia. The requirement for dikes and their maintenance is already mentioned on the stele of laws from Hamurabbi (about 1700 BC). Law 53 reads:

"In case somebody is too lazy to maintain his dike in good order and in case this dike fails and all fields are inundated then this person in whose reach the failure occurred shall be sold …"

Every year after the melting of the snow in the upper reaches there was the permanent threat of inundation in spring in the vast plains of the Euphrates and Tigris. This threat required great flood protection measures not only for the settlements but also for the fields. Therefore many dikes were constructed.

Another example of flood protection measures can be seen in the Siq gorge in Petra (Jordan) mentioned above. In 1926 a group of visitors drowned there after a heavy thunderstorm. As a consequence the ancient flood protection system was rebuilt. This consists of a dam which prevents the water from Wadi Musa entering the Siq. Instead the flood will flow through a tunnel into a neighbouring wadi thus bypassing the vulnerable part. Furthermore, the walls in the side gorges of the Siq mentioned above ensured that no flash floods could develop along the vital access route to the Nabataean capital.

However, the peculiarity of Petra's flood protection measures is, that it was integrated into the whole water management system. Every drop of water available, either as ground water or surface water coming from precipitation, was collected, cleaned, stored and finally used (Bellwald 2003). Therefore it is justified to call Petra a water-managed-desert-city.

The question in the headline of this paper whether water was the basis for the development of settlements can at least for Petra be nothing but assented to.

SOCIETY

It was explained before that the principal methods of water management are as old as the history of mankind. The people more or less imitated nature. Technical developments concerning the number and quality of the necessary structures were made possible by the technical skills of artisans who used natural materials after thorough studies and analysis of their characteristics.

But huge structures would not have been built based on technical skills alone. The great innovation was principally the logistic and organisational coordination of the work of hundreds or even thousands of people to realize gigantic projects for that time. The masses of soil to be moved for dams, and dikes, or the many kilometre long canals could not be performed by the inhabitants of single villages. Furthermore there was the knowledge that the newly built structures had to be maintained and if necessary to be repaired. This required not only competence and organisation but also rules and regulations which were commonly accepted. And this was obviously the case when one looks once more at the stele of Hamurabbi, for instance.

OUTLOOK

When nearly 30 years ago here in Teheran Prof. Garbrecht successfully suggested to set up a Working Group on History in the ICID-family it was done with the understanding that even engineers in the 20th century can learn from history. And naturally this was therefore the topic of many sessions which were organized in the past at ICID-meetings. But these were always reports of single projects which many scholars had investigated.

Five years ago the German Water History Association (DWhG) was founded, which has close relations with WG-HIST of ICID from its beginning. Now the DWhG hopes to start a bigger research project supported by one of the largest German Research Centres. The aim is to recreate ancient structures and technologies especially in areas where scattered estates lack water and cannot be included into a public supply system.

In this context it is unquestionable that modern materials for aqueducts are by far superior compared to those used in antiquity. However, can they always be financed? And what about dams? Large dams are already a focus for critics since long ago, especially in developing countries. Small scale storage facilities are often better adapted to the requirements of the people. Probably there are also problems of acceptability. A recent publication in Israel shows that in the northern part of that country many people, especially Arabs, use cisterns instead of the public water supply system although it is more expensive. And they are even constructing new cisterns. The reason is that thus they gain a larger security for their independent supply.

Another recent study of cisterns in Umm Quais in northern Jordan shows that cisterns were still used there until 20 years ago. In 1987 their operation was stopped. Why? It needs little effort just to clean and reuse them in order to collect water in winter, when it would otherwise flow unused to the valley. The same applies to a big pond in Beidras in Jordan (fig. 5), for instance. Obviously the ancient walls are still strong. They just would have to be cleaned and newly plastered to become impermeable. Thus about 10000 m^3 of additional water could be used at this place. But today it is no more than a garden. The reuse of these structures could be the beginning of a reinvention of old techniques and structure in this wonderful country.

Here mostly the examples of Jordan were mentioned. But surely the situation in many other countries is similar. The German Water History association likes to invite you for cooperation at similar projects in your respective country.

Figure 5: Ancient pond as garden in Beidras (Jordan)

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IRANIAN WATER HERITAGE:
PAST WISDOM FOR FUTURE CHALLENGES

Kamran Emami[1]

ABSTRACT

In the long history of mankind, the 21st century would be very distinct from the other centuries and may be considered as the most challenging era for humanity. For the first time in human history, the 21st century is likely to see the end of world population growth. With the current trend of sophistication of technologies, it may be envisioned that by the end of the 21st century even the poorest human beings would enjoy the basic needs of life. Nonetheless reaching this status may involve unimaginable human suffering. Furthermore, according to climate scientists, more floods and droughts would be very likely in 21st century and the people living in poverty would be worst affected by the effects of climate change. The development of societies in arid and semi-arid areas in the last 5,000 years is closely connected with water management problems that have shaped the relevant society and its structures. In the course of the centuries, systems and methods worked out under these conditions have conclusively demonstrated their sustainability. Today, the knowledge and structural remains of these methods are not only interesting archaeologically and historically, but can also help solve current problems. In view of Data, Information, Knowledge, Intelligence and Wisdom hierarchy studied in knowledge management, the water wisdom of the past which was achieved in a period of hundreds of years, can be regarded as a unique and irreplaceable gift from our ancestors to our generation. The Persians of ancient times recognized the importance of irrigation to the sustenance of civilization. By excavating underground water tunnel and gallery systems (qanats) and by constructing many dams, they accomplished projects that rank among the greatest in history. This paper tries to highlight the accumulated knowledge and water wisdom of Iranian civilization by a comprehensive review of their accomplishments in water resources management in very diverse situations

Key words: Water wisdom- Iranian heritage – Qanat – Historical Dams – Climate change - Sustainability

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1- INTRODUCTION

This paper would be presented in the context of water history; still this introduction focuses on future. The 21st century would be very distinct from the other centuries in thousands years history of mankind. The 20th century was the century of explosive population growth, resulting in unprecedented impacts. In contrast, for the first time in human history, the 21st century is likely to see the end of world population growth. With the current trend of sophistication of technologies, it may be envisioned that by the end of the 21st century even the poorest human beings would enjoy the basic needs of life. Nonetheless reaching this status may involve unimaginable human suffering. Based on a report of UNICEF report entitled "THE STATE OF THE WORLD'S CHILDREN 2005, CHILDHOOD UNDER THREAT", for nearly half of the two billion children in the real world, childhood is starkly and brutally different from the ideal we all aspire to. Poverty denies children their dignity, endangers their lives and limits their potential. Conflict and violence rob them of a secure family life; betray their trust and their hope. HIV/AIDS kills their parents, their teachers, their doctors and nurses. It also kills them. A summary of horrible statistics given in the report is presented in table 1. This is the situation of in 2005. If the current trend of resources and demands continues, in coming years we would face unprecedented disasters similar to the tsunami of 2004 in south Asia. According to above discussions the influential groups should recognize that the next few decades could be critical for the whole well being of human race and adopt appropriate measures to "make poverty history" with very limit resources and in a very short time in the context of severe constrictions imposed. The challenges are immense but the eventual potentials of human being are unimaginable at the same time.

