Contributing Paper

Technological Potential for Improvements of Water Harvesting

Dieter Prinz; Anupam Singh
Independent Expert, Germany

Prepared for Thematic Review IV.2:
Assessment of Irrigation Options

For further information see http://www.dams.org/

4.2 TECHNOLOGICAL- POTENTIAL FOR IMPROVEMENTS OF WATER HARVESTING[1]

Prof. Dr. Dieter Prinz & Anupam K. Singh, M.Sc.
Institute of Water Resources Management, Hydraulic
and Rural Engineering (IWK), University of Karlsruhe/ Germany

[1] *This technical report has been prepared for World Commission on Dams, Cape Town, South Africa.*

4.2.1 INTRODUCTION

The problem of water shortage in arid and semi-arid regions is one of low rainfall and uneven distribution through out the season, which makes rainfed agriculture a risky enterprise. Therefore new interest came up in recent decades to evaluate traditional water management techniques (Prinz et.al. 1999) most of them being simple, sure to implement and of low capital investment. The classical sources of irrigation water are often at the break of overuse and therefore untapped sources of (irrigation) water have to be sought for increasing agricultural productivity and providing sustained economic base. Water harvesting for dry-land agriculture is a traditional water management technology to ease future water scarcity in many arid and semi-arid regions of world.

This old technology is gaining new popularity these days. As the appropriate choice of technique depends on the amount of rainfall and its distribution, land topography, soil type and soil depth and local socio-economic factors, these systems tend to be very site specific. The water harvesting methods applied strongly depend on local conditions and include such widely differing practices as bunding, pitting, micro-catchments water harvesting, flood water and ground water harvesting (Prinz 1996, Critchley and Siegert 1991).

4.2.2 TYPES OF WATER HARVESTING

To facilitate the presentation of the various types of water harvesting techniques, the following three groups of water harvesting can be distinguished (Table 4.2.1). A brief description of these water harvesting techniques along with sub-types is given below:

1. **Rainwater harvesting:** Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions (Boers & Ben-Asher 1982). Three types of water harvesting are covered by rainwater harvesting.

a) Water collected from roof tops, courtyards and similar compacted or treated surfaces is used for domestic purpose or garden crops.
b) Micro-catchment water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration basin. The basin is planted with a tree, a bush or with annual crops.
c) Macro-catchment water harvesting, also called harvesting from external catchments, is the case where runoff from hill-slope catchments is conveyed to the cropping area located at hill foot on flat terrain.

2. **Flood water harvesting** can be defined as the collection and storage of creek flow for irrigation use. Flood water harvesting, also known as 'large catchment water harvesting' or 'Spate Irrigation', may be classified into following two forms:

a) In case of '**floodwater harvesting within stream bed**', the water flow is dammed and as a result, inundates the valley bottom of the flood plain. The water is forced to infiltrate and the wetted area can be used for agriculture or pasture improvement.
b) In case of '**floodwater diversion**', the wadi water is forced to leave its natural course and conveyed to nearby cropping fields.

It is difficult to give exact figure on the present area under various forms of floodwater harvesting systems. Pakistan has more than 1.5 million ha under floodwater harvesting. Fig. 4.2.1 shows the irrigated area under floodwater harvesting in selected countries in North Africa and Middle East regions.

Fig. 4.2.1 Irrigated area under floodwater harvesting (Source: FAO 1997).

3. **Groundwater harvesting** is a rather new term and employed to cover traditional as well as unconventional ways of ground water extraction. Qanat systems, underground dams and special types of wells are few examples of the groundwater harvesting techniques. For example, **Qanats**, widely used in Iran, Pakistan, North Africa and even in Spain, consists of a horizontal tunnel that taps underground water in an alluvial fan, brings it to the surface due to gravitational effect. Qanat tunnels have an inclination of 1-2% and a length of up to 30 km. Many are still maintained and deliver steadily water to fields for agriculture production and villages for drinking water supply.

