Indigenous knowledge for using and managing water harvesting techniques in Yemen

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Abstract

Yemen is a country suffering water shortage. Therefore rainwater harvesting is a common practice since the antique. Ruins of dams and reservoirs as well as the unique, spectacular mountain terraces, confirm the long history of water harvesting. The great historical Marib dam and its collapse are mentioned in the Holy Koran. Recent archaeological excavations discovered ruins of irrigation structures around Marib city dating from the middle of the third millennium BC (some 4000 years ago). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement.

Villagers in the mountainous areas are well acquainted with ware harvesting systems for hundreds of years. They use the collected water for drinking, animal watering and supplementary irrigation particularly in the drier seasons. They mainly building cisterns to collect run off from clear and well selected catchment areas well away from the villages to prevent pollution. Old local manufactured material such as *Khadad* is used to cement the cisterns which proved to be of high quality and can withstand all environmental changes such as weather, rain, temperature, etc and can last longer periods. However, further research is needed on such material.

This study aims to describe the state of the art of water harvesting techniques in Yemen. Also, it emphasizes the integrated development of water resources in wadi systems, through the application and development of technologies. It based on real experimental applications and development initiatives. This study concludes by evaluating the approaches of applied methodologies for sustainable development of surface water recourses of wadis, the role of Rain Water Harvesting and the appropriate techniques and their relative viability. Viable techniques has identified and described in some details in order to facilitate and promote the transfer of experience and exchange of know-how in the Arab region.

Key words: water harvesting, spate irrigation, wadis, traditional techniques

INTRODUCTION

Yemen, historically, had one of the oldest civilizations in the Middle East based on agricultural development, in which the people of Yemen managed to establish the spectacular mountain terraces system on the steep slopes of the rugged mountainous areas, some thousands of years ago, in order to conserve soil and to optimize rainfall water use. Yemen depends on rainfall to cultivate and produce crops, so that Yemeni people cultivate their land under rainfall conditions at large scale, and they efficiently use and control flood water and spring water. Water rights of flood water and springs were well established and efficiently used to cultivate farmland according to its location from the source of water and to agreements between land owners. It (water right) became well-known among the people, due to continuous practices and/or according to written documents which were transferred from generation to generation till today.

For centuries, Yemen was self-sufficient in food production, both crops and animals production, and the surplus was exported to neighboring countries. Recently, changes have happened to the life style and consumption pattern of the increasing population, which in turn caused increasing demand on food, water and other daily requirements. These changes encouraged the people to turn to internal and external migration, which caused abandonment of terraces and their maintenance, as well as the absence of traditional cooperation among farmers due to migration of men and shortage of labor forces and increasing labor wages (MAI, 2000).

SOCIO-ECONOMIC FEATURES

Population: The total population is around 20.0 million (MPD, 2004), of which 74.4 % is rural. The average population density is about 31 inhabitants/km^2, but in the western part of the country the density can reach up to 300 inhabitants/km2 (Ibb province) while in the three eastern provinces of the country the density is less than 5 inhabitants/km^2. This is closely related to the physical environment. By far the largest part of the population lives in the Yemen Mountain area in the western part of the country, where rainfall is still significant, although not high in many locations. The hostile environment of the desert and eastern upland areas is reflected by low population density. The average demographic growth rate is estimated at 3.5%, which is very high.

Agriculture and economy: Agriculture contributes 21% to the Gross Domestic Product (GDP) in Yemen, employs 60% of the population, and provides livelihood for rural residents who constitute about 76%of the total population. Agriculture is characterized by low and uncertain crop yields due to drought, insufficient and erratic rainfall, declining soil productivity due to soil erosion and poor crop management practices, and crop losses due to damage by insects and diseases, and malnutrition resulting from inadequate supply of feed (Figure 1). Oil has been a main activity in the Yemeni economic. In 2000, Yemeni's oil production reached 143 million barrels at a total value of 412 billion Yemeni Riyals (around 68% of total state revenues).

Cultivated land has expanded from 1.21 thousand hectares in 1990 to 1.28 thousand hectares in 2005, an increase of14% of land for cereals crops, vegetables, fruit, cash crops and animal food.

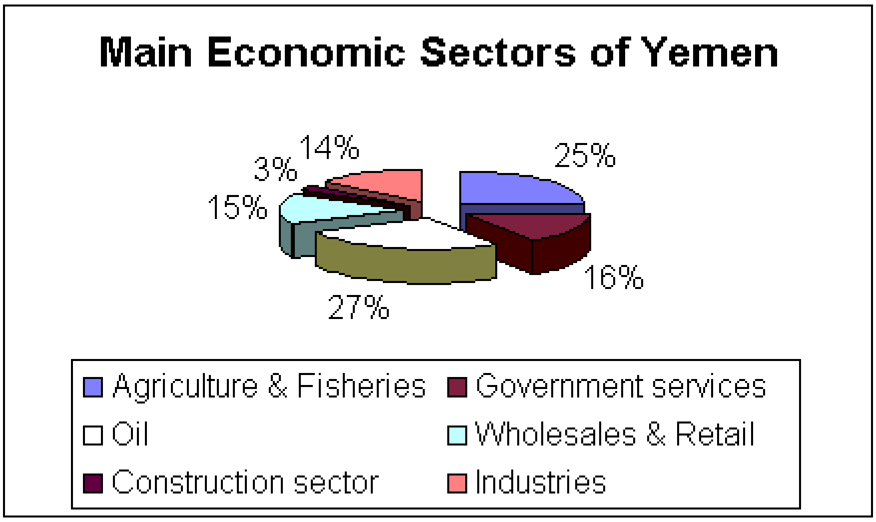

Fig.1 Main Economic Sectors in Yemen (MAI,200)

