Development of Water Resources and their Efficient Utilization in Water Scarce Regions

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Human habitats spread out on the earth's surface initially wherever food could be gathered and later where it could be produced. Survival and growth of mankind in the face of adverse environments was due to man's ingenuity in meeting with the food requirements. Food consumed by mankind comes from agricultural crops and livestock products, both of which require ample supplies of water. Water in the form of rain and snow is made available by nature in the yearly hydrologic cycle. Water is recycled continuously through transpiration by biomass and evaporation from land, river systems and oceans, besides precipitation through condensation and snow. A river basin is a natural entity for planning beneficial uses of available waters from precipitation, which are highly variable in space and time. Often, some parts of a basin are surplus in availability, while some others face deficit (Sharma, 2002). Presently, only about 17% of the world's arable land (i.e. 260 m ha) is covered under irrigation and the rest 83% depend only on rainfall and are thus prone to seasonal or prolonged water deficits and droughts.

Drought is a natural occurrence which claims its causalities every year worldwide. Dryness and drought is the resultant of the special interaction between natural and social environment. The concept of drought is a complex one as it expresses the effects on living organisms, mainly on plants and plant stands, but also on micro-organisms, animals and human beings. This may result in economic, social and environmental impacts. Each drought differs in magnitude, duration, severity, frequency and beginning and termination period of drought. From an agricultural point of view drought is the permanent and considerable high water shortage of a give plant stand on a given agricultural and/or forest area, which limits the life processes of the plants to a great extent (Vermes, 1998).

The root cause for deficit rainfall that results in drought is the widespread and persistent atmospheric subsidence arising from general circulation of the atmosphere. Recent studies on interactions between global circulation and drought showed that the El Nino phase of the Southern Oscillations (ENSO) contributes substantially to summer

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droughts. Krishnamurthy and Surgi (1987) observed a close relationship between deficit rainfall years and ENSO index. Climatic changes as a result of increased concentration of the atmospheric carbon dioxide (CO2), methane and nitrous oxide also influence the frequency of drought.

Extent of Water Scarce Regions

Large parts of Australia, Indian sub-continent, China, countries in the Middle East, small parts in Americas and Europe and significant parts in North Africa are generally water deficient and the situation may further aggravate due to enhanced biotic pressures. Drought is a regular feature of the Australian environment. Rainfall variability is high both within seasons and between years. Long term records show that there have been periods of decades or longer when rainfall was generally low over a large part of the continent. Drought in Australia is often broken by heavy rains that can in themselves be quite damaging to bare soils and landscapes (White et. al., 1995).

IWMI Water Scarcity Study (Seckler et. al., 1998) reveals that by 2025:

- Nearly one-third of the world's population, some 2.7 billion people will live in regions that will experience severe water scarcity. One third of the population of India (464 million people) will live in regions that will face absolute water scarcity.
- The world's primary water supply will need to increase by 22 per cent to meet the needs of all sectors.
- Seventeen per cent more irrigation water will be needed for the world to feed itself in 2025.
- Groundwater reserves will be increasingly depleted in large areas of the world, more spectacularly in India and C
- Salinization of soils, compounded in many cases by increasingly saline or poisoned groundwater, will continue to seriously affect land that has been highly productive in recent decades.
- The people most affected by growing water scarcity will continue to be the poor, especially rural poor, and among poor people, women and children will suffer most.

Water shortages and drought impose a serious threat to agricultural production in China. Statistics show that in 50 years from 1949 to 1998, the annual average drought affected area was 307 million *mu* (15 *mu* equals one hectare).During severe water scarcity years, viz., 1959, 1960, 1961, 1978, 1979 and 2000 cultivated areas affected by drought were over 500 million *mu*. From 1949 to 1990, the annual grain loss caused by water scarcity reached 10.11 million tons. In the spring and summer of 2000, China experienced a very severe drought in terms of duration, area and loss in agricultural production (Pan Wembo, 2002).It was present in most parts of northern China, Yangtze-Hanshui River valley, Yellow River-Huaihe River valley and eastern parts of Northwest China. Overall 50 million tons of agricultural production was lost due to this drought.

Since 1998 water year, Iran has been hit by extensive and disastrous drought every year. Although localized droughts hit Iran every year, extensive ones occur, on the average every five years and may last for two to three seasons. There are 278 cities and thousands of villages hit with serious water shortages. The rate of precipitation during 1998-99 and 1999-2000 was, respectively 20.6 and 35.7 % lower than the long term average. The highest decline was for Sistan-Baluchestan (80%) and Bushehr (70%) (Shariati, 2002). Out of 30 river basins of the country, 5 are in 'critical', 11 in 'water shortage' and 8 in 'water tension' conditions. The monetary losses for the year 1999-2000 were estimated at US$ 3500 million.

