Water Harvesting Techniques in the Arab Region

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Abstract

The Arab world is facing one of the severest water scarcities in the world. The aridity, low rainfall, high evaporation, uneven distribution of water resources, complexity of the hydro-political conditions, the rapidly growing human population, the deterioration of water quality and the accelerated demand for water are factors contributing to water resources vulnerability in the Arab Region. Water availability per capita is continuously decreasing and water shortages are rapidly growing. As long the water demand continuously increases, the Arab conventional water resources, particularly groundwater resources, will be always stressed and depleted. Accordingly, there is a great need for effective and efficient use of all water resources potentialities in the Arab region. The total average annual volume of rainfall within the boundaries of the region is about 2,238 billion m^3 contributing only 200 billion m^3 of renewable surface and groundwater resources. Consequently, water harvesting can be a key element to alleviate water scarcity problems in the Arab region. Different water harvesting techniques have been widely practiced in the Arab region from a long time ago. This paper outlines some of the water harvesting techniques in the Arab region. Moreover, water harvesting projects in two major wadis in Egypt are presented and discussed.

1. Introduction

The total surface area of the Arab region is approximately 14 million km^2 extending between latitudes 4º S and 37º 22` N covering southwest Asia and North Africa. Most of the Arab countries are located in arid and semi-arid zones. It is characterized by scanty annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. The total average annual volume of rainfall within the boundaries of the region is about 2,238 billion m^3 contributing only 180 billion m^3 of renewable surface and groundwater resources. Additionally, the region receives 160 billion m^3 of surface water from catchments outside the Arab region (UNESCO Cairo, 1995). The renewable water resources in the Arab region have been estimated by many researchers. Salih (2002) pointed out that the published figures range from 246 to 441 Billion m^3 with an average of 340 Billion m^3. This amount of renewable recourses can not meet the future needs of the Arab region.

The Arab conventional water resources, particularly groundwater resources, have been considerably stressed and resulted as depletion of the storage associated with deterioration of groundwater quality. The average annual recharge to groundwater is estimated at 45 Billion m^3, whereas 135 Billion m^3 is available in wadi system. This indicates the potentiality and importance of maximizing water harvesting in the Arab region. Moreover, in most of the Arab countries, wadi flow constitutes an important source which could be recharged to strained aquifer systems confront problems of depletion and degradation of eater quality. Since water shortage is becoming a major constraint for socio-economic development in the Arab region, most of the Arab countries have focused attention to the development of water resources of ephemeral wadis through different water harvesting techniques.

2. Rainfall-Runoff Characteristics

There is a severe spatial rainfall distribution over the Arab region (Figure 1). Only 2.66 million Km^2 receives 1488 billion m^3 constituting 19% of the total area of the Arab region, while 406 billion m^3 of rain fall on 15% of the total area. Two thirds of the Arab region which is arid and hyper-arid deserts (9.24 million Km^2) receives 344 billion m^3 of rainfall

According to the rainfall regime, the Arab region can be divided into three sub-regions, namely (UNESCO Cairo, 1995):

1. *The Mediterranean (northern) sub-region:* Rainfall is high over the coastal mountains of Lebanon (1500 mm/yr) and decreases southwards to about 400-500 mm/yr in Jordan. Moreover, in

Morocco, the annual rainfall reaches 1800 mm and it decreases southwards over the high plateau and Sahara Atlas to about 500 mm dropping to100-200 mm on the slopes adjacent to the Sahara.

2. *The Arabian Peninsula:* The rainfall is low with significant temporal and spatial distribution. The average annual rainfall ranges from 70-130 mm/yr except in some locations in Saudi Arabia, Yemen and Oman where more rainfall is received.

3. *Southern sub-region region:* Most of the area of Mauritania and Somalia has an annual rainfall of less than 300 mm/yr. In Sudan, there is a wide rainfall variation from 1800 mm/yr in south Sudan to 25 mm/yr at its boarder with Egypt.

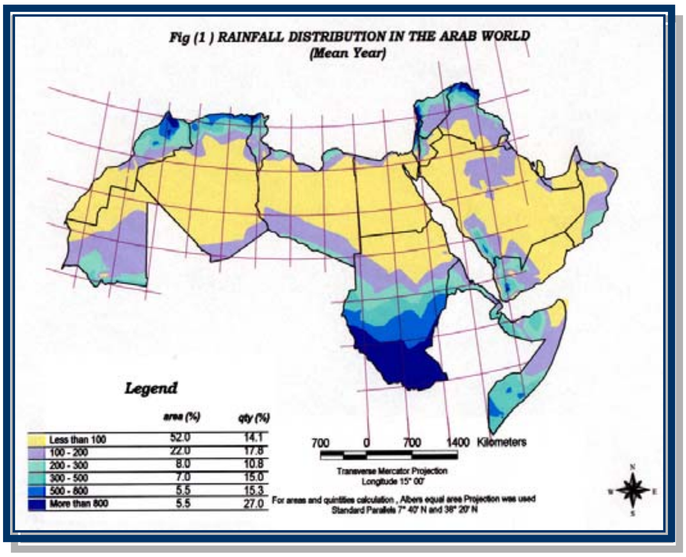

Figure (1) Rainfall Distribution in the Arab region (ACSAD, 2000)

3. The Water Harvesting Concept

Water harvesting is the capture, diversion, and storage of rainwater for many uses (Abdo and Eldaw, 2004). Water harvesting deals with all methods which manage rainfall and runoff through effective storage in the soil or underground for later beneficial use.