Land resources: Yemen is among the oldest countries in the world where land and water resources practices have been developed. Terraces erection, rainwater harvesting and dam irrigation techniques were developed since many countries ware trackless waste.

The cultivable land is estimated at about 1.67 million ha, which is 3% of the total area. In 1998, the total cultivated area was 1.28 million ha, or 68% of the cultivable area, of which 0.87 million ha consisted of annual crops and 0.41 million ha consisted of permanent crops. About 32 million ha is estimated as desert and rock outcrops, while range land are estimated to occupy 16 million ha including those areas which are covered by shrubs, perennial vegetation and grass. Only 1.5 million ha of the total area is considered as a forest and woodlands. (MAI, 2000).

Agroecological systems: Yemen is characterized by varieties of environmental zones. Since early 80s there were many attempts to classify the agroecological zones, occasionally by using the physiographic features and time to time by using landforms and climatological characteristics.

Recent demarcation of Agroecological zones in Yemen is not comprehensive, but the country could be divided into three major zones (Figure 5) derived from the five physical divisions these are:

The Coastal Region: This region includes the low coastal plains facing the Red Sea, the Gulf Aden and the Arabian Sea. Its is makes a coastal strip extending to the Omani border in the east towards the southwest to Bab al Mandab, and north wards to the Saudi border. It starches over an area 2000km long and 20-60km wide, with an altitude ranges 0-500m a. m. l. Many seasonally flowing wadis dissect the region. An arid sub-tropical climate dominates the region with average annual rainfall in the range of 50-300 mm. The climate becomes semi-arid subtropical in areas adjacent to the foothills of the western escarpment.

The Mountainous Region: This region includes the most complicated landscapes of the country. It is very irregular and dissected topography, with elevation varies from 500m at the foothills of its western and southern escarpments up to 3700m in the western peaks, then down to 1200m at its north-eastern escarpment. Due to this extreme physiographic diversity, differences in slope and location relative to the Red Sea, Gulf of Aden and Al Rub al-Khali, rainfall varies considerably within the region, with annual averages ranging from less than 300 mm to more than 1000mm. This region is divided into three main catchments, the western slopping towards the Red Sea, the southern towards the Gulf of Aden and the north-eastern towards the empty quarter (Al Rub al-Khali). The climate is characteristic of the semi-arid tropics, with limited areas of dry temperate intermountain plains at altitudes above 2000m.

Eastern plateau: This region is bordered by the mountains zone to the west, the southern coastal plains to the south and the Empty Quarter to the north. It covers vast expanses of sand desert and dissected plateau with elevation ranging from 500m on its northern and southern sides, to about 2400m on its western side. The average rainfall in this region is generally below 200mm, an arid sub-tropical climate dominates its major agricultural lands.

To show more detail with respect to aridity, a classification proposed by UNESCO (1979) can be used. It is based on the ratio between average annual precipitations (P) and annual reference evaporation (E), and in principle marks five different classes:

- hyper-arid	$P/E < 0.03$
- arid	$0.03 < P/E < 0.25$
- semi-arid	$0.25 < P/E < 0.5$
- subhumid	$0.5 < P/E < 0.75$
- semi humid	$P/E > 0.75$

Figure 2 shows the results of this classification. In terms of aridity, the climate in Yemen is shown to vary from hyper-arid (deserts, most of the plateaux, parts of the coastal plains) to subhumid (scattered wetter zones on the Western and Southern Slopes), with perhaps even humid sites on a very small scale in Ibb.