Groundwater dams like '**Subsurface Dams'** and '**Sand Storage Dams'** are other fine examples of groundwater harvesting. They obstruct the flow of ephemeral streams in a river bed; the water is stored in the sediment below ground surface and can be used for aquifer recharge. Sand filled reservoirs have the following advantages:
(1) Evaporation losses are reduced,
(2) no reduction in storage volume due to siltation,
(3) stored water is less susceptible to pollution, and
(4) health hazards due to mosquito breeding are avoided.
Groundwater harvesting does not play the same role globally as rain- and floodwater harvesting; therefore special consideration is given here to the latter two.

4.3.3 KIND OF STORAGE

Above-ground water storage: In most rain- and floodwater harvesting schemes the water delivered by surface runoff and overland flow is stored (only) in the soil matrix. This means, that its application is limited to the rainy season. To allow cropping outside the rainy season, a number of storage media are employed, ranging from ferrocement tanks of a few m^2 content to large reservoirs, storing millions of m^3.

In India and Sri Lanka, more than 500000 tanks store rain water, sometimes supplemented by water from streams or small rivers. Tanks play several important roles e.g. as flood-control system and in preventing soil erosion and wastage of runoff during periods of heavy rainfall. Additionally, they recharge the groundwater in surrounding areas. The larger ones, 10 to 30 hectares in size, feed several thousand hectares of irrigated land. They are equipped with sluices, which deliver water to an extensive canal system. Without this tank system, paddy cultivation in large parts of the country would be impossible (Agarwal & Narain 1997).
These rainwater reservoirs are not only employed for irrigation in arid or semi-arid regions, but in semi-humid areas (up to 1300 mm/a rainfall), too.

Underground Storage: As several disadvantages are connected with surface storage of water - large evaporation losses, loss of storage caused by siltation, pollution problems and loss of agricultural land- , underground storage of water may be an interesting alternative (see chapter on groundwater dams). This storage can be done in near surface **aquifers** (e.g. in wadi beds), calling for a conjunctive management of water resources, or in cisterns. **Cisterns** are man-made caves or underground constructions to store water. Often the walls of these cistern are plastered; their water losses by deep percolation or by evaporation can be minimal. The construction of cisterns was already practised several thousand years ago; chalky rocks were preferred. Traditionally, in Mediterranean houses, one cellar room was specifically designed to store rainwater. Similar in-house cisterns are known from Rhajastan, NW India. In the same region, 'Kunds', covered underground tanks with a plastered catchment, are found (Agarwal & Narain 1997). Nowadays cisterns are often constructed using concrete.

4.2.3 PARAMETERS FOR IDENTIFICATION OF SUITABLE RAIN- and FLOODWATER HARVESTING AREAS

The most important parameters to be considered in identifying areas suitable for rain- and floodwater harvesting are as follows:

a) **<u>Rainfall:</u>** The knowledge of rainfall characteristics (*intensity and distribution*) for a given area is one of the pre-requisites for designing a water harvesting system. The availability of rainfall data series in space and time and rainfall distribution are important for rainfall-runoff process and also for determination of available soil moisture. A threshold rainfall events (*e.g. of 5 mm/event*) is used in many rainfall-runoff models as a start value for runoff to occur. The intensity of rainfall is a good indicator of which rainfall is likely to produce runoff .
Useful rainfall factors for the design of a rain- or floodwater harvesting system include: (1) Number of days in which the rain exceeds the threshold rainfall of the catchment, on a weekly or monthly basis. (2) Probability and occurrence (in years) for the mean monthly rainfall. (3) Probability and reoccurrence for the minimum and maximum monthly rainfall. (4) Frequency distribution of storms of different specific intensities.

b) **<u>Land use or vegetation cover:</u>** Vegetation is another important parameter that affects the surface runoff. From the studies in West Africa (Tauer & Humborg 1992) and Syria (Prinz et. al. 1999) proved that an increase in the vegetation density results in a corresponding increase in interception losses, retention and infiltration rates which consequently decrease the volume of runoff. Vegetation density can be characterised by the size of the area covered under vegetation. There is a high degree of congruence between density of vegetation and suitability of the soil to be used for cropping.