A water harvesting system is a facility for the collection and storage of runoff water. Systems which harvest water from roofs or ground surfaces are classified as “rainwater harvesting”, whereas systems which collect water from water courses are classified as “floodwater harvesting”. Survey of traditional water systems has revealed that some 25 systems are used in the Arab region. Promising traditional water systems have been grouped into four categories (UNESCO Cairo, 1995):

a. Water harvesting and storage systems;
b. Water harvesting and spreading systems;
c. Groundwater systems; and
d. Water lifting systems.

Table (1) Distribution of traditional water system in the Arab States, after UNESCO Cairo (1995)

Category	**Name of system**	**Jordan**	**Un-Arab Emirates**	**Bahrein**	**Tunisi**	**Algeria**	**Saudi Arabia**	**Sudan**	**Syria**	**Iraq**	**Oman**	**Qatar**	**Kuwait**	**Lebanon**	**Libya**	**Egypt**	**Morocco**	**Mauretania**	**Yemen**
Water harvesting and storage systems	Cisterns	x			x				x	x				x	x	x	x		x
	Small dams	x	x		x	x	x	x	x	x				x	x	x	x	x	x
	Hafirs	x					x	x	x	x		x	x	x				x	x
	Tree trunks							x											
	Koroum / Ghadirs	x					x	x		x				x		x	x		
Water harvesting and spreading systems	Terraces / Masateh	x			x	x	x		x	x				x	x		x		x
	Irrigation diversion dams	x			x	x		x	x	x				x		x	x		x
	Water spreading dykes	x				x	x	x	x	x				x		x	x	x	
	Miskat				x										x				
	Artificial recharge	x	x					x				x				x	x		x
	Check dams				x										x				

Groundwater systems	Foggaras		x		x	x	x		x	x	x			x	x	x	x		
	Surface wells	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x	x
	Springs	x			x	x	x		x	x	x	x		x	x	x	x	x	x
	Ghoutas					x	x								x	x			
Water lifting systems	Shadouf					x		x		x						x	x	x	
	Saquia / Naoura				x			x	x	x						x	x		
	Tambour															x			
	Bucket and pulleys	x			x	x	x	x	x	x				x	x	x	x	x	x
	Wind mill				x			x	x					x	x	x	x		
	Hydraulic mill																x	x	

security in many communities like in Yemen, where, more 1.5 million hectares have been regularly cultivated (Abdulrazzak, 2003).

Table (1) shows the distribution of the different traditional water systems in the Arab countries. It worth mentioning that water harvesting in the Arab region dates back to 9000 years ago. The earliest systems are located in Jordan, Iraq and the Arabian Peninsula (Abdo and Eldaw, 2004).

In arid and semi arid areas, the main purpose of water harvesting is for growing crops or for rehabilitation and development of rangelands. Harvesting one millimeter of rainfall is equivalent to one liter of water per square meter. Accordingly, the catchment area is a major criterion for classifying water harvesting systems as follows:

1. Micro-catchment water harvesting systems where the catchment area and cultivated area are adjacent. It belongs to rainwater harvesting systems. Negarim microcatchments (Figure 2) and contour bunds (Figure 3) are examples of this water harvesting technique.
2. Macro-catchment water harvesting systems where the catchment area is located upstream the cultivated area, in most cases called external catchment system where overland flow is harvested.
3. Spate irrigation system which depends on harvesting flood water from wadi channels. Their catchment area is larger than the other two systems.

Figure (2) Negarim microcatchment

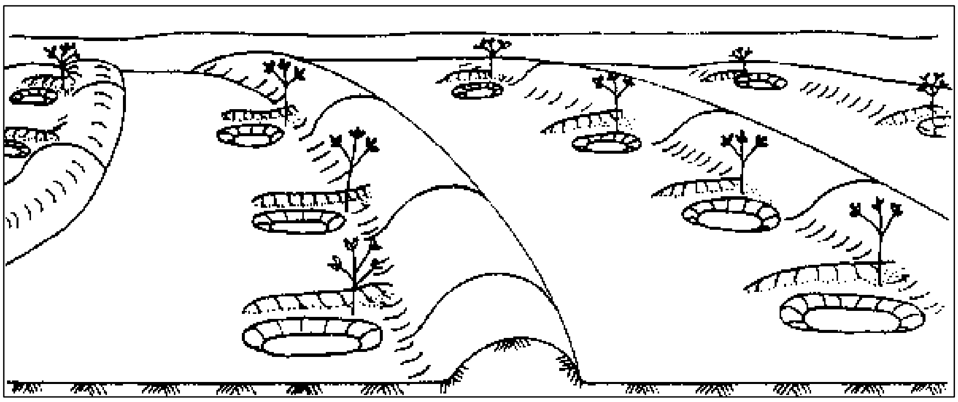

Figure (3) Contour bunds for trees as a simplified form of microcatchments
(after FAO, 1991)