In India, severe droughts affecting more than 40% of the country's geographical area occurred in 1918 (71%), 1965 (41%), 1972 (47%), 1979 (45%), 1987 (50%) and 2002 (45%). During the pre-Green revolution period, loss in food grain production due to drought used to be as high as 25% of total produce. During 1987 drought in India, the productivity of pearlmillet dropped by 78, 74 and 43% in rainfall zones of < 300, 300-400 and > 400 mm/annum, respectively (Ramakrishna and Rao, 1991). For eastern India, the annual loss in production of food grain due to drought over 1970-96 has been estimated at US $ 400 million, which is equivalent to 8% of the value of food grain production in the region (Pandey et. al.,2000).With expansion of irrigation and other improved agricultural production technologies, the overall impact have been considerably moderated.

Impact of Drought on Water Resources

The duration and amount of availability of water in surface water bodies reduces significantly during drought year. Small water bodies dry up even before the onset of summer. The groundwater table declines and the shallow wells dry up. Higher concentration of toxic elements like arsenic, fluoride and nitrate in the ground waters has also been observed during the drought years. Small and marginal farmers suffer the most since they own the shallow wells and cannot afford to deepen them. As such the water management issues are inextricably linked to population density, settlement pattern, uneven socio-economic development, reliable assessment of available water, its scope for augmentation, distribution, re-use/recycling and its protection form depletion and degradation (Sharma, 2001). Therefore, more effective and better-integrated water resource management at the regional scale is needed more than ever to complement the increasing demand on water resources and alleviate drought situations in arid and semi-arid regions.

I. DEVELOPMENT OF WATER RESOURCES

Rainfall is the principal resource of water which augments soil moisture, groundwater and surface flows. Agriculture in dry areas depends on the vagaries of weather, especially of the rain. Without doubt, the greatest climatic risk to sustained agricultural production in these areas is rainfall variability, which unfortunately is usually greater in zones of lower mean annual rainfall. Most of the drought affected /drought prone areas are characterized by an annual rainfall of less than 300 mm which is too low to support continuous cropping with a reasonable economic value. Small and scattered rainstorms fall on land that is generally degraded with poor vegetative cover and infertile soil. Rainfall is lost almost completely through direct evaporation or through uncontrolled run off. Economic agricultural production can be achieved by concentrating the water into smaller areas through water harvesting techniques. Water harvesting supports a flourishing agriculture in many dry areas, where rainfall is low and erratic in distribution. The worldwide potential for the introduction of water harvesting has not been fully assessed, but this potential is quite large. In the drought prone areas of India, such as Decean plateau of Central India, the western regions of Rajasthan and Gujarat, and Bihar, water harvesting remains an important source of water for agriculture (Kolavalli and Whitaker, 1996). Besides for agriculture, rainwater is also harvested for domestic use and to recharge groundwater aquifers.

Water Harvesting

Water harvesting is an ancient art practiced in the past in many parts of North America, Middle East, North Africa, China and India. It is relevant to areas where the rainfall is reasonably distributed in time, but inadequate to balance potential evapo-transpiration (ET) of crops. More precisely, water harvesting can be defined as the process of concentrating rainfall as runoff from a larger catchment area to be used in a smaller target area. This process may occur naturally or artificially. The collected runoff water is either directly applied to an adjacent field or stored in some type of on-farm storage facility for domestic use and as supplemental irrigation of crops. Water harvesting is generally feasible in areas with an average annual rainfall of at least 100 mm in winter rains and 250 mm in summer rains.

1. Runoff Farming Water Harvesting (RFWH).

When the collected runoff water is diverted directly into the cropped area during the rainfall event, the technique is called runoff-farming water harvesting (Oweiss et. al., 1999). Generally, the quantity of runoff exceeds the infiltration capacity of the soil. Therefore, ridges, borders or dikes are placed around the cropped area to retain the water on the soil surface. A further differentiation is based on the size of the water harvesting system. Micro-catchment runoff farming systems are primarily used for trees and are characterized by a relatively small runoff producing catchment. Mini-catchment runoff farming systems are primarily used for row crops or strips of annual crops and the runoff producing catchment is a long strip. In both systems, water from the catchment area runs directly into the cropped area. The catchment usually receives an appropriate treatment regarding shape, configuration, surface condition, and runoff inducement practices. Macro-catchment runoff farming system refers to large-scale rainwater harvesting. This may be the diversion of a natural *wadi,* a stream in a gully, or a *wad*i flowing from a natural catchment. The collected flow is immediately diverted by a diversion structure to flood irrigate an adjacent agricultural field (Kolarkar, Murthy and Singh, 1980; Khan, 1996). This method is suitable for all kinds of crops (trees, row crops and closely growing crops). The catchment should be big enough to provide the needed irrigation water. Strategic placement of rock barriers and crops will allow the maximum use to be made of the floodwaters with the minimum damage to land and crops. Ancient "*Khadins*" system of cultivation in Rajasthan is a typical example of the macro-catchment runoff farming system.

2. Surface Storage Water Harvesting

Surface storage based or supplemental irrigation water harvesting system is highly recommended when inter-seasonal rainfall distribution, or variability, or both are such that crop water requirements cannot be met. Surface storage structures range from an underground storage cistern/ *tanka,* on-farm pond or tank to a small dam constructed across the flow. Storage capacity, storage location, type of storage structure and geometry of storage tank should be given due consideration in the design of surface storage facilities. The cost of the storage facility and hence the cost of water depends on the ratio of the storage volume and the volume of the excavated earth, known as the storage/excavation (S/E) ratio.