c) **Topography and terrain profile:** The land form along with slope gradient and relief intensity are other parameters to determine the type of water harvesting. The terrain analysis can be used for determination of the length of slope, a parameter regarded of very high importance for the suitability of an area for macro-catchment water harvesting. With a given inclination, the runoff volume increases with the length of slope. The slope length can be used to determine the suitability for macro- or micro- or mixed water harvesting systems decision making (Prinz et al 1998) (Table 4.2.2).

d) **Soil type & soil depth:** The suitability of a certain area either as catchment or as cropping area in water harvesting depend strongly on its soils characteristics viz. (1) surface structure; which influence the rainfall-runoff process, (2) the infiltration and percolation rate; which determine water movement into the soil and within the soil matrix, and (3) the soil depth incl. soil texture; which determines the quantity of water which can be stored in the soil.

e) **Hydrology and water resources:** The hydrological processes relevant to water harvesting practices are those involved in the production, flow and storage of runoff from rainfall within a particular project area. The rain falling on a particular catchment area can be effective (*as direct runoff*) or ineffective (*as evaporation, deep percolation*). The quantity of rainfall which produces runoff is a good indicator of the suitability of the area for water harvesting.

f) **Socio-economic and infrastructure conditions:** The socio-economic conditions of a region being considered for any water harvesting scheme are very important for planning, designing and implementation. The chances for success are much greater if resource users and community groups are involved from early planning stage onwards. The farming systems of the community, the financial capabilities of the average farmer, the cultural behaviour together with religious belief of the people, attitude of farmers towards the introduction of new farming methods, the farmers knowledge about irrigated agriculture, land tenure and property rights and the role of women and minorities in the communities are crucial issues.

For example in a West African study on water harvesting (Tauer & Humborg 1992), the distance between the suitable areas and the villages was regarded as an important criterion. It was assumed that farmers were willing to walk not more than 6 km from their homes if the proposed water harvesting system is acceptable to them. The existing or planned infrastructure as well as regional development plans have to be duly taken into account when planning a water harvesting scheme (Siegert 1994).

g) **Environmental and ecological impacts:** Dry area ecosystems are generally fragile and have a limited capacity to adjust to change (Oweis et al. 1999). If the use of natural resources (land and water), is suddenly changed by water harvesting, the environmental consequences are often far greater than foreseen.

Consideration should be given to the possible effect on natural wetlands as on other water users, both in terms of water quality and quantity. New water harvesting systems may intercept runoff at the upstream part of the catchment, thus depriving potential down stream users of their share of the resources. Water harvesting technology should be seen as one component of a regional water management improvement project. Components of such integrated plans should be the improvement of agronomic practices, including the use of good plant material, plant protection measures and soil fertility management (Oweis et al. 1999).

Khadin- A traditional successful water harvesting system in India

Khadin is an ancient skilful and sound scientific example of rainwater harvesting system in Western Rajasthan/ India. This system has great similarity with the irrigation methods practised in the Middle East and in Negev desert. The Khadin system is based on the principles of harvesting rainwater on farmland and subsequent use of water-saturated land for crop production .

A Khadin is an earthen embankment built across the general slope which conserves the maximum possible rainwater runoff within the agricultural field. The size of the Khadin is designed on the basis of local rainfall patterns, catchment characteristics and soil type. On an average, the cultivated area under each Khadin is 10-14 ha with an average dam size between 1.2-1.7 m high x 1.0-1.5 m wide and 100-300 meters in length, depending upon catchment area and number of land holdings. The spillways and sluice gates are usually provided at a proper location for excess water during flood conditions. The embankment not only helps to increase moisture in the submerged land, but also prevents the washing away of the top soil and the manure added to it. For efficient agriculture, a minimum of 15:1 ratio of catchment area to crop area is required. A rainfall of 75-100 mm is sufficient to charge the Khadin soils with sufficient soil moisture content to raise a successful local crop.