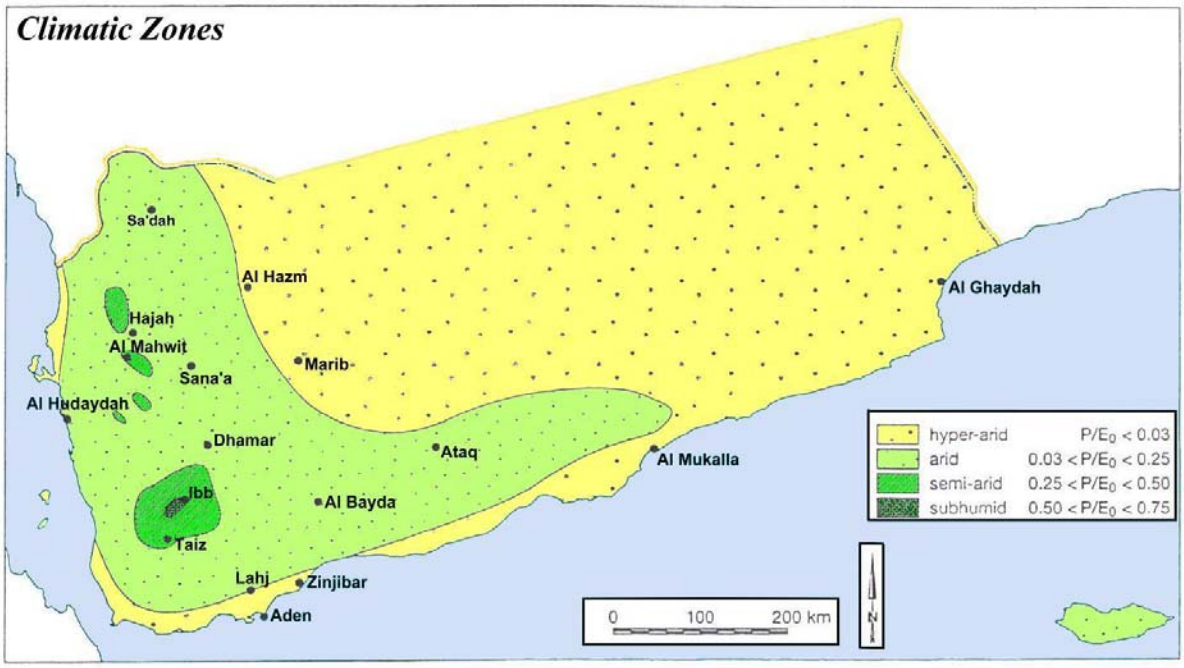

Fig. 2 Climatic zones in Yemen (Van der Gun,1995)

Land use: There is inventory of national land cover or land use, except for western northern governorate and of limited scattered areas. There is no clear boundary between land use and land cover in Yemen. Agricultural land consisting of arable land and land under permanent crops forms about 3% (of which about 450,000ha of mountain terraces is rainfed, 650,000 ha of relatively flatland in the inter-mountain region). Irrigated lands occupy some 489, 000 ha distributed as 98,000 ha spate irrigation, 28,000 ha spring irrigation and 363,000 ha well irrigation.

CLIMATE AND WATER RESOURCES

Climate: Yemen has a predominantly semi-arid to arid climate, with rainy seasons during spring and summer, and high temperatures prevail throughout the year in low-altitude zones.

The many different landscapes of Yemen can be grouped into five main geographical/ climatological regions (see figure 3):

- **The Coastal Plains:** The Plains are located in the west and south-west and are flat to slightly sloping with maximum elevations of only a few hundred meters above sea level. They have a hot climate with generally low to very low rainfall (< 50 mm/year). Nevertheless, the Plains contain important agricultural zones, due to the numerous wadis that drain the adjoining mountainous and hilly hinterland.
- **The Yemen Mountain Massif:** This massif constitutes a high zone of very irregular and dissected topography, with elevations ranging from a few hundred metres to 3 760 m above sea level. Accordingly, the climate varies from hot at lower elevations to cool at the highest altitudes. The western and southern slopes are the steepest and enjoy moderate to rather high rainfall, on average 300-500 mm/year, but in some places even more than 1000 mm/year. The eastern slopes show a comparatively smoother topography and average rainfall decreases rapidly from west to east.
- **The Eastern Plateau Region:** This region covers the eastern half of the country. Elevations decrease from 1 200-1 800 m at the major watershed lines to 900 m on the northern desert border and to sea level on the coast. The climate in general is hot and dry, with average annual rainfall below 100 mm, except in the higher parts. Nevertheless, floods following rare rainfall may be devastating.
- **The Desert:** Between the Yemen Mountain Massif and the Eastern Plateau lies the Ramlat as Sabatayn, a sand desert. Rainfall and vegetation are nearly absent, except along its margins

where rivers bring water from adjacent mountain and upland zones. In the north lies the Rub Al Khali desert, which extends far into Saudi Arabia and is approximately 500 000 km² in area. This sand desert is one of the most desolate parts of the world.

- **The Islands:** The most important of all the islands is Socotra, where more exuberant flora and fauna can be found than in any other region in Yemen.