4. Terracing

Terracing is widely used in Yemen as one of the effective conservation techniques (Figure 4). Moreover, it is successfully used for rainfall utilization and soil conservation in the mountainous areas of south western Saudi Arabia and Oman. Different forms of terracing are available depending on its purpose such as soil conservation and water use. In the Arab region, there are a number of practiced terracing systems such as weir terraces across narrow wadis, barrage terraces, linear dry field terraces, and stair terraces (Abdo and Eldaw, 2004). Rained agriculture is practiced on terraces achieving food

Figure (4) Terraces on mountain slopes in the Yemen Highlands (after Noman, 2003)

Lack of maintenance, migration of labor and emphasis on large scale agricultural development are the main problems of terracing in the Arab region (Abdo and Eldaw, 2004).

5. Spate Irrigation

This kind of water harvesting may also called flood irrigation. It mainly counts on water spreading where the flood water is diverted from the wadi course to an immediately adjacent cultivated area. Spate irrigation is practiced in Sudan, Yemen, Oman, United Arab Emirates, Tunisia, Algeria and Saudi Arabia. Ahmed (2005) stated that agricultural land may be graded and divided into basin for storing enough water to allow enough water to be stored for the season. Therefore, soils should be deep with sufficient water holding capacity. Table (2) provides some figures about the spate irrigation areas in some Arab countries in relation to the total irrigated areas in these countries, (FAO, 1999)

In large wadis with high discharges, a temporary earth dams created in order to retard the flow and receive the first wave of flood. The traditional methods practiced in Yemen ad several Arab countries consists of constructing earthen bunds (Ogmas) ahead of the rainy season across the wadi channel to direct the floodwatrer. This is a cheap system to build however, it needs regular maintenance and repairs from flood damages.

Table (2) Spate Irrigated areas versus total irrigated areas in some Arab countries (FAO, 1999)

Country	Year of Irrigation data	Spate irrigation area in ha	Total irrigation area in ha	% of spate irrigation coverage
Yemen	1987/1997	98,320	481,520	40
Algeria	1992	110,000	555,500	20
Morocco	1989	165,000	1,258,200	13
Tunisia	1991	30,000	385,000	8
Sudan	1995	46,200	1,946,200	2.5

In eastern Sudan the spate irrigation system in the ElGash seasonal river delta involves several uncertainties due to unpredictable in timing, volume and sequence of flood water. Such situation represents the main cause of risks in crop production and uncertainties under spate irrigation. The spate irrigation system in El Gash wadi is consisted of six main canals. These canals are crossing the wadi deltas from East to West with a bed slope ranges from 1:1000 to 1: 2000 (Ahmed, 2005). The control structures along the canals are operated by stop-logs. Heavy sediment load of the river creates the closure of the canals. Basins of 1000-1500 ha is watered for more than 40 days continuously leading to heavy water losses through evaporation (400 mm) and deep percolation which reaches 6m deep. The wetted area in the ElGash Scheme is about 40,000 Feddans. About 36,000 farmers is working this scheme. The irrigated lands are rotated from year to another. As pointed out by Ahmed (2005), the rotational use of land by the lottery system is one of the main problems complicating the spate irrigation water management.

In many areas of the Arabian Peninsula, direct use of flood water for irrigation or groundwater recharge is small compared to the amount of available surface runoff. Water spreading involves the percolation of excess water into shallow groundwater alluvial aquifer. This method is used in Saudi Arabia, Yemen, Oman and United Arab Emirates. There are many examples of either indirect artificial recharge projects in the Arab region. In Qatar water is collected in shallow depressions and injected into the underlying aquifers through wells.

Beyrouth artificial recharge project is one of the earliest applications of artificial recharge in the region. Surface water has been diverted from streams flowing in karstic terrain to the limestone aquifer in coastal areas and was recharged through a number of wells. It was pumped during dry seasons when the base flow of streams become insufficient to meet peak demand in Beyrouth. This pilot project demonstrates that artificial recharge could be used for addressing water supply problems arising from high degrees of karstification in the main channels of perennial or intermittent streams flowing in limestone terrains (UNESCO Cairo, 1995).