Excessive evaporation and seepage losses and siltation of the structures have been reported as the major problems of storage facilities. Seepage losses can be reduced by compaction, use of clays and other materials and covering the side slopes and bottom with lining materials. Low-density polyethylene films, silpaulin, stone/slab pitching, cement-concrete and brick lining have been tried with varying degrees of success in different regions. Limiting the surface area reduces evaporation losses. Floating covers, application of surfactant layers and compartment tank method have been tried to reduce the excessive evaporation losses. Land surfaces may be treated for inducing runoff. Comparison of some of the techniques for runoff inducement is given in Table 1.

Table 1: Comparison of some of the techniques for runoff inducement.

Technique	Runoff (%)	Estimated useful life (Year)
Land clearing	20-30	5-10
Soil smoothing	25-35	5-10
Sodium salts	40-70	3-5
Paraffin wax	60-90	5-8
Concrete	60-80	20
Membranes	70-80	10-20
Asphalt-fabric	85-95	15
Artificial rubber	90-100	15

3. Rainwater for Ground Water Recharge

All over the world, regions having sustainable ground water balance are shrinking fast. Growing ground water scarcity and alarming declines in ground water levels in many developing countries (especially in drought prone regions) indicate that groundwater polices in most of these countries are failing to protect life's most vital resource. Nearly 1.5 billion people rely on ground water as their sole source of drinking water (Shah et. al. 2000; Sharma, 2002). Some of this water comes from deep sources that are isolated from the normal runoff cycle, but much ground water comes from shallow aquifers that draw from the same runoff that feeds fresh water ecosystems.

As problems of groundwater depletion and its deleterious consequences in the form of droughts and famines have surfaced in different parts of the world, a variety of responses have been forged to mitigate or reverse these. India has built more than its share of the world's dams but 1150 km^3 of its rainwater runoff still goes to the seas annually in the form of "rejected recharge" (INCID, 1999). If a fraction of this could be stored underground by artificial recharge, ground water supplies could be enhanced significantly. Several water scarce countries have begun to take rainwater harvesting and groundwater recharge seriously at all levels. Several interventions under the Integrated Watershed Development Program, percolation tanks, recharge wells, recharge shafts, recharge through unlined canal irrigation systems, surface spreading etc. all help to store the precious rainwater in underground storage and augment the water supplies during water scarcity.

Some of the successful water resource development strategies popular in the water scarce and drought prone regions are briefly enumerated in the following paras:

1. ***In-situ* Rain Water Harvesting**

Extensive research efforts on *in-situ* rainwater harvesting have been made in different parts of the world. Field bunding, contour bunding, ridging, conservation furrows, key line and contour cultivation have given useful leads in the past. The concept of vegetative barriers to replace or supplement earthen bunds that emerged in 1980s has been tried in a number of countries with mixed results. In a study on constructed micro-catchments of 45^o slope, ridge-furrow system (60:40 cm), and flat regular planting were compared with respect to soil moisture storage and yield of pearl millet. The ridge furrow system and micro-catchments resulted in 210% and 120% higher yield, respectively than regular flat planting. In micro-catchment based cropping, rainwater is concentrated in a small proportion of the cultivated area. Tree crops being deep rooted can utilize the moisture stored in the sub-stratum and hence, form a better option for micro-catchment based farming in sandy soil situations (Sharma, 1986). Arid horticultural plants like dates, pomegranate*, ber, jujube* and several others can be successfully grown with appropriate micro-catchments in the water scarce regions.

2. Cisterns/ *Tankas*

Underground storage cisterns/ *Tanka* is the most common rainwater harvesting system in the Indian Arid Zone, China and several other countries, generally constructed for storage of surface runoff. Almost every household, school, religious center in rural areas constructed *tankas* for meeting drinking water needs. The *tanka* is constructed by digging a circular hole of 3.00 to 4.25 m diameters and plastering the base and sides with 6-mm thick lime mortar or 3 mm thick cement mortar. The catchment of *tankas* are made in a variety of ways using locally available sealing materials like pond silt, *murram,* wood, coal ash, gravel etc. Improved designs of *tankas* have been developed and adopted under Drinking Water Missions in drought prone developing countries. It is estimated that more than 10,000 such structures are successfully functioning in Indian arid region.

Gansu province in China has attained remarkable achievements by carrying out "121" Project. Under this project, each farm household has built up two cisterns for irrigating one *mu* of farmland so as to ensure high and stable yield. Pengwa village in Qinan County has solved the drinking water problem of 1820 persons by building 359 cisterns each with a capacity of 20-30 m^3 .Besides, the village also built up 642 cisterns with a capacity of 45 m^3 for irrigation purposes. It has now been possible to establish 300 *mu* of fruit trees, 1,000 *mu* of food crops and 100 *mu* of sunlight glasshouse. During the severest drought of 2000 when all other neighboring villages had no harvest, this village had almost normal yield of 110 kg wheat/*mu*. The net income per capita rose from 680 Yuan to 1020 Yuan after construction of the cisterns.