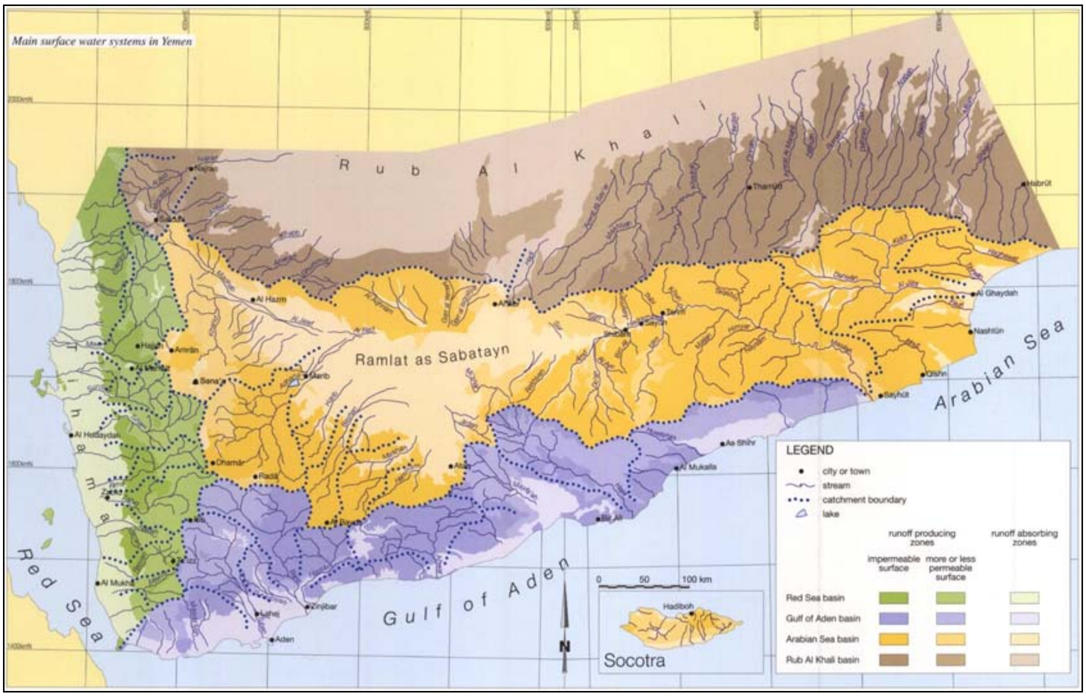

Fig. 3 Main geographical/ climatological regions (Van der Gun, 1995)

Rainfall: The climate of Yemen is strongly influenced by the mountainous nature of the country (van der Gun, 1995). Rainfall rises from less than 50mm along the Red Sea and Gulf of Aden coasts to a maximum of 500-800mm in the western highlands and decreases steadily to below 50mm inland (Figure 4).

The rainfall depends on two main mechanisms, the Red Sea Convergence and the Monsoonal Inter tropical Convergence Zone. The former influence is most noticeable in the west of the country, this is active from March to May and to some extent in autumn, while the latter reaches the country in July-September, moving north and then south again so that its influence lasts longer in the south. Seaward exposed escarpments such as the western and southern slopes receive more rainfall than the zones facing the interior. The average temperature decreases more or less linearly with the latitude.

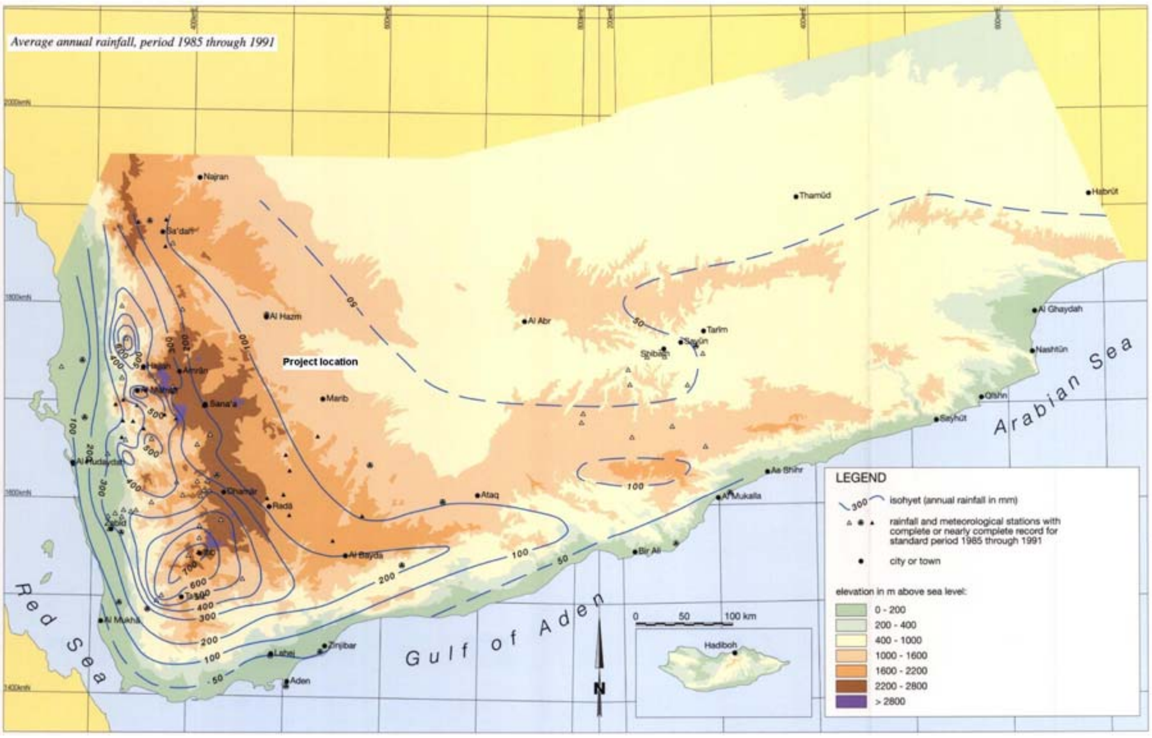

Fig. 4 Average monthly rainfall patterns for selected rainfall stations (Van der Gun, 1995)

Temperature: Average temperatures are dominantly controlled by elevation. There is an approximately linear relation, this relation is disturbed by the proximity of the sea in the coastal areas. Mean annual temperature range from less than 12.5ºC in the central highland to 30ºC in the coastal plains. However, the winter temperatures may decrease to freezing the highlands.