The majority of dams built in Oman and UAE are for recharge of depleted aquifer systems. In addition to surface dam few “sub-surface dams” have been built to regulate groundwater flow. Dams built on Wadi Aridah and Wadi Turba ner Taif in Saudi Arabia are examples for this kind of wadi development (Al-Hajeieiry and Shaikh, 1982). It was noted that after the construction of these dams an amount of 6.5 million m^3 were made available instead of losing it due to seepage to highly permeable wadi-fill deposits which was the case before the dams construction.

In Oman, usually stored surface water upstream dams last for almost 15 days after which the stored water is diverted to spreading grounds beside the wadis. These areas usually exist downstream and water reaches them through channels dug for this purpose.

6. Meskat

The Miskat System is one of the ancient methods employed in harvesting rainwater. They are used in the Arab Maghreb specially in Tunisia, Morocco and the north west of Libya in Nafousa mountain. At present, the state of these Miskats have been deteriorated because of the intensive agricultural development that took place since the middle of the century (UNESCO Cairo, 1995). The Miskat secures water deficit resulting from the difference between water consumptive use of the crop in the basin (Manka') and the available annual rainfall. The deficit is covered by harvesting water during the period of rainfall occurring over an area called Miskat. This water is later diverted to the basins where it is stored in the soil. The Miskat (Figure 5) is simply a piece of flat land with a mild slope (3 to 6%) with few or no drainage channels. The land is prepared for rain water harvesting and then water is directed to another piece of land of half its area and located directly below; which is called the collector where crops are planted.

In Tunisia, the "Meskat" and the "Jessour" systems are widely practiced. The "Jessour" system (Figure 6) is a terraced wadi system with earth dikes reinforced by dry stone walls. The sediments accumulating behind the dikes are used for cropping. Most "Jessour" have a lateral or central spillway (Prinz, 1996). Up to 1984, "Meskats" covered 300,000 ha where 100,000 olive trees were planted; "Jessours" covered 400,000 ha (Tobbi, 1994). The government of Tunisia started in 1990 adopted a strategy comprising the construction of 21 dams, 203 small earth dams, 1,000 ponds, 2,000 with the aim of recharging groundwater aquifers and 2,000 works for irrigation through water spreading (Achouri, 1994). Prinz (1996) indicated that modern spate irrigation techniques are harvesting about 20 Mm^3 of water annually to serve an area of 4,250 ha.

In Libya, Al-Ghariani (1994) indicated that on the slopes of the western and eastern mountain ranges, runoff-based farming agriculture are practiced. Historical studies have noted that such techniques were used during Roman times. In different parts of Libya, experimental sites of contour-ridge terracing covering more than 53,000 ha have recently been established (Al-Ghariani, 1994).

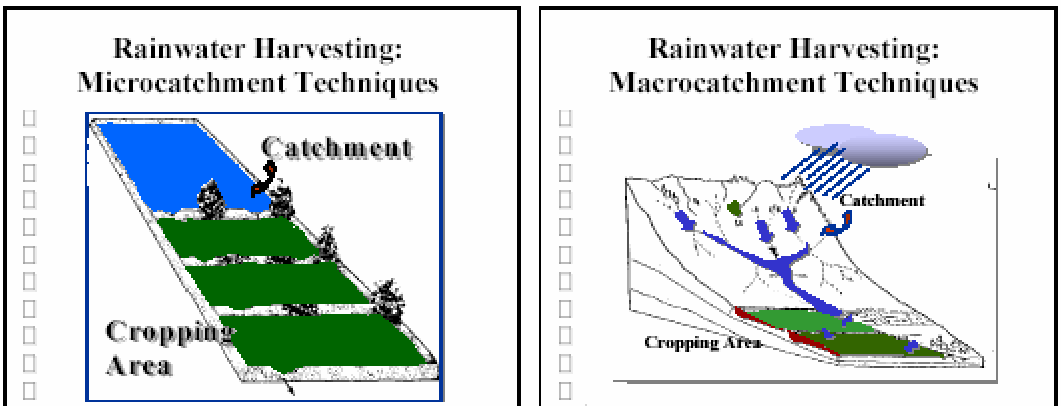

Figure (5) Examples of rainwater harvesting techniques with general features. Microcatchment: Meskat system from Tunisia (Prinz 2002)