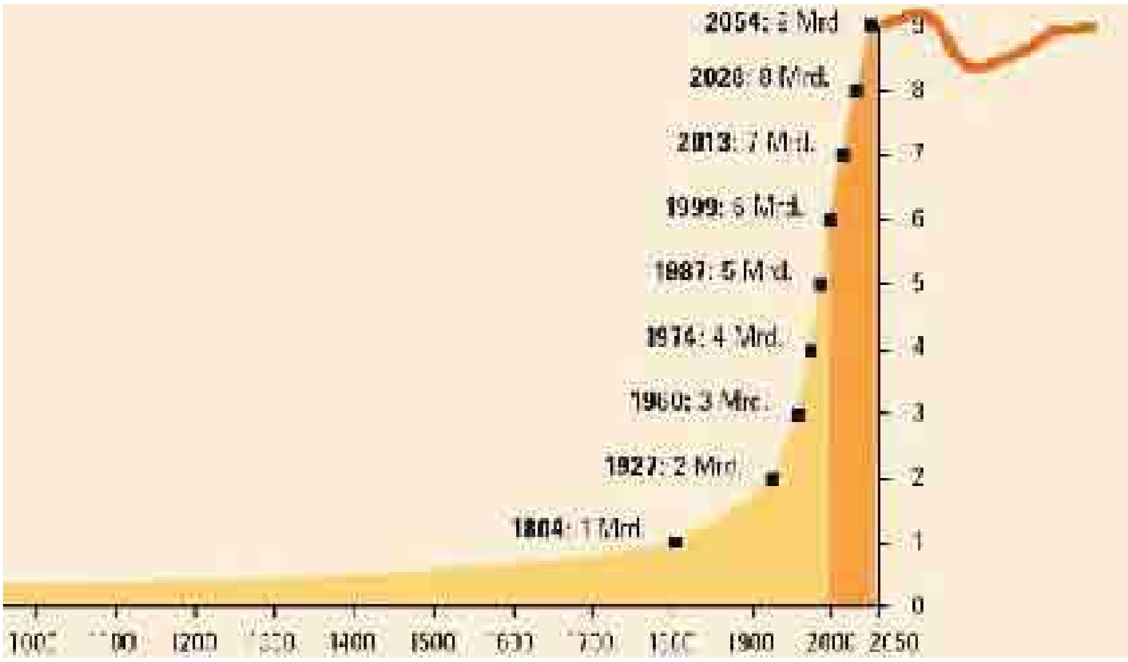

Figure (1) World population from 1000 BC to 2300 BC

Table (1) A summary of UNICEF report on THE STATE OF THE WORLD'S CHILDREN 2005

Number of children in the world:	**2.2 billion**
Number of children living in poverty:	**1 billion**
Number of children in developing countries who live without adequate shelter	**640 million**
Number of children who have no access to safe water: one in five	**400 million**
Number of children who have no access to health services	**270 million**
Number of children who are out of school	**121 million**
• Total number of children younger than five living in France, Germany, Greece and Italy: • Total number of children worldwide who died in 2003 before they were five	**10.6 million** **10.6 million**
Daily toll of children in the world who die before their fifth birthday:	**29,158**
The number of children who die each day because they lack access to safe drinking water and adequate sanitation:	**3,900**

2- WATER-RELATED CHALLENGES IN 21ST CENTURY

Based on IPCC WGII Fourth Assessment Report on climate change in 2007, climate change would be one of the key challenges of mankind in the next decades. Key findings of the report include:

- 75-250 million people across Africa could face water shortages by 2020;
- More heavy rain events are very likely and more areas are likely to be hit by drought;
- Crop yields could increase by 20% in East and Southeast Asia, but decrease by up to 30% in Central and South Asia;
- Agriculture fed by rainfall could drop by 50% in some African countries by 2020;
- 20-30% of all plant and animal species at increased risk of extinction if temperatures rise between 1.5-2.5C;
- Glaciers and snow cover expected to decline, reducing water availability in countries supplied by melt water.

The report states that the observed increase in the global average temperature was "very likely" due to man-made greenhouse gas emissions. The scientific work reviewed by IPCC scientists includes more than 29,000 pieces of data on observed changes in physical and biological aspects of the natural world. Eighty-nine percent of these, it believes, are consistent with a warming world. People living in poverty would be worst affected by the effects of climate change. The finding of the report underlines how important it is for every country to adapt to the climate change that is already under way.

This paper is trying to demonstrate that coping with the water-related challenges in the 21st century requires major technical jumps and innovations in all fields and in this context, water wisdom of the past may play a vital role.

3- DATA, INFORMATION, KNOWLEDGE AND WISDOM HIERARCHY

In knowledge management literature it is often pointed out that it is important to distinguish between data, information, knowledge and wisdom. The generally accepted view sees data as simple facts that become information as data is combined into meaningful structures, which subsequently become knowledge as meaningful information is put into a context and when it can be used to make predictions. This view sees data as a prerequisite for information, information as a prerequisite for knowledge and knowledge as a prerequisite for wisdom. In Figure 2, data are assumed to be simple isolated facts. When such facts are put into a context, and combined within a structure, information emerges. When information is given meaning by interpreting it, information becomes knowledge. At this point, facts exist within a mental structure that consciousness can process, for example, to predict future consequences, or to make inferences. As the human mind uses this knowledge to choose between alternatives, behavior becomes intelligent. Finally, when values and commitment guide intelligent behavior, behavior may be said to be based on wisdom.