Evaporation and evaportranspiration: The penman method, Doorenbos and Pruitt (1984) version was used to calculate potential evaportranspiration. Table 4 presents the results in term of average annual totals. The annual totals range from 1579mm (Dhamar) and 3427mm (Al Jawf) for the meteorological stations considered. Thus factors other than average temperature must have a notable influence on the potential evaportranspiration variations. Analysis shows that quite a large part of the variation is explained by differences in wind speed, which possibly reflects local rather than regional effects.

In spite of all restrictions and inaccuracies, the data allow the following ranges for the annual Penman evportranspiration in different zones of the country to be indicated tentatively:

- Costal zones and foothills:	1800-2700 mm
- Mountain zones of Western Yemen	1500-2500 mm
- Arid zones of the interior	2000-3500 mm

Evaporation exceeds rainfall over most of the territory of Yemen this implies that except in some limited areas, soil moisture deficit prevails most of the year; evaportranspiration rates are usually far below their potential level, which my only be reached during and shortly after rainy spells. For such areas, reduction factors must be used when actual evaportraspiration is estimated from potential evaportranspiration may be close to the potential value.

Potential evaportranspiration is closely related to open water evaporation (as a first approximation it can be estimated at 70% to 80% of the evaporation rate). However, the actual evaportranspiration is substantially lower in Yemen, except in well-irrigated areas.

HISTORY OF WATER HARVESTING SYSTEMS IN YEMEN

In Yemen, ruins of dams and reservoirs as well as the unique, spectacular mountain terraces, confirm the long history of water harvesting. The great historical Marib dam and its collapse are mentioned in the Holy Koran. Recent archaeological excavations discovered ruins of irrigation structures around Marib city dating from the middle of the third millennium BC (some 4000 years ago). Farmers in this same area are still irrigating with floodwater, making the region perhaps one of the few places on earth where runoff agriculture has been continuously used since the earliest settlement (Bamatraf, 1994).

Recent studies in Yemen on water harvesting, (Tahir, 2002), indicate that villagers in the mountainous areas are well acquainted with ware harvesting systems for hundreds of years. They use the collected water for drinking, animal watering and supplementary irrigation particularly in the drier seasons. They mainly building cisterns to collect run off from clear and well selected catchment areas well away from the villages to prevent pollution. Old local manufactured material such as *Khadad* is used to cement the cisterns which proved to be of high quality and can withstand all environmental changes such as weather, rain, temperature, etc and can last longer periods. However, further research is needed on such material.

RAINWATER HARVESTING SYSTEMS IN YEMEN

Rooftop water harvesting systems

The roof water harvesting in Yemen has the advantage of being low cost, relatively simple in design (household technology), less laborious and it saves time. It provides adequate water during the rainy season, a period when the rural people are busy with farming activities. They are more appropriate in mountainous areas where there are no ground water sources, and where rainwater is the only feasible means of providing a water supply. In such areas it is difficult to think that communities can be served by a centralized water supply schemes which proved to be very expensive in terms of implementation, operation and maintenance. Other sources require long walk and time for women and children to fetch water. The quality of water is also reported as good compared to other water sources in the rural areas.

In Taiz Region, during the rainy season, roof water is collected in a dug-out structure, known as Seqaya. These structures are excavated into the hard rocks. In addition to roof water surface runoff is also collected into the hard rocks. Surface run-off is also collected into the dug-out structures for multifarious uses. In hilly areas of Al-Hujaria District, roof with provision of border-line lead pipe and outlet is common. The harvested rainwater, in turn, is guided to an underground storage tank through a settling tank for domestic use.

Terracing

Terraced mountain land in Yemen was continuously cultivated Early settlers of Yemeni mountain land faced an ambivalent situation. Rich soil derived from volcanic laves and pyroclastics were an asset, as were the spring and summer rains of the semiarid monsoonal climate. But where rainfall was highest, relief energy was also highest. With an amazing labor input, the settlers constructed millions of terraced fields on steep, rugged mountain slops and began simple, highly effective methods of harvesting rainwater (Bamatraf, 1994).