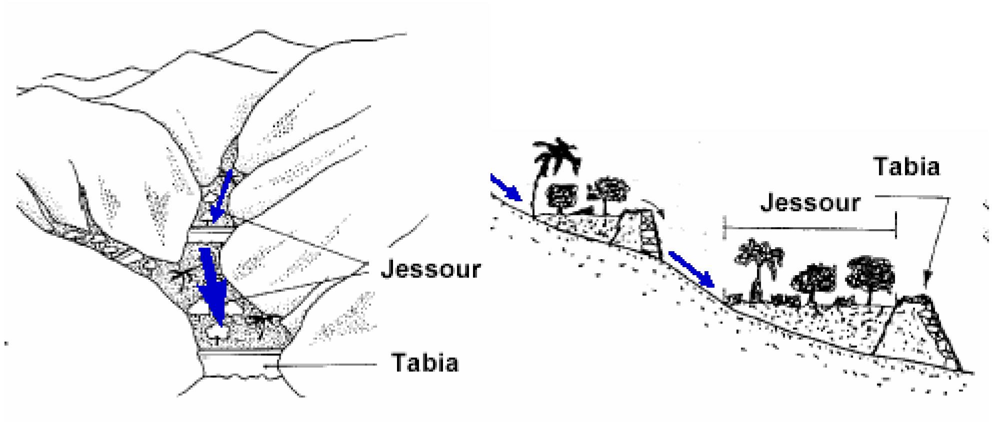

Figure (6) A row of "Jessour" in the South of Tunisia. (Prinz 1996).

7. Dams and Reservoirs

Dams of various sizes were constructed in most Arab countries for the purposes of irrigation, flood control and groundwater. Dams assist in reducing flood damage downstream by reduce the magnitude of peak discharge. Moreover, sediment which carried by floods is trapped upstream dams creating good soil for agriculture. Most of the dams built in Saudi Arabia, the United Arab Emirates and Oman were built for the purposes of groundwater recharge flood control (Abdulrazzak, 2003). Few large dams in Saudi Arabia, Egypt, Tunisia, Sudan and Jordan have multi-purposes (Abdo and Eldaw, 2004). These dams have been built either at the head waters of catchments in the mountainous regions or in the downstream portions of catchments as in Saudi Arabia, Sudan, Egypt, Tunisia, Jordan, Yemen, the United Arab Emirates, and Oman. Abdo and Eldaw, (2004) stated that due to flat topography and limited runoff in the remaining countries of Bahrain, Kuwait and Qatar, and parts of Sudan small diversion structures are used instead of dams to create detention basins.

8. Water harvesting projects in two major wadis in Egypt: Case Studies

8.1 Wadi Watier

Wadi Watier (about 3600 km^2) in southeastern Sinai, Egypt receives large amount of rainfall. Wadi Watir is distinguished with its strong flash floods, appropriate fruitful soils for cultivating, inhabitance with Bedouins, natural springs, constructed wells, and tourism Canyon area. Moreover, at the delta of the Wadi, there are Nuweibaa City, many tourism villages, and roads network. The floods of Wadi Watier usually cause huge destruction in the area and endanger the life of people (see Figure 7).

The catchment area is covered by basement rocks, mainly granites which are highly fractured and intruded by basic dikes trending in NE-SW direction. The basement rocks are non-conformably over lain by Cretaceous rocks, mainly sandstones followed by shales and limestones (Fahmi et al., 2002). Figure (8) shows the general classifications of the land cover in wadi Watier. Alluvial deposits derived from local rocks fill the drainage streams of the Wadi.

Figure (7) Destruction effects of Wadi Watier flash floods

For the purpose of water resources development of the area and to minimize the harmful destruction effects of Wadi Wateir flash foods, seventeen detention dams and five storage dams are proposed. These dams store direct water for seasonal agriculture sufficient to irrigate about 4500 feddans/year. Moreover, reuse of recharging water for groundwater aquifers, as indirect contribution, can cover the requirements of about 3000 feddans/year. Another positive impact is the creation of a good agriculture-land upstream the proposed structures amount to about 500 feddans. Fahmi et. al. (2002) indicated that the costs of structures can be compensated within few years after executions of the proposed control works.

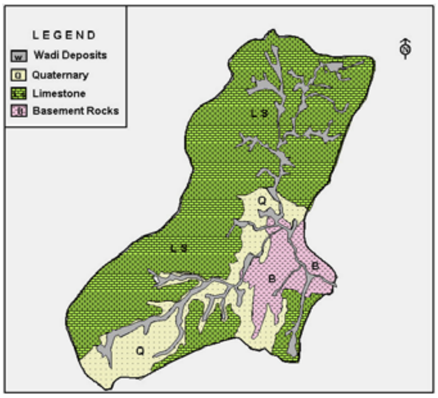

Figure (8) General Geological Map of Wadi Watir

Dams locations were selected upon field investigations according to the most practical and suitable sites. Figure (9) gives example of Wadi Wadi Watier dams. This includes construction process and transportation of the equipments and materials. The hydrological aspects of reservoir planning deal with:

1. Water availability in the area on which the dam is proposed to be constructed;
2. Determination of storage capacity to serve the target pattern of demand; and
3. Operation of reservoir with the given target pattern of demand.