In the Khadin area, the collect runoff percolates into the ground with time recharges the subsoil. Of the total runoff collected only 50-60% of the water is utilised. The remainder is lost to evaporation, or percolates into the underground, recharging an aquifer. Depending upon the amount of rainfall and consequent runoff received during the monsoon, one or two crops are grown. There is 3-4 fold increase in agriculture production, in comparison with non-Khadin conditions depending upon rainfall quantity and distribution. This system assures the farmers of at least one crop even in very dry tracts. The construction cost for single Khadin ranges from US $ 125-175. This construction cost can be repaid back within three to five years. Other than improving socio-economic conditions of desert dwellers, Khadins also have created positive impact on the ecology of the region, effectively checking soil erosion and increasing vegetation cover. *Source: Agarwal & Narain, 1997*

4.2.4 CONCLUSIONS

Rainwater and Floodwater Harvesting have the potential to increase the productivity of arable and grazing land by increasing the yields and by reducing the risk of crop failure. They also facilitate re- or afforestation, fruit tree planting or agroforestry. With regard to tree establishment, rainwater and floodwater harvesting can contribute to the fight against desertification. Most of these techniques are relatively cheap and can therefore be a viable alternative where irrigation water from other sources is not readily available or too costly. Unlike pumping water, water harvesting saves energy and maintenance costs. Using harvested rainwater helps in decreasing the use of other valuable water sources like groundwater. Remote sensing and Geographical Information Systems can help in the determination of areas suitable for water harvesting (Prinz et al. 1998).

Rainwater harvesting should suit its purpose, be accepted by local population, and be sustainable in local environment. In dry areas (and without storage facilities), field crops with deep rooting and drought resistant trees constitute the most promising application (Boers 1994).

The decision making process concerning the best method applicable in particular environmental and geo-physical conditions depends on kind of crop to be grown and prevalent socio-economic and cultural factors.

Local availability of labour and material are the most important factors. The accessibility of the site has also to be considered for construction of water harvesting structures and distance from village. There are number of studies reports that rainwater harvesting can be **economically** profitable (Rodriguez 1996). e.g. In Pakistan highland Balochistan - wheat grown under micro-catchment water harvesting is more viable and profitable than any of the traditional methods.

One of the crucial social aspects for the success is the involvement/ **participation** of the stakeholders or beneficiaries. All stakeholders have to get involved in planning, designing and implementation of water harvesting structure. A consensus is necessary for operation and maintenance of water harvesting structures. Involvement of local NGOs may also benefit the community for collective action.

Water management problems can only be tackled in a **holistic** way, integrating land, water and labour management.

Finally a **comparison** between water harvesting terchniques and the construction of large or medium dams shows that:

(1) Through the introduction of water harvesting, water resources in upstream watershed can be managed more efficiently.
(2) Water harvesting can supplement irrigation water supply during water scarcity or low water availability periods. Its proximity to cropping area can be an important point in improving water use efficiency and avoiding field losses.
(3) Water harvesting may be of small scale but certainly have edge over dams due to its suitability for immediate local environment, they are labour intensive (*local employment generating*), democratic and participatory in nature.
(4) With the small scale of water harvesting technology, no foreign investment is needed (but banking facilities are sometimes needed).
(5) Some of the benefits of large dams like generating hydropower energy, supplying drinking water for big cities etc, can not be offered by water harvesting.
(6) Water harvesting to be successful requires local capacity building and agriculture extension services, training and credit facilities for resources users, co-operation and extensive participation.

4.2.5 RECOMMENDATIONS

- The possibility of **transferring** water harvesting methods to other areas shows that the transfer is possible in principle. A close examination of the other factors determining their success, such as socio-cultural environment, the possibility of adapting the population to agricultural innovations, the development policy objective of the country are important for final consideration. This can be achieved by an agro-ecological, social-economic **feasibility study** covering the proposed area under consideration.

- National **institutional arrangements** should be made to co-ordinate the design and implementation of various water harvesting projects and to built a data base to record the experience. There is need to systematically collect and collate data on soil, natural vegetation and land use, cropping pattern, rainfall amount and distribution, water resources and crop and water requirements as a national inventory of the potential of water harvesting.

- The planning of water harvesting systems should be a part of an **integrated land and water resource management** plan, and should include the agronomic practices and farmers training.

- Local resource **users** should be involved in all aspects of the planning, designing, implementation, and monitoring of water harvesting systems. As mentioned before, planning should explicitly the effect on downstream water users of the hydrological changes brought out by implementation of water harvesting. Opportunities for **equal access** of women and other disadvantaged farmers to the benefits of the new technology should be provided; and the relation between land tenure, water rights and the introduced water harvesting technologies should be carefully considered.