Rain water collects in the terraces and soaks into the shallow soil. Walls at the edge of the terraces prevent runoff form flowing down to the next terrace except during intense rainfall events. The walls of the terraces are built of stones, while voids between the stones allow water to move down to successive terraces without eroding the soil. Water can also move from level to level near the sloping bedrock. Subsurface drainage is required in these areas to channel flow from one terrace to the next trap fine sediment. They are designed and constructed in a manner to allow the passage of runoff through sheet flow, which prevents damage to the terraces from runoff concentrating at certain points. This method is effective if terraces are constructed in the upper parts of the wadi (see figure 5)

Fig. 5. Terraces on mountain slopes in the Yemen Highlands (Author)

Ponds

Farm ponds are small storage structures used for collecting and storing run-off water. As per the method of construction and their suitability for different topographic conditions farm ponds are classified into 3 categories, viz. Excavated farm ponds suited for flat topography, embankment ponds for hilly and rugged terrains with frequent wide and deep water courses; and excavated-cum-embankment type ponds. Selection of the location of the farm pond is dependent on several factors such as potentiality for yielding sizeable quantity of run-off, rainfall, land topography, soil type and structure, permeability/water-holding capacity, land-use pattern etc. Structurally, the excavated farm ponds could be of 3 types: square, rectangular and circular. All farm ponds must have the provision of removal of excess run-off water by providing 'drop inlet spill-way under normal condition' and 'emergency spill-way' to dispose off overflow of water after heavy rains. Such spill-way should ideally discharge into a grass waterway to avoid excessive erosion.

Cistern system

Karif or *Majel* is a local name for cistern in the mountainous area of Yemen (see figure 6). It is generally underground tank, constructed from masonry or concretes and usually covered and used for the collection and storage of surface run-off. This system of rainwater harvesting is also common in the rural areas of Botswana, Ghana, Kenya, India, Sri Lanka, Thailand and Indonesia. Water thus collected in is generally used for drinking and other domestic uses.

Fig.6 Traditional water harvesting cistern in Yemen

FLOOD WATER HARVESTING (SPATE IRRIGATION)

Flood water harvesting, known as ‘large catchment water harvesting’ or ‘Spate Irrigation’, is the simplest type of water harvesting, where cultivated areas lie within and immediately adjacent to an ephemeral stream or wadi. It is rations the occasional floodwaters form storms in the mountainous catchment areas to the coastal and foothill areas.

Traditionally, agriculture in Yemen has depended on dry farming using either rainfall or spate irrigation. Rained agriculture is practiced on terraces in most of the highlands, while spate irrigation is practiced along the wadi courses and coastal plains of Tihama and south and eastern parts of Yemen. More than 1.6 million hectares are regularly cultivated. Of the cultivated area, 50% is rain fed, 32% under well irrigation, and 18% under spate irrigation and base flow. Spate irrigation is widely used in Yemen for the production of major crops; A large portion of the cultivated area relies on spate irrigation. Figure 3 shows the irrigated area under floodwater harvesting in Yemen and other countries in North Africa and the Middle East, according to FAO (1997).

The country’s particular topographic structure affects and modifies the climate on a regional basis, especially rainfall distribution, and influences the availability of water for agriculture. The majority of Yemen consists of rugged terrain of igneous and metamorphic rock. Some areas receive rainfall in excess of 500 mm/yr. Extensive terracing is being practiced in the mountainous areas.

The hydrographic system of Yemen consists of rain fed watercourses (wadis) occasionally flooding but usually dry, draining from the main watershed along the three major escarpments. In the rugged slopes of the Western escarpment seven major wadis run toward the Red Sea, which they sometimes reach during periods of heavy rain. In the southern slopes the wadis of Tuban and Bana run, through a similar but less precipitous course, to the Gulf of Aden. Table 1 presents average of total annual flow at some selected wadi in Yemen.

Table 1. Mean catchment yield for gauged wadis in Yemen(Van der Gu, 1995)

Wadi Name	**Bana**	**Zabid**	**Surdud**	**Mawr**	**Adhana**	**Masila**	**Tuban**	**Jaza'a**
Catchment Area (km^2)	6200	4632	2370	7912	8300	22500	5060	15000
Average Annual flow (Mm^3)	169.9	125	69.3	162.3	87.5	51	109.4	60

The floods of the wadis in Yemen are generally characterized by abruptly rising peaks that rapidly recede. In between the irregular floods the wadis are either dry or carry only minor base flows. Surface water is considered to be an important source for irrigation in Yemen; it is estimated to be about 1,500 Mm^3/year. Several dams and dikes were built on many main wadis for the purpose of directing spate waters into man made spate irrigation systems. Cultivation of flood is carried out through the sources of water include either direct rainfall or flood water spate as seen in Plate 3. The flash flood, as it appears along the wadi banks, is diverted using temporary structures to small individual farmlands located along the wadi banks, and the diverted water is spread into the field as to irrigate crops.

TRADITIONAL SPATE IRRIGATION IN YEMEN

The fundamental feature of traditional spate irrigation systems in Yemen is the well-established principle which gives upstream irrigators priority rights to water abstraction over the downstream users. Once the upstream user has satisfied his needs, he has an obligation to release water downstream (Tahir et al, 1996). With traditional systems, modest and often temporary deflectors allow water to pass to lower off-takes, thus creating a perception amongst farmers, of a large degree of fairness in water utilization. During the early part of the season, one or two run-off irrigation improves the establishment of the crop stand and the last season runoff (three or four irrigation) will bring the crop to full maturity.