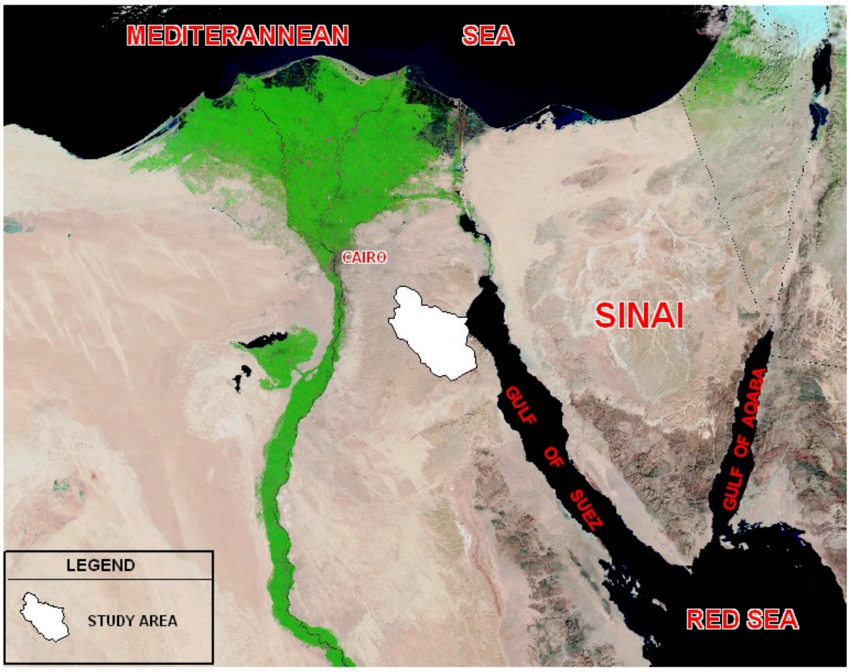

Figure (9) Wadi Watier dams example

8.2 Wadi Ghuweiba

On the other side in the Eastern Desert of Egypt, Wadi Ghuweiba extends between Lat. 29º 10’ and 29º 45’ E and Long. 31º 40’ and 32º 30’ N. It covers an area of about 2500 km2 and main stream length of about 130 km. The Wadi is generally rugged with strongly slopes range between 10 and 28 m/km and elevations between 1300 m to about 100 m (See Figure 10).

The area mainly consists of Eocene limestone outcrops all over the area and overlained by wadi deposits and underlained by different types of rocks. The thick limestone formations attain a thickness of more than 400 m underlained by Esna shale and upper Cretaceous limestone and a thick section of sandstone belong to lower Cretaceous and Paleozoic ages (Fahmi et. al., 2004). The delta of this wadi is characterized by gradually sloping irregular surface dissected by fan drainage lines and covered by alluvial deposits which is considered as an important source of Quaternary groundwater that can be withdrwal by shallow dug wells taking into consideration the sea water intrusion from Suez Gulf due to over pumping. Permeability coefficients along wadi Ghuweiba main stream, at the outlets of each subbasin, have been measured as listed in Table (3).

Figure (10) Location Map of Wadi Ghuweiba

Table (3) Permeability coefficients at subbasins' outlets (after Fahmi et. al., 2004)

Subbasin's Name	Shona and Khafory	Esaimer	AA	Abiad	Noot	Ghuweiba
Permeability (cm/sec)	1.95 x 10-1	2.15 x 10-1	1.8	4.5 x 10-1	4.5 x 10-2	1.6 x 10-1

Field geoelectrical survey was conducted in Wadi Ghuweiba comprising 16 vertical Electrical Sounding (VES) using Stumberger electrode configurations. The location of these VES's is shown in Figure (11).

Field measurements aimed to explore a depth of about 700 meters. The main purpose of interpretation of geoelectrical resistivity sounding is to determine the number of geoelectrical layers in terms of thickness (or depth) and relative true resistivity. Interpretation of vertical electrical soundings has been correlated with some available boreholes, thus, a reliable control can be achieved for portraying the subsurface picture in the study area. The results of such interpretation in the form of layer thickness and true resistivities are illustrated on the geoelectrical cross-sections (Figure 12).