From 1996 to 2000, Shanxi Province built up about 0.4 million cisterns and dry wells, effectively supplementing irrigation water for 53,000 km^2 of dry farmland.

3. Run-off Water Harvesting based Farming (*Khadin Farming*)

Khadin system of water harvesting and moisture conservation is well suited in deep soil plots surrounded by some sort of natural catchment zone. The soils in such pockets have developed from the silt load carried in runoff and hence are fine textured. Such soil situations are available in deep Thar Desert having rainfall as low as 150-350 mm/ annum. In this system, runoff from upland and rocky surfaces is collected in the adjoining valley by enclosing a segment with an earthen bund. Any excess water in *khadin* bed is passed out through a spillway provided in the bund. The plots are rigorously built and managed to make the entire system a self-contained unit for winter cultivation. The total energy input of rainwater, sand-silt-clay accumulation and cultivators' own activities are interwoven into a complete production system of winter crops. There is progressive increase in crop yield every year, as more and more fresh silt and clay accumulate in the bed.

The ratio of farmland and catchment areas is regulated to be about 1:6 to 1:18, so that a suitable moisture supply is uniformly maintained. The basement of *khadin* is invariably a hard surface upon which sand-silt-clay is made to accumulate just to the depth of a few meters. A study conducted at Central Arid Zone Research Institute, Jodhpur (India) has shown that even without the use of chemical fertilizers, the average crop yield in *khadin* ranges from 2.5-3.0 t/ha of wheat and 1.5-2.5 t/ha of chickpeas. Even during severe drought years, *khadins* may be used for getting a successful crop on stored soil profile moisture.

4. Village Ponds *(Nadis*)

Nadis are small to medium sized excavated or embanked village ponds, for harvesting meager precipitation to mitigate the scarcity of drinking water and domestic needs in water scarcity regions. Pond water is available for periods from two months to a year after rain, depending upon the catchment characteristics and amount and intensity of rainfall. It consists of two components, viz., catchment area and water storage area. The *Nadis* range from 1.5 to 12 m in depth, 400 to 700,000 m^3 in capacity and have drainage basins of various shapes and sizes (8 to 2,000 ha). These *Nadis* can also be used for recharging the groundwater through construction of infiltration wells and recharge pits in the bed of the storage area. Under suitable conditions, a recharge pit of 3mx3mx3m was sufficient to divert 6,500 m^3/annum water to ground water reservoir. Recharge from a village pond of 2.25 ha water spread area and storage capacity of 15,000 m^3 in north Gujarat alluvial area, could be induced to create groundwater recharge of 10,000 m^3 in one rainy season (NDWM, 1989).The optimized characteristics of the village ponds for minimizing the storage losses are given by Sharma and Joshi(1983,Table 2).

Table 2. Optimized village pond characteristics to minimize the storage losses *(under Indian Arid zone conditions*)

Physiography	Optimized depth (m)	Optimized surface area ($m^2 \times 10^3$)	Water availability (months)
Dune complex	2.5	29.1	4.8
Sandy plain	2.0	27.1	8.3
Younger alluvial plain	5.0	161.0	12.0
Older alluvial plain	3.0	96.0	12.0
Rocky/ gravel pediment	6.0	126.5	12.0

5. Series of Check Dams on Natural Streams

In this system the artificial recharge is made to restrict the surface run off through streams and by making additional water available for percolation. The surface water is impounded during monsoon behind the structure and spread over the entire stream bed and thereby increasing the wetted area. The impounded water helps in replenishment of groundwater. A series of check dams can be constructed on a stream to recharge the depleted groundwater aquifers. With the construction of check dams at village Ujalian, district Jodhpur, static water level in wells in the zone of influence increased from 1.8 – 2.2 m as compared to increase of only 0.5 m in wells located outside the zone of influence. In an another study made in Pali district of Rajasthan it has been observed that the presence of check dams in series have increased aquifer recharge from 5.2 to 38% (Khan, 1995).

6. Percolation Tanks

Percolation tanks are generally constructed on the small streams or rivulets with adequate catchment for impounding surface runoff. These tanks are used entirely for recharging the aquifer through percolation. Constructions of percolation tanks take into account the catchment area, likely runoff, designed storage as well as the area of benefit of the structure. The construction of such structure is considered useful as means of conserving water and strengthening the drinking and irrigation water sources.

In comparison to ponds, percolation tanks conserve water to a greater extent because the filling and recharge occur mostly during the monsoon when the evaporation rate is about the half of potential rate in summer through which ponds contain water. Selection of suitable site for the construction of percolation tanks and subsequent maintenance is crucial for its effective functioning. Where hydro-geological conditions are favorable, percolation rates may be increased by constructing recharge (intake) wells within percolation tanks (Raju, 1987).