With today's sophistication, the time step for a typical data to wisdom process may be a day or a week or a month in industrial cases. But in the context of water engineering, the time step may be a year or a decade or a century. Consequently the water wisdom of the past which was achieved in a period of hundreds of years can be regarded as a unique and irreplaceable gift from our ancestors to contemporary water engineers. Hopefully, the water wisdom of our ancestors would play a key role in our adaptation with the water related challenges of the 21st century. It is therefore necessary that we look back at the ancient creation of the fertile human brains that used the synergy of science and art at that moment of time to provide us with abundant food for thought. It should be remembered that foundation of the future rests on the achievement of the past. In this context, it would sustainable water management in some arid and semi-arid areas may be ensured by using traditional processes and construction methods

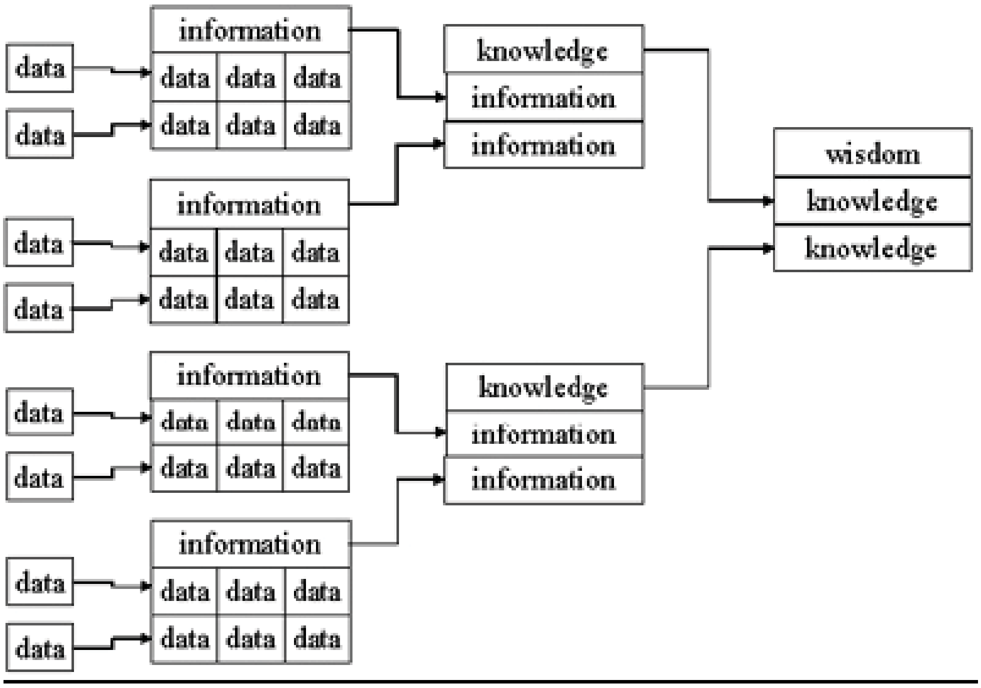

Figure 2: Building on data in the Wisdom Hierarchy.

3- THE LONG AND HONORABLE HISTORY OF IRANIAN WATER ENGINEERING

The water engineering is a vital part of the story of civilization. Reservoirs for water supply were undoubtedly among the earliest structures devised by mankind. The role that water management structures have played over the ages is documented in many records of historical lands. These structures have been linked closely to the rise and decline of civilizations, especially to those cultures highly dependent upon irrigation.

The Persians of ancient times recognized the importance of irrigation to the sustenance of civilization. By excavating underground water tunnel and gallery systems (qanats) and by constructing many large dams, they accomplished projects that rank among the greatest in history. In the ruins at Sialak, near Kashan, are to be seen traces of irrigation channels that are considered to be as much as 6000 years old, suggesting that irrigation was practiced there from very early time, even before the arrival of the Aryans in the land now known as Iran (Jansen, 1983).

With an annual mean precipitation of less than 150-mm for most regions in the country, efficient water resource management has been literally vital to sustainability of the Iranian civilization. Throughout the history of the country, ancient Iranian had to introduce many innovations to utilize the available resources such as qanat. The qanats were dug below the ground surface to intercept groundwater. They resemble under drains or culverts. At the end of the qanat, the water discharged by gravity into an irrigation canal. Along the qanat, closely spaced vertical shafts were dug during construction and were also used for maintenance and repair. More than 54000 qanats have been identified in country and some 36000 qanats are still in operation with the total annual discharge of 9000 MCM. Fig. 3 illustrates 73 historical Iranian weir, bridge-weir and dams. As mentioned above, many of these hydraulic structures are quite remarkable:

- The most ancient dams in the country were built on the River Kur south of Persepols around 500 BC. Along with the dams constructed later on the river, at least one of these dams is still in operation.
- 2500-years old Amir dam can be regarded as the world oldest dam constructed by stage construction. The dam was heightened by about 5 m around 1000 AD
- 18 m high Ezadkhast dam built around 200 AD near Shiraz may be regarded as the oldest and highest true arch dam in the world (R=18m and central angle=130 degrees). It should be mentioned that the true arch dams built by the Romans were 12 m high Vallon de Baume in southeastern France and 5.7 m high Monte Novo in southeastern Portugal.
- Amir dam mentioned above was actually a “power dam” with as many as 30 water wheels driven by the impounded water (Schintter, 1994).
- 21-m high Fariman dam near Mashhad had been the highest buttress dam in the world till 24 m high San Blas dam was constructed in Mexico in the 18th century.
- As figure 3 clearly indicates, the most important characteristic of Iranian historical dams is remarkable height. 21 historical dams higher than 15 m have been identified in Iran as shown in the figure. This is another world record in dam engineering. Spain with 10 and Solvakia with 9 historical dams higher than 15 m rank second and third respectively (Schintter, 1994). Among the Iranian historical dams, the most important and the highest is 60 m high Kurit dam.