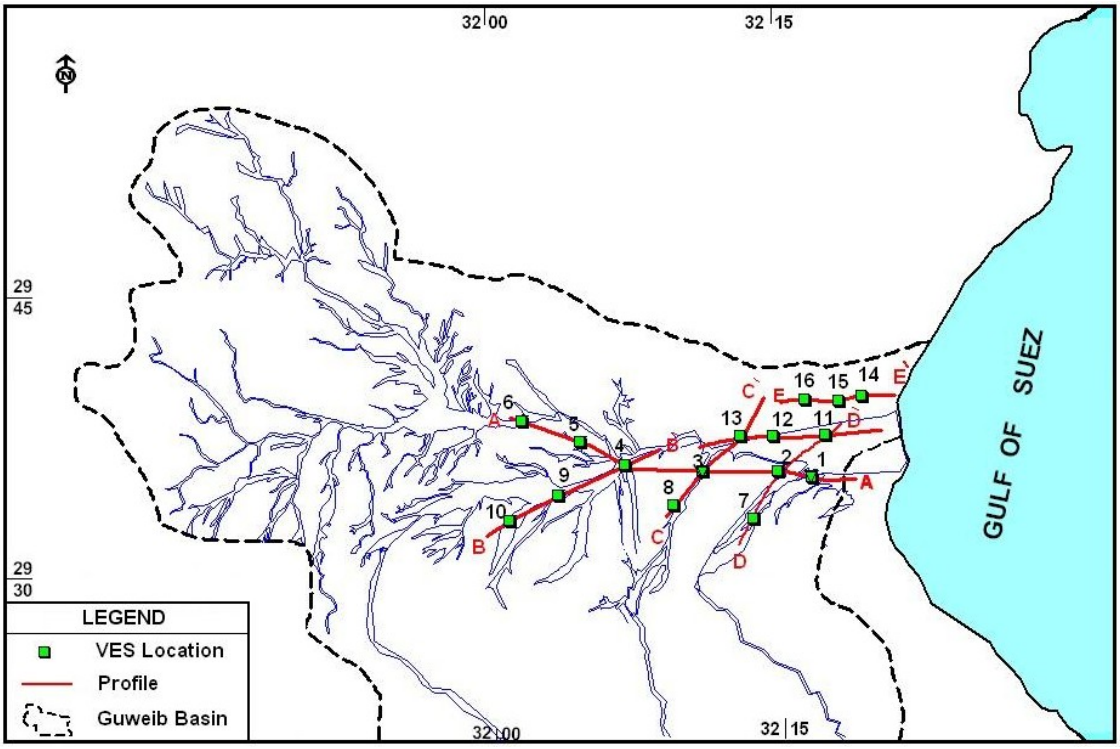

Figure (11) VES Location and Profile Direction in Wadi Ghuweiba

From this investigation, it can be pointed out that there are two main aquifers in Wadi Ghuweiba area; the upper Quaternary aquifer which can be harvested by drilling wells to a depth of about +150 m, and the second is the Tertiary aquifer which can be harvested by drilling wells of about +450 m (Fahmi et. al., 2004).

To increase the rate of recharge to the Quaternary aquifer, an artificial recharge system was suggested. Six locations were employed to induce infiltration into the Quaternary aquifer using of instream structures. These structures were series of rechargeable dams which are changing the hydraulic regime of wadi Ghuweiba stream, decreasing flow velocities and encouraging the growth of riparian vegetation.

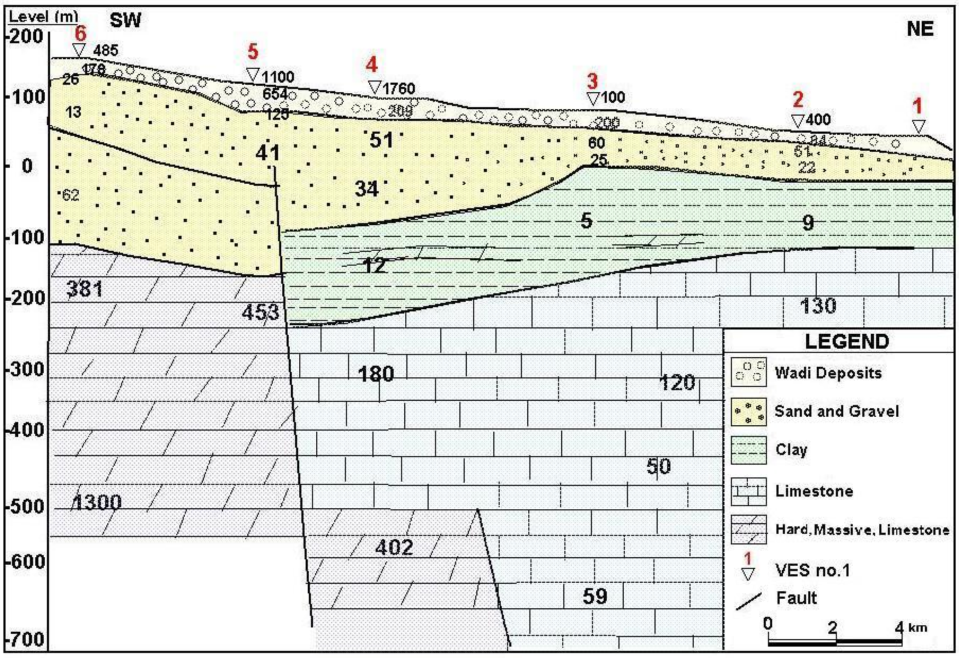

Figure (12) Geoelectrical Cross-Section along Wadi Ghuweiba Main Stream

Moreover, they aid in the replenishment of subsurface and groundwater. Dams' heights ranged between 3 and 7 meters with capacities ranged between 60x103 to 6500x103 cubic meters. Figure (13) shows the location of dams and their expected storage area in Wadi Ghuweiba. The dams are designed to fill with course sediment over a period of several years following construction. The sediment behind the dams serves as an artificial aquifer for the storage of flood waters and their eventual release as streamflow.