Studies conducted on artificial recharge through percolation tanks constructed in hard rock and alluvium formations revealed that the rate of percolation ranged from 14-52 mm/ day (Table 3). Partitioning of water loss from percolation tanks suggests that percolation loss accounted 65-89% whereas; the evaporation loss was only 12-35% of stored water (Khan, 2001). The results also indicate that the tanks at Sablipura, Dhaneri and Mev under hard rock area contain water for longer period of time and the rate of percolation in these tanks was considerably low when compared to other non-perennial tanks. This perhaps may have been due to other long-standing water column that may facilitate suspended silt to deposit on bed and act as impervious layer. In case of non-perennial tanks, farmers de-silt the tank beds every year as they spread this silt on agricultural fields to increase the fertility.

The rate of percolation from a newly constructed percolation tank in deep alluvium formation near Sojat city, district Pali was 2.4 m (77 mm day $^{-1}$) in July when the static water head in tank was 5.4 m and 1.82 m (59 mm/day) in August when the static water head was 3.3 m. The rate of percolation reduced to 4.8 mm day^{-1} in the month of December when the water column in tank was only 0.27 m. The recharge form the percolation tank accounted 88% whereas; evaporation accounted only 12% of the stored water in the tank (Khan, 2001).

Table 3.Percolation and evaporation losses from percolation tanks

Location of tank	Basin	Formation	Tank capacity (m^3)	Average annual rate of percolation (mm/day)	Percolation rate (%)	Evaporation (%)
Sablipura	Guriya	Hard rock	35,400	18	77	23
Dhaneri	Lilri	Hard rock	25,700	14	65	35
Sojat	Sukri	Alluvium	3,80,000	52	88	12
Sheopura	Sukri	Alluvium	64,300	38	83	17
Dhabar	Phunpheriya	Alluvium	29,500	33	89	21
Mev	Guhiya	Hard rock	67,000	27	81	29

5. Sub-surface Barriers (SSB)

Sub-surface water harvesting systems exploit water already infiltrated and concentrated through natural hydrological processes into the sand rivers that fill valleys in arid and semi-arid regions. Such barriers are quite suitable structures as they are safe from flood havoc, do not need elaborate overflow arrangement and periodic de-sitting. The silt from surface area upstream of barriers is flushed away during flashfloods whereas entire storage of water being underground, evaporation losses are also insignificant. The construction needs a 30-60 cm wide concrete or brick impermeable basement or compact foundation. Surface barriers may also be constructed with angular pieces arranged in form of dry masonry 100 cm wide wall or with 250 micron polythene sheeting, properly embedded in the soil. Construction of two sub surface barriers across an ephemeral stream within 300 m from the water supply wells at a site in Jodhpur district have been found to store sufficient water required for a village with a population of 500 persons. Studies conducted for 3 years (1996-98) at Kalawas and Chauri-Kalan village in Jodhpur district revealed that with the construction of SSB, the annual rate of depletion of groundwater has been reduced from 1.0 m to 0.3 m and from 1.0m to 0.23 m for Kalawas and Chauri Kalan, respectively (Table 4).

Table 4. Effect of sub-surface barrier (SSB) on groundwater recharge in Kalawas and Chauri-kalan villages (India).

Item	Kalawas		Chauri-kalan	
	Before SSB	After SSB	Before SSB	After SSB
Rate of depletion of groundwater (m/year)	1.00	0.20-0.40	1.00	0.23
Water yield in wells (m^3/day)	80-120	100-145	60-90	80-120
Number of tube wells	-	5	-	2
Irrigated area (ha)	-	10	-	5
Groundwater recharge (% of rainfall)	3-10	15-29	10-15	28-37
Recharge zone (m)	-	1200	-	850

6. Recharge Tube wells

Excess rainwater collected behind check dams, surface ponds or percolation tanks can be efficiently utilized for recharging groundwater through recharge tubewells. The floodwater, which has to be mixed with groundwater occurring at a deeper depth, should be potable and free from suspended solids. To achieve this, filter bed should be provided on top of the recharge tubewell. Recharge tubewell may be drilled in the area of the dam or percolation tank down to the prevalent depth of exploitation. Diameter of the borehole may be around 50 cm and PVC pipe of 6 kg/m^2 strength having a diameter of 20 cm be used. The annular space between the borehole and the pipe is filled with gravel and developed with compressor till it gives clear water. On top a 6m x 6m x 6m dimension pit should be dug out keeping the tubewell at the centre and the section is filled with rounded boulders, chips and sand. The slotted section at the top is wrapped with coir, 10 cm gravel pack and sand layers should be provided around the slotted pipe upto the filter bed. Top 1m of the filter bed is filled with sand. Air vents of 7.5 cm diameter need to be provided for escaping the entrapped air. The filter bed and coir filter appears to be adequate for cleaning the flood water. This recharge tubewell can also be used for pumping ground water in case of emergency. Every year 20 to 30 cm of sand should be removed from top of the filter bed and replaced with clear sand. Recharge tubewell should be developed with compressor/ pump every monsoon season to prolong its effectiveness.