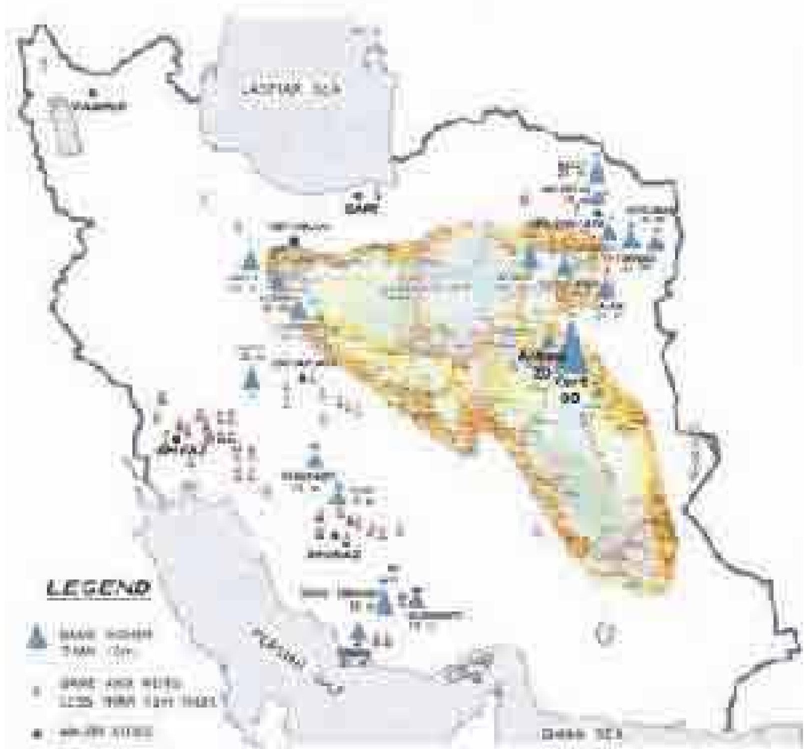

Figure (3). The historical weirs, bridge-weirs and dams of Iran (the deserts are highlighted)

4- LESSON LEARNED FROM THE HISTORICAL WATER WISDOM OF IRANIAN

This paper tries to highlight the accumulated knowledge and water wisdom of Iranian civilization by a comprehensive review of their accomplishments in water resources management in very diverse situations. Consequently the most important milestones of Iranian water heritages were reviewed and the lessons learned were classified in the following sections. It should be noted that it is just a pilot study and much has to be done on the subject.

4-1- CREATIVITY IS THE KEY TO SUCCESS

Creativity is the means to advance civilization into the future and throughout history it has played a key role in development and management of water resources especially in arid and semi-arid regions.

Creativity is vital for coping with diverse circumstances of water engineering and it can be promoted by the great challenges and limited resources. Many of the achievements of Iranian in water engineering are vivid symbols of creativity and can be considered as technical jumps:

- Qanats are probably one of the greatest hydrologic achievements of the ancient world that has made sustainable development possible in many arid and semi arid regions. Qanats were first developed in Iran but their use spread to India, Arabia, Egypt, North Africa, Spain and even to the New World. Most of the area that qanats serve to irrigate is arid and rainless. Without an effective and sustainable form of irrigation, such as is provided by the qanats, agriculture in those regions would have been impossible. For that reason, one cannot over-estimate the important role the qanats have played in Iran. To quote H. E. Wulff, "They have made a garden of what otherwise would have become an uninhabitable desert." In practice Qanat may be considered as a very intelligent scheme for conveying groundwater to the surface by gravity force. It has been proved to be an efficient and effective simple method in very diverse conditions. The great advantages of transporting water underground in this way are obvious. As the qanats are often dug into hard subsoil and, when necessary, lined with relatively impermeable clay hoops, there is little seepage, no rising of the water-table, no waterlogging, no evaporation during transit - and hence no Stalinization or alkalization in the area surrounding the conduits. Nor do they provide a niche for the vectors that transmit the water-borne diseases that so seriously affect the population of areas irrigated by modern technological means.

- To avert the construction of a diversion tunnel, a number of Iranian historical dams were built on a brick arch. The lower part of the dam would be constructed in a dry season after the completion of the upper part as shown in Figure (4). Consequently there was no need for river diversion during the construction.

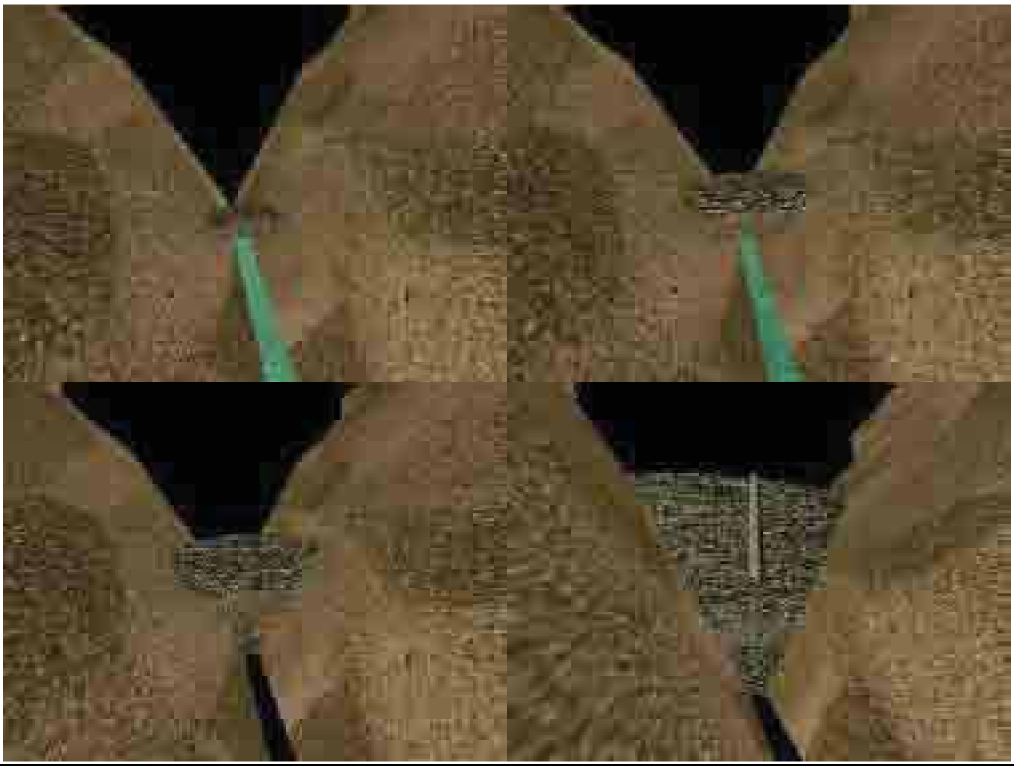

Figure (4). Construction of the dam on a brick arch to manage floods during construction