Table (4) shows the recharged water to the different groundwater aquifer. Development and settlement criterion are preferable to be based on the average seasonal rainfall and the considerable floods happened in a specific return periods.

9. Water Harvesting Constraints in the Arab Region

The following lists some of the constraints facing water harvesting in the Arab region:

- Rainfall and runoff data availability
- Un-gauged Catchment conditions
- Suitable hydrological techniques for arid conditions
- Up-scaling problems from experimental catchments (if exist) to water harvesting scale
- Socio-Economic aspects
- Maintenance
- Financial support for establishing monitoring systems
- High cost of water harvesting constructions in the Arab region in relation to its immediate use.

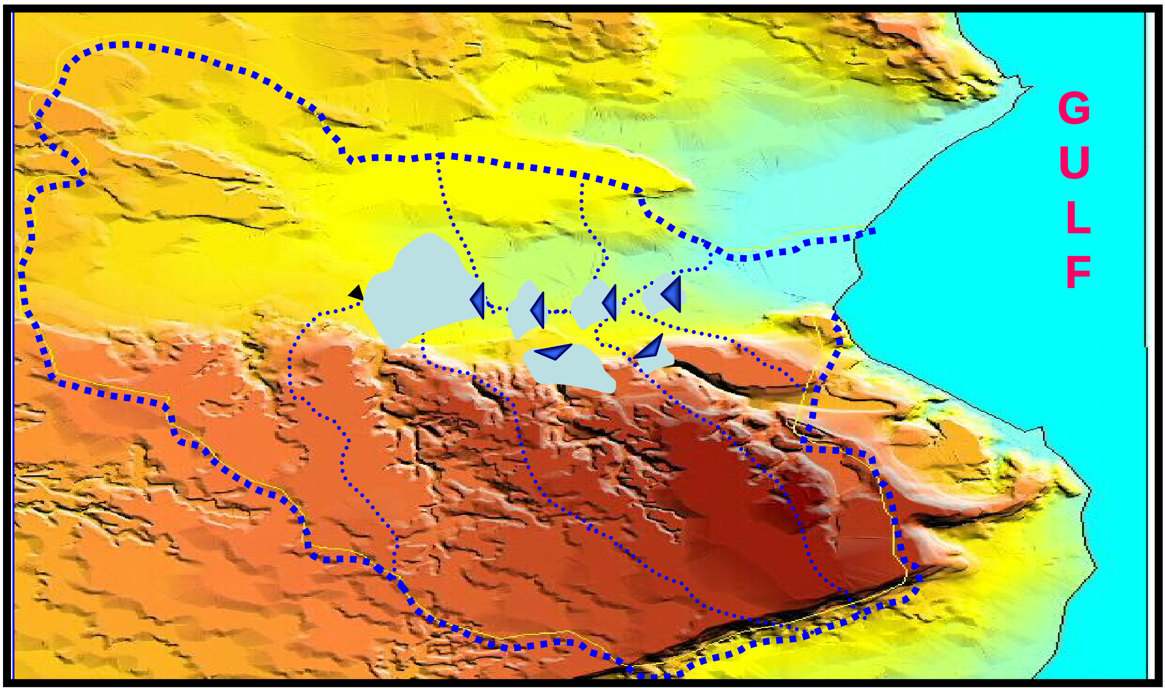

Figure (13) Location of dams and their storage area in Wadi Ghuweiba

Table (4) Recharged water to different aquifers (1000 m^3)

Subbasin's Name	Average	Return periods (years)				
		5-yr	10-yr	25-yr	50-yr	100-yr
Shona	1260	840	3360	5460	10440	13320
Khafory	2501	2066	3515	7760	11360	13930
Esaimer	88	88	184	264	516	814
Abiad	43	36	70	180	228	598
AA	638	510	829	3168	3550	13345
Noot	46	23	57	132	234	435

10. Recommendations

1. Strengthening the existing hydrological monitoring systems in the Arab region
2. Establishing more new experimental basins in the Arab region for more understanding of the hydrological characteristic of the region.
3. Establishing regional database and strengthening the existing ones in the Arab region.
4. Encouraging more joint research activities in arid zone hydrology.
5. Enhancing capacity building and fostering networking in the field of water harvesting in the Arab region.

6. Raising public awareness for increasing the water use efficiency with special focus on the ethical dimension.
7. Encouraging the involvement of the stakeholders, NGOs and communities in th maintenance of he water harvesting construction.
8. Enhancing the coordination among the scientific institutes in the Arab region for more experience exchange in the field of water harvesting techniques.

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