Spate systems are made in such a way that ideally the largest floods are kept away from the command area. Very large floods would create considerable damage to the command area. They would destroy flood diversion channels and cause streams to shift. This is where the ingenuity of many of the traditional systems comes in. Spurs and bunds are generally made in such a way that the main diversion structures in the river break when floods are too big. Breaking of diversion structures also serves to maintain the floodwater entitlements of downstream landowners. The structures can be classified as follows (Camacho, 1986).

Deflectors or (Al-Qaid): Low earthen bunds, protected with brushwood and stones from the wadi extend into the minor bed of the wadi at a acute angle to the bank (Figure 7); This structure built to divert water from the main wadi to agricultural lands in quantities proportional to the irrigated area and the size of the flood in the wadi.

High earthen bunds or (Ogma): Local farmers build an earthen bank or (Ogma) of wadi bed material across the low flow channel of the wadi, with the object of diverting the entire low stage of the spate flow to their fields. During a large spate, as there is no prevision for a spillway, the (Ogma) is either breached deliberately or it is over-topped and breaches as the flood rises. See (Figure 4).

Drop structures (Al Masaqit): These are built in spate canals when a channel has a steep longitudinal gradient, or the water is transferred from a high channel to lower one. The structure is built on a foundation of dry stone, occasionally mixed with a little concrete. The remaining part of the structure is constructed with stone interlocked properly, the gaps filled with smaller stone.

Spillways (Al Masakhil): The purpose of these structures is to control the quantities of water which enter the main spate canal. Al Masakhil is usually built on the earth embankment of the canals from medium size stone. The frame of the structure on both sides of the embankments goes down deep in to the foundation, so the supporting soil has no direct contact with the water.

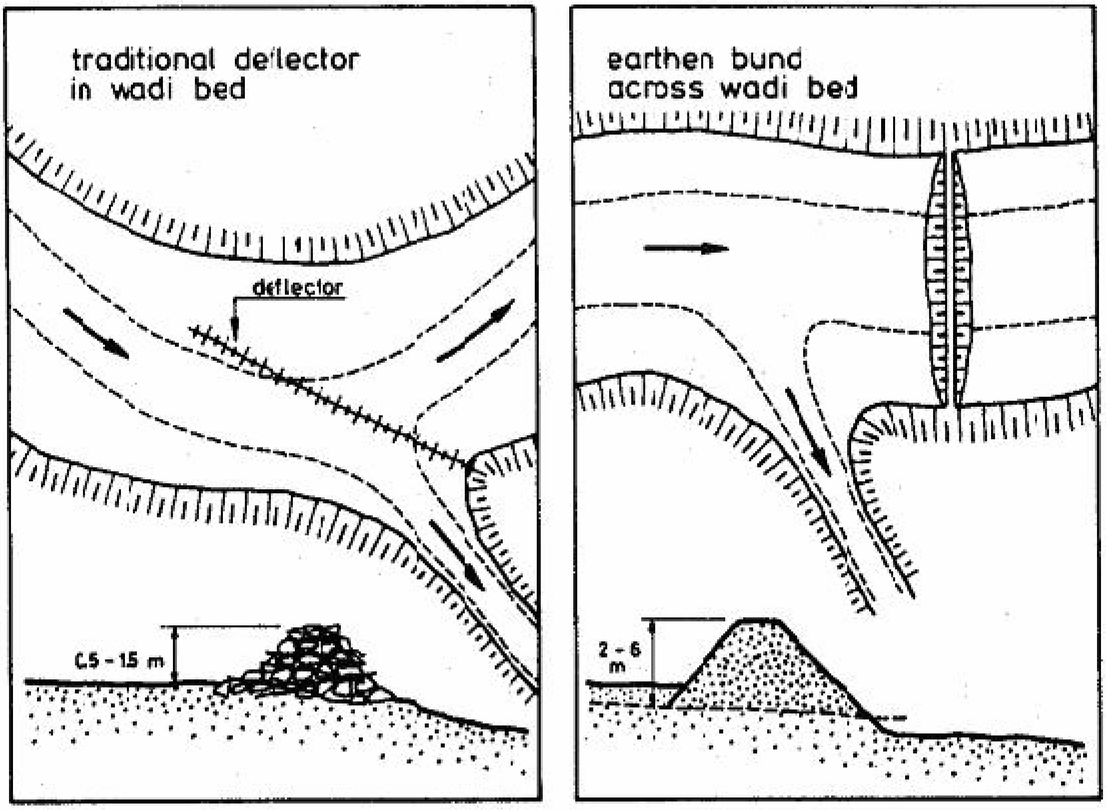

Fig 7 Schematic layouts of the traditional spate irrigation in Yemeni wadis (Oosterman, 1986)

TRADITIONAL LAW OF WATER RIGHTS

The traditional law of water rights in the mountain terraces is varying from area to area. There is one person in each area (call him AL-Moqadem), he is a local expert in these side and he know very will the area and the land owners. From the discussions with the farmers, the runoff water harvesting rights can be divided into two main parts;

- First of all when the farmer has own land as a catchments area for his terraces. He has shoos to utilize these runoff or to divert it to the down terraces. The farmer down dose not however have any legal rights to the runoff water and the farmer farther up may prevent him from receiving it.
- Secondly, when the farmers chare one catchments area together, for example natural rocky mountain; this catchments area divided between the farmers based on the area of the land owners. There are diverted channels for each land, and no body can divert runoff water from the other. When the flood occurs, the farmers drain the extra water from up terraces to down until the wadi bed. The main drainage canals should repairing and maintenance with cooperation all the farmers.