4-1- A RICH WATER CULTURE IS PREREQUISITE TO SUCCESS

Our knowledge of the past is mainly on successful water projects of the country and in practice they are just the tip of the iceberg. In comparison to successful hydraulic structures, there are many more doomed endeavors because our ancestors had to rely on trial and error. Due to the primitive technologies of past, the Iranian had to rely on their vision, intuition, imagination, creativeness, hard work and courage to accomplish these astounding achievements in water engineering. A rich water culture is prerequisite of the above mentioned characteristics and it is exactly the case of Iranian water culture. In this context it is interesting to note that In Farsi (the Iranian language), the first word in the dictionary is *ab*, water, and *abadan* -derived from it- means civilized. Throughout history Iranian water culture has motivated the people for sustainable, efficient and effective development, management and use of the limited water resources of the country. Water has been and will be a powerful cement in the organization and social cohesion of Iranian communities. This is why whenever any group has sought to destroy this country and bend them to its will; it has first attempted to wipe out their water culture and its material infrastructure. Raised to the status of a touchstone value, water has always reflected three dimensions -sacred, social and economic- in Iranian society. Fortunately Iranian water culture was further enriched by Islamic values. In the Islamic culture, Water is a gift of God. The importance of water in Islam does not derive from the facts of life in the Arabian peninsula, but directly from the revelation of God. "We made every living thing of water." (21:30). The Qur'an states that water is a source of life. The Qur'an reveals the importance of water in more than one hundred places. The

Qur'an generally link water to life and God is the giver of rain and snow. In this respect Allah says in the Qur'an: "See ye the water which ye drink? Do you bring it down from the cloud or do We?" (56:68). The importance of water is also highlighted by the traditions of the Holy Prophet Muhammad and he forbade the wasteful use of water, even when one is at the side of a river.

Finally it should be noted that Erik Swyngedow, a town-planner and geographer based at the University of Oxford, demonstrated that the modernization of the Spanish state went hand in hand with fundamental changes in the way water was used, and that water culture, water policy and water engineering played a key role in the formation of Spanish society.

4-2 RESPECTING THE YIELDS OF THE HYDRO SYSTEMS WOULD ENSURE THE LONG-TERM BENEFITS

What is particularly important about Qanats, as Pazwash points out in Civil Engineering, is that the discharge from qanats "is fixed by nature". They can only provide water produced naturally by a spring in a mountain area and then transport it by the force of gravity. As a result, the aquifer is not depleted and the quality of its water is maintained. By contrast, the amount of water extracted in a modern irrigation system by pumps and other technological means "is to some extent determined by man, who, in a modern economy, will be under pressure to extract the maximum amount possible, thereby depleting the aquifer and reducing the quality of the water." Gunter Garbrecht, former Chairman of the Working Party on History of the International Commission for Irrigation and Drainage, makes the same point. Qanats "tap the groundwater potential only up to, and never beyond the limits of natural replenishment and, as a consequence, do not unbalance the hydrological and ecological equilibrium of the region."

"If water can be withdrawn at will, regardless of the limits of natural recharge, a water supply can certainly be increased for a period of time. But sooner or later, the water potential will become exhausted and agriculture and economy will have to fall back to its original level, a process that inevitably carries serious socio-economic consequences for the society."

In this context it is not surprising to note that there are some 36,000 operating Qanats in Iran, comprising more than of thousands of miles of underground channels. Equally astonishing, much of that network is still functioning, sometimes thousands of years after the channels were originally built. Indeed, until recently, qanats still supplied 75 percent of the water used in Iran, for both irrigation and household purposes.

4-3- OOD PRACTICE CAN BE ACHIEVED BEFORE THE DEVELOPMENT OF THE RELEVANT THEORY

Some of achievements of Iranian in water resources were astounding and have only surpassed in the 20th century, such as 60 m high Kurit arch dam built in Iran around 1350. Iranian used the synergy of science and art to compensate for lack of the technologies we enjoy today. Despite their handicaps and constraints, they were ingenious enough to devise their own techniques to harness the bounty of the Mother Nature. Here are some examples:

- The application of arch, buttress and gravity dams at different dam site by Iranian clearly demonstrate the understanding of structural behaviors of dams. In this context it should be mentioned that except for the 20th century, Iran held the world record for the highest arch dam with:

- Ezadkhast, 1800 years old, 18m high,
- Kebar, 700 years, 25 m high
- and Kurit, 650 years, 60 m high.

- The deep understanding of Hydraulics by Iranian is vividly shown by many examples such as:

- Abassi Flood detention dam (Section 5 of this paper);
- Construction of water intakes in high historical dams to decrease the exit velocity of water;
- Widespread application of siphons and pipes in water transfer schemes;
- Construction of the dam on arch to eliminate the needed for a diversion system;
- Long water transfer systems;
- Construction of numerous Water wheels.

- Many considerations of modern dam site selection practice, such as topography, availability of construction materials, diversion works during construction, stream flow regime and so on, seem to have taken into account for selecting the most appropriate dam site of historical dams in Iran. So it is not surprising that the recent studies for construction of new dams have suggested the old dam axis as the best alternative. The examples are Doorodzan, Jareh, Saveh, Fariman and Kurit historical dams. Ironically, proper site selection has actually threatened the sustainability of many historical dams in Iran.

4-4 MONITORING THE HYDRO SYSTEMS, ADAPTATIONS AND NON-STRUCTURAL METHODS

Based on the existing documents, the every drop of water available, either as ground water or surface water coming from precipitation, was collected, cleaned, stored and finally used by the Iranian in arid and semi-arid areas and the water resources were closely watched during all phases. Based on the monitoring, appropriate measures (mainly non-structural) would be adopted. Some examples are presented below:

- The people of Sistan in South-East of Iran used to relocate their villages to adapt to changes of the courses of Hirmand and Sistan rivers.
- Erection of many ancient dams in remote mountainous areas where access is still difficult indicates how carefully all possible sites were investigated. This is also

indicative of closeness of Iranian engineers with the Mother Nature throughout history.