Hundreds of such recharge tubewells have been constructed in Kutchh and other parts of Saurashtra for harvesting groundwater. In Rayan Micro watershed in Kutchh 18 check dams, one percolation tank and 2 recharge tubewells were constructed creating storage of 44,715 m^3. The artificial recharge through rainwater harvesting structure constructed has resulted in the rise of water level varying from 1.2 to 3.65 m and improvement in the water quality by reduction in TDS varying from 10 to 420 ppm. The quantity of recharge was of the order of 66,469 m^3 with much improvement in water quality. There was an increase of 15% of the cropped area with 30-35% higher yields even in drought years of 1993-94.

7. Optimizing Rainwater Conservation in Paddy Fields.

The paddy crop provides a great potential for storage of rainfall. The increases in rainfall conservation in paddy fields results in reduction in irrigation water applied and increase in ground water recharge. Long term studies were conducted to examine the impact of rainfall storage depth on irrigation water applied, crop yield and deep percolation (Khepar et al. 1999, Table 5). Based on the generalized water balance model, input data obtained from the long term experiment, long duration climate data especially daily rainfall, deep percolation losses under different soil conditions, a procedure was developed to determine optimum dike heights ensuring maximum storage of water. The optimum dike heights for light, medium and heavy soils as obtained by the above procedure were 15.0, 17.5 and 20.0 cm respectively, under average rainfall conditions of major paddy grown

Table 5: Impact of rainfall storage depth on irrigation water applied and crop yield (ET* = 53.4 cm, Rainfall = 52.3 cm).

Particulars	Effective storage depth		
	10 cm	15 cm	20 cm
Irrigation water applied (cm)	80.52	74.2	73.45
Runoff (cm)	11.77	2.12	0.00
Deep percolation (cm)	67.65	71.25	72.37
Yield of paddy (tones/ha)	6.37	6.84	6.71
Average depth of ponding /day(cm)	1.345	1.38	1.396
Average deep percolation/ day (cm)	0.753	0.79	0.803

*Upto the period of 15 days before harvesting.

areas in semi-arid regions. Similar studies conducted in Orissa (high rainfall region) showed that dike heights of 22.5 cm around paddy fields were able to retain about 97% of the rainwater.

8. Renovation and Reuse of Waste Water

The wastewater which mainly constitutes sewage, storm water, drainage effluents and village pond water could be renovated for unrestricted irrigation/groundwater recharge. Rather than making optimum reuse of this water, most of it is disposed off into nearby drain, stream or a river body, thus polluting the surface and groundwater resources. As an alternative on a limited scale, the sewage water is being used for restricted irrigation as it contains large amount of N, P, K, S and micronutrients. However, the concentration of toxic elements may prove detrimental to human health. Direct irrigation with sewage water results into groundwater pollution due to seepage form irrigated fields. One of the possibilities to renovate sewage water and reuse the same for unrestricted irrigation is renovation through Soil Aquifer Treatment System (SAT) (Bouwer, 1987). The studies on renovation of sewage water by SAT and bio-remedial measures conducted at CSSRI, Karnal; PAU, Ludhiana and under pilot projects of Central Pollution Control Board (India) have proved quite successful.

9. Integrated Watershed Development

Upper catchments and foothill regions of several regions provide the greatest scope for rainwater harvesting and groundwater recharge because of favorable hydrological formations and heavy rainfall. An integrated watershed development programme in Kandi Area of Indian Punjab (foothills) including (i) forest rehabilitation in 45,000 ha in upper catchments (ii) 19 water harvesting dams (iii) seven medium capacity irrigation dams having cultivable command area of 9,606 ha and (iv) on-farm development by various departments during the last two decades has already paid dividends by reversing the declining water table as well as increasing the ground water recharge in the downstream irrigated area. The water balance has increased from (-) 97,867 ha-m in 1979-80 to (+)52,075 ha-m during the period 1997-98, thus reversing the falling trend of water table to a rising water table .

Similar studies/projects undertaken elsewhere suggest that upper catchment of falling water table areas should be taken up on priority basis for watershed management including water conservation/ harvesting structures and low irrigation dams.

10. Rainwater Harvesting form Urban Areas

Efforts should be made to harvest the rainfall runoff and using the same for groundwater recharge in urban areas. Some of the possible sources of water include roof top rainwater, storm water, outflow from households/community buildings etc. The water harvested from these sources can be used for ground water recharge through adoption of site specific recharge techniques such as recharge wells/shafts/pits etc. Some of the municipal corporations have already introduced building bylaws making roof water harvesting as essential component of buildings having roof area larger than specified norms. The roof top water harvesting is of special importance in case of institutional buildings, which have large roof area and space for installation of ground water recharge structures.