- **Performance assessment** of water harvesting system should be carried out to facilitate comparison between various systems. The should include the suitability data and information on the size and type of water harvesting system, crop grown and yield levels, annual rainfall, amount of runoff collected per unit catchment area, socio-economic impact and social acceptance.

4.2.6 REFERENCES

1. Agarwal, A. and S. Narain. 1997. Dying Wisdom- Rise, fall and potential of India's traditional water harvesting systems. State of India's Environment Report 4. Centre for Science and Environment, New Delhi.
2. Critchley, W. and Siegert, C. 1991. Water Harvesting Manual. FAO Paper AGL/MISC/17/91, FAO, Rome
3. Oweis, T., A. Hachum, and J. Kijne. 1999. Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. SWIM Paper 7. Colombo, Sri Lanka: International Water Management Institute.
4. Siegert, C. 1994. Socio-economics of water harvesting. Water Harvesting for Improved Agricultural Production. Expert Consultation, Cairo, Egypt 21-25 Nov. 1993, FAO, Rome
5. Prinz, D. 1996. Water Harvesting – History, techniques, trends. Z. f. Bewaesse-rungswirtschaft 31, (1): 64 - 105
6. Prinz, D., S. Wolfer. 1999. Traditional techniques of water management to cover future irrigation water demand. Z. f. Bewässerungswirtschaft, 34 (1), 41-60. ISSN 0049-8602

7. Prinz, D., T. Oweis and A. Oberle. 1998. Rainwater harvesting for dry land agriculture- Developing a methodology based on remote sensing and GIS. Proceedings, XIII International Congress Agricultural Engineering, 02-06.02.1998 ANAFID Rabat Morocco.
8. Rodrigues, A., 1996. Sustainability and economic viability of cereals grown under alternative treatment of water harvesting in highland Balochistan, Pakistan. Journal of Sustainable Agriculture 3: 305-315.
9. Tauer, W., G. Humborg. 1992. Runoff irrigation in the Sahel zone. CTA (Technical Centre for Agriculture and Rural Co-operation) Ede/ Wageningen, NL

Annexures

Table 4.2.1 Groups, types and sub-types of water harvesting for agriculture production								
WH Group	**Rainwater Harvesting**			**Floodwater Harvesting**		**Groundwater Harvesting**		
WH Type	Court-yard WH	Micro-catch-ment WH	Macro-catch-ment WH	FWH within stream bed	Flood-water diversion	Qanat system	Ground water dams	Spe-cial wells
Tech-niques	Paved/ sealed surface	Inter-row WH	Hillside conduit system	Jessour type	Wild flooding	Short Qanat	Sand storage dams	Horiz ontal wells
	Compac t/ treated surfaces	Negarin/ Meskat type WH	Semi-circular hoops	Dike type	Water dispersion	Medium Qanats	Sub-surface dams	Arte-sian Wells
		Pitting tech-niques	Culti-vated reser-voirs	Perco-lation dams	Water distri-bution	Long Qanats		
		Eye-brow terraces	Stone dams					
		Valle-rani type WH	Liman terraces					
Kind of Storage	Cisterns	Soil profile		Soil profile				
	Ponds		Cistern	Reser-voirs	Ponds			
	Jars		Ponds					
	Tanks		Reservoi rs					
Aquifer Recharge	none	very limited	limited	strong	very strong	limited	medium	
Source: Prinz et.al 1999								

Table 4.2.2 Terrain Classification in Central Syria using LANDSAT TM April 1995			
Land form	**Slope Gradient (%)**	**Relief Intensity (m/ Km)**	**Different units of land form**
Level Land	0 to 8	50	• Intermontane plains • Flat saline plains • Slightly undulating plains with dry wadis and desert type outliers • Plateaux • Depressions • Low gradient foot slopes Wadi beds
Sloping Land	8 to 30	50-600	• Medium gradient mountain with undulating hilly relief • Ridges • Plains dissected by wadis
Steep Land	> 30	> 600	• High gradient mountains • High gradient hills (badlands)
			Source: Prinz et. al. 1998