- The large spring floods of large rivers such Karun, Dez and Marun could endanger many river qanats. The villagers used to plug the qanat entrance before the floods.
- Water division is a traditional method which was institutionalized in all parts of Iran and everybody obey this method. If this method was not established or obeyed, the result of dispute would be nothing but the waste of main part of the crops. In this context, the Iranian devised accurate techniques for fair division of water.
- The most important cause for destruction of historical hydraulic structures was improper maintenance. The phenomenon was usually associated by wars and invasions.
- Community effort was required for the maintenance of qanats and historical dams and in many cases this effort has many similarities with participatory irrigation management.
- Ebrahimabad village was relocated twice to cope with the changes of the village qanat.
- A diversion channel called Gavshir was used to divert the river during the construction of 1000-years old Band Amir near Shiraz. The same channel has been used for passing large floods and sediment flushing (Figure 5).

4-5-RENEWABLE ENERGIES HAVE MUCH GREATER POTENTIALS

The future and the past would have a clear distinction from 20th and 21st centuries; there would much less use of fossil energy (relatively). The experiences of ancient Iranian clearly demonstrate that much more of the potentials of renewable energies may be captured to ensure sustainability. Some examples are as follows:

- Thousands of Qanats were and are in operation for hundreds years. The reliance of gravity force to transfer water to surface has been the key to their sustenance.
- Hundreds of Water wheels have been used in various regions of Iran to use the waterpower to rotate the stones. With 40 Watermills, the Shushtar Water wheel complex is the most important complex in Iran and it is to be included in wonders of human's cultural achievements listed by UNESCO.
- In Yazd province there has been extensive use of air conduit for cooling of the house and subterranean water reservoir.
- Iranian used ice chamber to store the freezing cold of winter as ice blocks for hot summer season without any need to fossil energy.

Figure (5). The remains of sediment flushing conduit of Amir weir (right)

4-6- THE UNIMAGINABLE POTENTIAL OF SYNERGY OF VISION, CREATIVITY AND PERSISTENCE

Due to the primitive technologies of past, the Iranian had to rely on their vision, intuition, imagination, creativeness, hard work and courage to accomplish many astounding achievements in all fields of water engineering. These milestones are indicative of potential of synergy of vision, creativity and persistence:

- It has been proposed that qanats should be listed as the Eighth Wonder:
    - Useful life (Hundreds of qanats with useful life of more than 500 years are currently in service)
    - Number (More than 54000 qanats have been identified in country and some 36000 qanats are still in operation with the total annual discharge of 9000 MCM).
    - Length (the total length of all the qanats in Iran is approximately equal to distance from earth to moon).
- The mother well of Gonabad qanat is approximately 300 meters deep! (measured by Power ministry authorities). The length of this qanat is 33 km and an underground dam near the 193rd vertical shaft, regulates the discharge of the qanat in fall and winter.
- With 21 historical dams higher than 15 m, Iran has more large historical dams than any other country in the world. Spain with 10 and Solvakia with 9 historical dams higher than 15 m rank second and third respectively (Schintter, 1994).

- The ancient Iranian constructed the earliest underground dams in the world in some qanats near Isfahan and Kashan. The largest of these underground dams is 9 m high and can store about 270000 m^3 in winter for subsequent use in dry season.
- Kurit water transfer system consisted of 60 m high arch dam, which was the highest dam in world for 550 years till early 20th century, a Qanat and a channel with a total length of 20 kms. The system regulated and transferred water from the Kurit dam site to Kurit village for irrigation for at least 600 years. Considering the dimensions of the project, i.e., the length of the transfers system (20 km) and the height of the dam (60 m), it is evident that the construction of the project required astonishing qualifications and capabilities 650 years ago.
- The 80-km long water transfer scheme from Shishpir to Shiraz in Fars province is only one of long distance historical basin to basin water transfer constructed by Iranian.

4-7- ENSURING THE HYDROLOGICAL SAFETY OF DAMS AND WEIRS BY STRUCTURAL DUCTILITY

The builders of historical dams could neither foresee the extreme floods probable during the life of the structure nor excavate a spillway in the rock. Accordingly they constructed the historical dams in such a way that could resist overtopping in large floods. To achieve this they avoid embankment alternatives, used arch configuration, protect the downstream from scour:

- The historical Kurit dam would serve as an illustrating example of structural ductility. The 60 m high dam, which was the highest dam for 550 years in world, has resisted more than 1000 overtopping ever since it has been constructed. The excellent overtopping resistance of the dam has resulted from the combined effect of arch configuration, suitable geotechnical conditions of abutments and foundation and erosion resistance of masonry (Figure (6)).
- Shushtar Bridge-weir has resisted the floods of Karun River which is the largest river in Iran for some 2000 years before its partial destruction by a flood in 1885.
- Many of the historical dams and weirs which are presently in service have resisted numerous overtopping for hundreds of years:
    - 5 dams on the Kor River near Shiraz (They are still in operation).
    - Weirs on Karun and Karkheh Rivers;
    - Bridge and weirs on Zayandehroud in Isfahan;
    - Weis on Hirmand and Sistan river in South-East of Iran;
    - 2000 years old Bahman weir near Shiraz;
    - Golestan, Fariman, Abassi and Torogh dams in Khorasaan province (They are still in operation).

Figure (6). A view 60 m high Kurit dam from the river bed (June 2004)
(The left picture is the first picture taken from the downstream river bed
due to difficult access to the downstream)

5- A HISTORICAL INNOVATION IN FLOOD MANAGEMENT

The construction of three arch dam in the 13th in Iran (Kebar, Kurit and Abbasi) was the first application of this type of dam since Romans and Iranian constructed 3 true arch dam 2000 years ago (Schnitter, 1994). Abbasi flood-retarding dam also known as Abbasi arch was constructed 600 years ago near Tabas, in Northeast Iran. The Abbasi flood-retarding dam is an illustrating example of water wisdom of the builders (Figure 7). The dam has protected the city of Tabas from floods of Nahrain River for 600 years. To avert construction of diversion tunnel, Iranian used to construct the dams on a brick arch in narrow canyons. The lower part the dam would be constructed during a dry season. This creative scheme has been used in many historical dams in Iran. At Abbasi dam site, the lower part was not constructed so during floods the outflow from the dam was automatically regulated. The scheme is so elaborate that most of the engineers visiting the site believed that the dam was uncompleted or it had suffered a wash-out because of the alluvium foundation (Schnitter, 1994). This is the first time that based on site visits by dam and flood experts and communications with the nearby villagers, the dam is called a flood-retarding dam. The dam site is located 100 m upstream of water springs that account for a considerable part of the base flow of the river. Consequently it is unlikely that the main function of the dam is water storage, otherwise they should have constructed the dam downstream of the springs. A historical document indicates that the main function of the dam is controlling the floods. Based on this document they did not construct the lower part of the dam in view of probable failure of the structures and risk to downstream. Although the area of the basin is just 200 km2, the floods have large peaks as shown in Table (2).