Salient characteristics of the roof top rain water harvesting structure installed in the building of Ministry of Water Resources, New Delhi, India are given below:

1. Source of water : Rain water
2. Roof top area : 3110 m^2
3. Average annual rainfall : 712.2 mm
4. Depth to ground water level : 9 m below ground level
5. Artificial recharge structures : Three recharge trenches with injection well
6. Recharge to ground water during monsoon 2000 : 3000 m^3
7. Net rise in ground water levels : 0.62 to 1.37 m
8. Cost of the scheme : US$ 9000
9. Average life of the structures : 20 years

11. Recharge through Drainage Networks

Surface drainage networks have been constructed in several regions for disposal of surplus floodwaters and control of waterlogging. These drains offer a good site for artificial ground water recharge, as good quality water is available during the monsoons. These drains can also be used for ground water recharge using surplus canal water during lean period of irrigation. Under natural flow conditions, most of the runoff flows out of drainage network and lost to the rivers. The recharge through the surface drains can be increased by providing check structure of height about 0.50 full supply depths above the bed level of the drain with enlarged cross section of the drain to take care of designed peak flow. Recharge through the drains can be increased further by adding recharge shafts (horizontal or vertical) and injection wells depending on sub soil strata beneath the bed of the drain.

One of the limitations for artificial recharge of groundwater through surface drains has been the suspended silt load, which clogs the recharge system. A composite vertical filter has been designed, developed and tested, which can be effectively used to provide silt free water for recharge. The optimum combination of different materials used for the filter was found as 4 layers of hassein cloth and 15 mm thickness of coconut coir alongwith 37.5-cm thickness of sand. Such a filtration system is working successfully in Raipur Link Drain in Indian Punjab (Khepar, 2001).

II. EFFICIENT USE OF THE SCARCE WATER RESOURCES

Equal importance should be given to proper and judicious use of the available water resources/harvested water so that we are able to achieve “More Crop per Drop” and also meet other requirements. Some of the possible methods to achieve this include:

1. Extensive Irrigation Approach

This approach aims at obtaining maximum production per unit of irrigation water. The limited amount of water is used to give irrigation in relatively large area so that maximum water use efficiency is achieved. Though the production from a unit area declines as the same amount of water is used to give irrigation in relatively large area, the overall production and water-use efficiency are increased (Narain et. al., 2000; Table 6)

Table 6: Effect of increased area under supplemental irrigation (same amount of irrigation water) on pearl millet production

Medium rainfall (266 mm)			Low rainfall (173 mm)		
Irrigation (mm/ha)	Area (ha)	Yield (kg)	Irrigation (mm/ha)	Area (ha)	Yield (kg)
292	1.0	3620	341	1.0	3540
145	2.0	5380	209	1.6	4528
73	4.0	7560	117	2.9	5829
0	1.0	1400	0	1.0	1080

2. Micro-Irrigation Techniques

The conventional methods of irrigation are generally inefficient under light textured undulating soils of the water scarce regions. Sprinklers and micro-sprinklers are most suitable for narrow spacing crops (wheat, mustard, barley, spices etc.). The system helps in saving sufficient amount of water (at least 20%). Sprinkler system of irrigation gave 33 and 37% higher yield as compared to check basin and border strip methods of irrigation, respectively (Sharma, 2001). However, high wind velocity and use of saline water may restrict its application in arid regions.

Drip irrigation method is not affected by high wind velocity as it applies water directly to the root zone. Though initial cost of the system is relatively high it is quite pertinent to the water scarce regions. The method is more suitable for wider spacing crops and orchards and yield increases by 40-50% are common for different crops. Water soluble fertilizers can also be applied through drip irrigation. The drip irrigation has a special utility in the arid region where groundwater is generally saline. Daily irrigation by drip forces the salts to the side and below the root zone, thereby allowing gainful utilization of water having a relatively high salt content (Table 7).

Table 7: Use of saline water for drip irrigation in potato

Method of irrigation	Water quality	Yield (t/ha)
Drip	3000 μ S m^{-1}	26.0
Furrow	Sweet	20.0

For reducing the cost and making it more affordable for small and marginal farmers in the remote areas drum based micro-irrigation kit has been devised for small vegetable gardens. It can irrigate 520 plants with just one drum (200 l capacity) of water. The kit consists of 130 micro tubes (1 mm diameter) fitted to 5 rows of laterals (12 mm dia.). The laterals can be substituted with in-line drippers (Hydrogol).These laterals are attached to a drum of water by 16 mm sub-main. Ideally one kit can irrigate an area of 120 m^2 and costs around $ 14.

Under remote farms close to the sand dunes, a camel operated drip irrigation system has also been developed where two flexible pipes are connected to the two camel-mounted water tanks. The camel stands at a sand dune at least 5 m high elevation from the field to be irrigated. The pipes are further connected to sub-mains, laterals and emitters. Water is carried by camel-back mounted two tanks from a nearby village pond and then applied to fruit/ vegetable plants. The low cost camel operated drip irrigation system may be applicable in remote areas of undulating topography in desert ecosystem with the locally available resources. The system can also be used for application of the locally available brackish water.