The runoff diverted by canals dose not have any legal right to cross land owned by another farmer. But in some places with the signed agreement between the farmers, there is a permeation to allow the diverted canals can a cross land owned by another farmer.

FUTURE ROLE OF WATER HARVESTING

Appropriate systems should ideally evolve from the experience of traditional techniques. They should also be based on lessons learned from the shortcomings of previous projects. Above all it is necessary that the communities appreciate the systems where they are introduced. Without popular participation and support, projects are unlikely to succeed. During recent years some developments took place in regard to water harvesting which might have some impact on the future role of water harvesting in general and may expand to other areas in the world:

Supplemental water system: Runoff water is collected and stored offside for later application to the cropped area using some irrigation method. The water stored allows a prolongation of the cropping season or a second crop.

Dual purpose systems: In a dual purpose system the runoff water flows first through the crop area then the excess water is stored in some facility for later irrigation use. In Arizona, USA, runoff irrigation was combined e.g. with trickle irrigation, using sealed soil surfaces to increase runoff rates.

Combined systems: If the irrigation water from aquifers or from rivers/reservoirs is not sufficient for year-round irrigation, a combination with runoff-irrigation (during the rainy season) is feasible. The combination of runoff- and furrow irrigation is reported from North Central Mexico (Frasier 1994).

Modeling: If more information on hydrological, soil and crop parameters is available, models can be developed and applied to water harvesting for certain environments.

Soil storage: The water is being stored in the soil profile. A high storage capacity of the soil (i.e. medium textured soils) and a sufficient soil depth (> 1 m) are prerequisites here (Huibers, 1985). The water retention capacity has to be high enough to supply the crops with water until the next rainfall event.

CONCLUSIONS

The following conclusions may be drawn:

- Appropriate systems should ideally evolve from the experience of traditional techniques - where these exist. They should also be based on lessons learned from the shortcomings of previous projects.
- Above all it is necessary that the communities appreciate the systems where they are introduced. Without popular participation and support, projects are unlikely to succeed.
- With the benefit of good maintenance, the terraces will continue to supply Yemeni households with productive crops. Neglect in the more marginal areas for food production means that uncontrolled runoff of rainfall and soil erosion can cause terrace collapse and food reduction.
- The government must strengthen rain fed agriculture and traditional methods of rainwater harvesting for agricultural and domestic use must be forced. These will increase expected returns on investment, particularly for food crops, and increase the willingness of landowners to invest in projects such as terrace maintenance
- Best use of available water resources
- Water harvesting increases groundwater recharge.
- It restores the productivity of land, which suffers from inadequate rainfall by increases yields from rain fed farming and runoff water collection and minimizes the risk in drought prone areas
- Water harvesting is considered as an alternative source for irrigation which reduces the dependency on groundwater
- Encourages the application of traditional techniques with possibilities for improvement according to the conditions of the project and enhances community participation and awareness.

RECOMMENDATIONS

The following strategies are suggested for sustainable use of water harvesting:

- Focus on small-scale water harvesting schemes that are now being promoted by NGOs.
- Involve the beneficiaries in the decision-making, planning, management and use of the available resources.
- There is rich indigenous knowledge in different parts of the Arab world and they should be researched and documented.
- Farmers need scientific and institutional support to start new projects
- Sufficient attention must be given to social and economic aspects.
- Learning from failures and successes, a high degree of sustainability might be reached.
- There should be cooperation between scientists and practitioners involved in water harvesting in the Arab countries and globally.
- Equal opportunities for of women and other disadvantaged farmers
- The relation between land tenure, water rights, and the introduced technologies should be carefully considered.
- No attempt is made to make an exhaustive list of the research needs. It merely brings together some suggestions to strengthen the studies on water harvesting. Existing studies on physical relationships should be complemented by studies on economic and policy implications of investments in the rural development of marginal lands. Studies are needed:
    1. On the extent to which traditional water harvesting systems can be used as a starting point for the new WH systems, and to evaluate the possibilities for optimizing water use efficiency.
    2. For the development of crops and crop species that produce well under conditions of limited water supply characteristic of WH systems in dry lands.
    3. On the hydrological behavior of small catchments and the development of simple and reliable methods for estimating runoff efficiency under a wide range of physical conditions and for variously sized catchments.
    4. On appropriate investment policies in harsh environments, where local populations are barely able to subsist without infrastructural interventions. These studies should assess the likely benefits in terms of economic, social, and environmental effects resulting from such investments. and finally

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