Figure (7) 25 m high Abbasi flood-retarding dam

Table(2). The flood peaks at Abbasi dam site

(Year)Return Period	**5**	**10**	**20**	**50**	**100**	**1000**	**10000**	**PMF**
Flood Peak (CMS)	**49**	**92**	**161**	**286**	**375**	**632**		**993**

10- RETARDING BASIN FOR FLOOD CONTROL

There are two basic types of flood-mitigation reservoirs - storage reservoirs and retarding basins - differing only in the type of outlet works provided. The discharge from a storage reservoir is regulated by gates and valves operated on the basis of the judgment of the project engineer. Storage reservoirs for flood mitigation differ from conservation reservoirs only in the need for a large sluiceway capacity to permit rapid drawdown in advance of or after a flood.

A retarding basin is provided with fixed, ungated outlets that automatically regulate the outflow in accordance with the volume of water in storage. The outlet usually consists of a large spillway or one or more ungated sluiceways. The Pinay retarding basin in France consists of two wing dams partially closing the river but with a gap between them for discharge the type of outlet selected depends on the storage characteristics of the reservoir and the nature of the flood problem. Generally the ungated sluiceway functioning as an orifice is preferable because its discharge equation [Q = Cd A(2gh)1/2] results in relatively greater throttling of flow when the reservoir is nearly full than would a spillway operating as a weir . A simple spillway is normally undesirable because storage below the crest of the spillway cannot be used. However, a spillway for emergency discharge of a flood exceeding the design magnitude of the outlets is necessary in any case.

As a flood occurs, reservoir fills and the discharge increases until the flood has passed and the inflow has become equal to the outflow. After this time, water is automatically withdrawn from the reservoir until the stored water is completely discharged.

An outstanding example of the use of retarding basins in the United States is the reservoir of the Miami Conservancy District in Ohio. Retarding basins were selected for this project because the small streams rise so rapidly that it would be difficult to operate storage reservoirs effectively. Moreover, the retarding basin assures the drawdown of the reservoir after a flood and prevents use of the reservoir for conservation purposes at the expense of flood control.

The planning of a system of retarding basins must assure that the basins will not make a flood worse by synchronizing the increased flow during drawdown with flood peaks from tributaries. When the entire drainage area is small, such an event is unlikely. However, separate tributaries within a large basin may be subjected to independent storms and the probability of synchronizing is greater. Hence retarding basins are preferable for relatively small streams and storage reservoirs are preferable for large streams.

11- THE ADVANTAGES OF THE PRESENT ALTERNATIVE

To control the floods of the river, there are other alternatives involving storage structure at Abbasi dam site. One of the alternatives is a dam with overflow outlet (overflow alternative). Undoubtedly the alternative of creative builders (bottom outlet alternative) has great advantages in comparison with the overflow alternative as follows:

Initial reservoir Elevation:

In overflow alternative reservoir may be partially full at the beginning of the flood. Consequently the routing of the peak of incoming flood in this alternative would be less than the bottom outlet alternative. Similarly retarding of the flood peak would be less in this case. Surprisingly the alternative constructed matches closely with modern criteria for retarding dams as motioned above.

Sedimentation

The bottom outlet alternative enjoys considerable advantage in terms of sustainability and sedimentation. A survey of the reservoir clearly indicates that there is virtually no sedimentation in the reservoir after 600 years of operation. As the Abbasi dam has been stable in many extreme events such as the Great earthquake of 1978 with maximum horizontal acceleration of 0.75g, it is virtually a sustainable dam. Very few dam in world enjoy such an advantage. On the other hand the maximum useful life of the overflow alternative would have been 50 to 100 years. Fortunately Abbasi dam is the only historical dam in Iran that has not been threatened by construction of a modern dam. It is hoped that many generations would have the privilege of visiting this outstanding human heritage than would be a source of inspiration for many engineers for centuries to come.

Risk to the downstream

As it was mentioned Tabas is located downstream of the dam near the river. Accordingly the failure of the dam would have disastrous consequences for the city. In the overflow alternative the total time that dam is full or nearly full is much more than the other alternative. So the total risk to the downstream is much less in the bottom outlet alternative. A historical document indicates that they did not construct the lower part of the dam in view of probable failure of the structures.

Overtopping Frequency

Evidently the frequency of overtopping is much lower for the bottom outlet alternative. Figures 8, 5 and 6 clearly indicate that the dam structure is intact after 600 years. With increased overtopping frequency and duration the probable damages to dam would have been more severe.