3. Pitcher Irrigation

Pitcher irrigation technique developed at Central Soil Salinity Research Institute, Karnal (India) is an indigenous alternate to drip irrigation. The technique utilizes baked, unglazed earthen pitcher as the basic component of the system. A pitcher of 5-8 liter capacity is appropriate for use in this system. The technology is potentially applicable to areas, where water is either scarce or expensive, where soils are difficult to level or where soils are light and limited amounts of available water can not be spread over the area easily. It is also useful in areas where water is highly saline and cannot otherwise be used to grow crops, remote areas where transport of vegetables is expensive and for initial establishment of horticultural and forest plantations. The yields of several crops when fresh water was used to irrigate the crop revealed that around 5-21 kg/ pitcher for various crops can be obtained (Table 8). Water requirements could vary from 2.8 to 12.5 cm/ha as the number of pitchers/ ha increase from 800 to 5000. It means, in pitcher irrigation water requirement may not exceed 2 irrigation equivalent in the surface irrigation method. A minimum life of 3-5 years could be assumed for satisfactory working of the pitchers.

Table 8: Yield of various crops under pitcher irrigation with fresh water

Crop	Yield (kg/ pitcher)	Crop	Yield (kg/ pitcher)
Watermelon	11.3	Tomato	5.8
Muskmelon	7.4	Cauliflower	5.2
Bottle gourd	21.5	Brinjal	5.1
Bitter gourd	7.5	Cabbage	4.8
Ridge gourd	4.5	Radish	8.0
Cucumber	14.0	Grapes	3.5

4. Use of Gypsum Chambers for Alkali Water

Significant portions of the underground waters in the arid region have poor quality and may be alkaline in nature. The use of such waters for irrigation purposes results in deterioration of the soil productivity in terms of build up of soil sodicity and pH and thus subsequent water stagnation problems. For mitigating these effects, use of amendments like gypsum is recommended especially when RSC>5me/l, soils are medium textured and annual rainfall of the area is less than 500 mm. The recurring cost on gypsum use demand for its efficient utilization. Thus the technology has been refined in terms of gypsum beds to improve its efficiency. The gypsum chamber is constructed with brick-cement-concrete, the size of which primarily depends upon tube well discharge. A net of iron bars covered with wire net (2mm x 2mm) is fitted at a height of 10-20 cm from the bottom of the chamber and this supports a bed of gypsum clods. This chamber is connected to the waterfall chamber from the bottom and water after passing through the gypsum bed is let into the irrigation channel. The calcium picked up by the passing water depends upon contact time and surface area of clods. Usually the height of gypsum bed recommended to bring RSC within permissible limits is 30-60cm. This method has considerable savings and produces higher crop yields (Table 9).

Table 9: Crop yields, gypsum requirement and net benefit with use of gypsum through chamber as compared to powdered gypsum (RSC of irrigation water: 15.0 me/l, chamber size: 6.75 m^3)

Crop	Yield, kg/ha			Gypsum requirement, t/ha	Net benefit over powdered gypsum, INR/ha
	Control	Powdered gypsum	Clod gypsum through chamber		
Wheat	1532	2731	2884	2.322	1890
Mustard	320	750	1235	1.161	6010
Cotton	42	279	363	1.935	2130
Pearl millet	178	323	373	0.619	350

III. COMMUNITY PARTICIPATION AND INSTITUTIONAL ASPECTS

Over the years, the role of government in water resources management increased while that of communities decreased and delivery of services deteriorated. The delivery of programs of water resources development and utilization is replete with difficulties and more so in water scarce regions. Worldwide, many projects have failed primarily due to lack of people's participation for mobilizing and utilizing their energies and resources in such programs. The consequences are wastage of public funds invested on construction of these structures which generally fail after the rains every year and have to be reconstructed. Unless the program stakeholders, i.e. beneficiary and affected people are convinced and own to harvest, store, conserve, repair and maintain the resources by investing their time, energy and money (even partially), water harvesting and conservation projects cannot perform satisfactorily (Samra, Sharda And Sikka, 2002).

Success of numerous projects in India, China and other developing countries undertaken to promote water harvesting and water management with active community involvement clearly suggest the need to community and household involvement in water management. Technologies built upon accumulated wisdom of the people will not only enhance the people's participation but also assist in adopting the conservation measures which are necessary to be adopted on community basis/ collectively by group action. One can say that success of water resources development and their sustainable utilization depends primarily upon the level of participation of the people living in the area. There are no fixed methods of ensuring peoples' participation, but the seven steps proposed by Sharma and Dixon (1995) may be helpful: 1) Community immersion, 2) Community mobilization, 3) Gender equity, 4) Community envisioning 5) Vision validation 6) Diagnostics and resource community participatory planning, and 7) Participatory monitoring and evaluation and refinement.

There is a need for a policy framework to develop institutional mechanism yo promote water harvesting at different levels such as user, watershed, urban locality, municipality, district, state and central level by having representatives from local level people's institutions, non-governmental organizations and concerned government departments. Social mobilization, more decentralization and community empowerment are needed to be explicitly included in government policies for success of community based water resources development. Village institutions and local level water users' associations may offer a platform for this to happen. Traditional technologies of water harvesting and conservation can be blended and augmented with modern tools and techniques, in view of the local socio-economic and socio-cultural needs. It is suggested that basin-wise planning and management of water resources should integrate participatory watershed management for sustainable development, and small and micro-water harvesting systems made integral part of the water resources development at the regional and national levels.

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