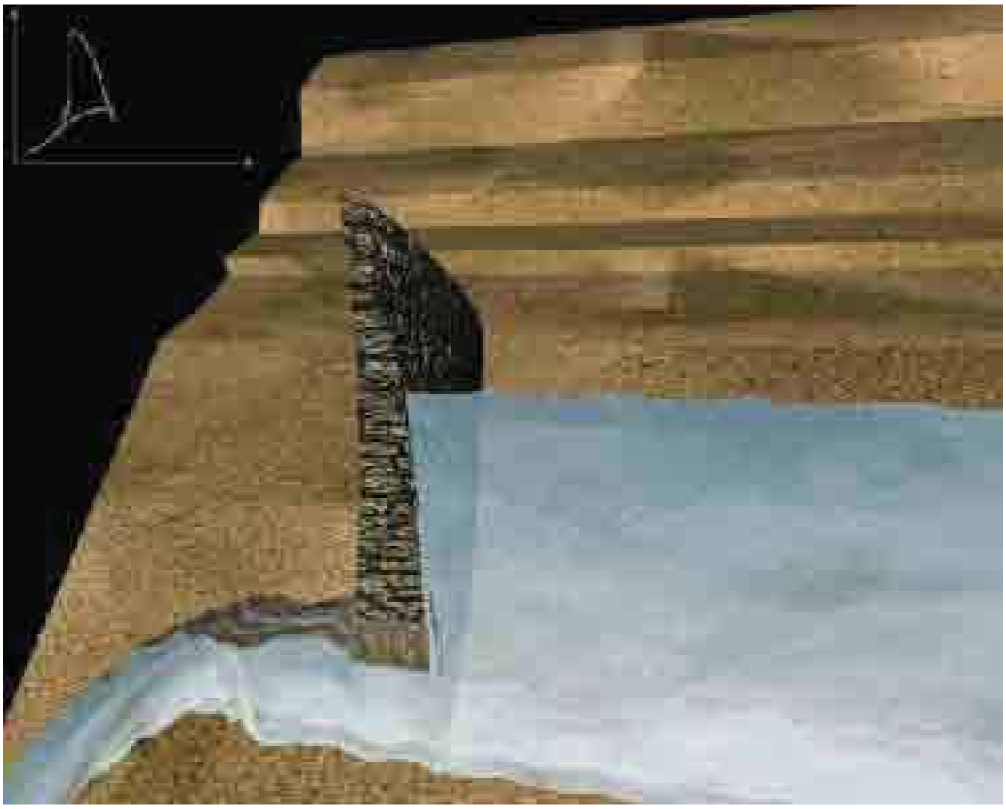

Figure (8). Flood Attenuation in Abbasi retarding dam

Passage of people

In the overflow alternative the passage of villagers is blocked because there is virtually no other way in the gorge. Still the bottom outlet alternative has allowed the passage of villagers.

Throttling of flood peak

For retarding dams the ungated sluiceway functioning as an orifice is preferable because its discharge equation results in a relatively throttling of flow when the reservoir is nearly full than would a spillway operating as a weir. The deep understanding of dam and flood hydraulics by ancient Iranian is very surprising, but it should be remembered that their survival depended on efficient water resources and flood management.

In addition to the above discussion the overtopping resistance of the masonry arch dam and application of arch, which is a superior structural element, should not be overlooked.

Figure (9). Downstream view of Abbasi retarding dam

Figure (10). A view of the arch of Abbasi dam from underneath

13. A SIMILAR CREATIVE SCHEME FOR HARMONY WITH FLOODWATERS IN JAPAN

The flood-retarding scheme of Abbasi dam has been used for solving flood control and environmental conflicts in Muko River in Japan (Hata, 2005). One of the biggest issues in the discussion on dams is the interception of biological continuity by a dam. On the other hand, it is necessary to keep the discharge less than the flow capacity of downstream. To satisfy the both conditions the following measures could be suggested. The Muko River in the Hyogo prefecture runs through the highly developed urban areas and also crosses the Japanese main road and railway, and flows into the Seto Inland Sea.

The river authority of Hyogo prefecture planned in 1983 to construct flood control dam in the valley at the middle stream to protect this important urban areas. However, as the place is famous for the beauty of the valley and is known as a scenic area, people who love the place have been against the plan for more than 20 years. The reexamination of the river plan including the design flood from the Zero Base has started in the Muko River Basin Committee. The Prefecture River Authority proposes a type of dam with orifices like a retarding basin without control gates at the outlets as shown in Figure 11 (A). Under a certain value of the design flood comprehensive flood management may be possible without dam construction. The following type of a dam may be a solution in these cases. The objective of these flood control dams is to decrease the discharge rate less than the flow capacity of the downstream. On the other hand the main problem of a dam is the interception of biological continuity as mentioned above. Therefore, a solution of this problem will be to enlarge and open the outlet of a dam along the riverbed, and preserve the continuity of the river flow (**Figure 11**(B)). If the orifice is enlarged to the size that maximum discharge rate becomes the flow capacity of the downstream, it will make it possible to keep the continuity of sediment and the migration of fishes through the dam. It seems to be important to keep the continuity of flow especially for the dam aimed for flood control.

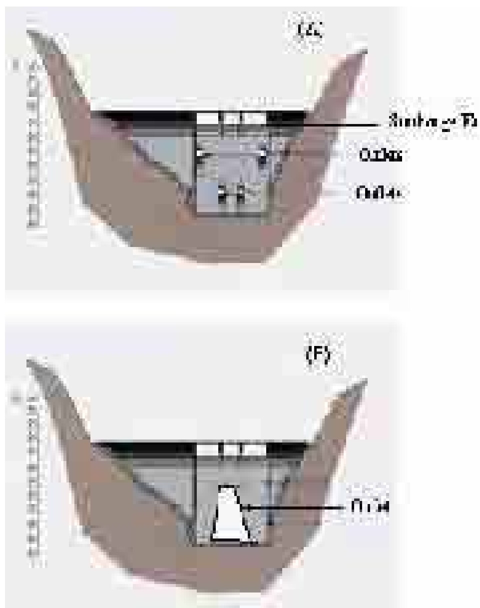

Figure (11). Modification of flood control dam in Japan
(A: Planned dam, B: Modified one)

As the stored water by the dam is quickly discharged after controlling the discharge rate, the damage to the plants will not be great. By designing the shape of the orifice the dam may harmonize with the surrounding as a well-designed bridge fits the landscape. It might be important to design a large aperture of orifice and the shape of it according to the calculated discharge to conserve ecological and sediment continuity and to decrease the damage to the landscape. The delay of runoff by the storage in the dam gives the time of warning and evacuation even in the case of exceeding the design flood when overflow of the dam crest happens and the danger of overtopping the downstream levee impends. The case study presented vividly demonstrates the main theme of this paper:

The past water wisdom can be used for coping with current and future challenges.

6- SUMMARY AND CONCLUSIONS:

Based on a comprehensive review of Iranian water heritage, the lessons learned can be classified as follows:

1. Creativity is vital for coping with diverse circumstances of water engineering and it can be promoted by the great challenges and limited resources.
2. A rich water culture is prerequisite for persistence, patience, courage and creativity required for efficient and sustainable management of limited water resources in arid regions.
3. Respecting the yields of the hydro systems would ensure the long-term benefits.
4. Good practice can be achieved before the development of the relevant theory.
5. Monitoring the hydro systems, adaptations and non-structural methods are vital for ensuring sustainability.
6. Relying on Mother Nature and her renewable energies would be the key to sustainability.
7. The synergy of vision, creativity and persistence can be used to achieve the most ambitious water management schemes with limited resources.
8. Structural ductility can be used to ensure the hydrological safety and sustainability of hydraulic structures in view of uncertainties.

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