Indigenous Water-Harvesting Systems in West Asia and North Africa

Editors

Theib Oweis
Ahmed Hachum
Adriana Bruggeman

International Center for Agricultural Research in the Dry Areas

Indigenous Water-Harvesting Systems in West Asia and North Africa

Editors
Theib Oweis, Ahmed Hachum and
Adriana Bruggeman
ICARDA, Aleppo, Syria

International Center for Agricultural Research in the Dry Areas
ICARDA

Recommended Citation: Oweis, Theib; Ahmed Hachum and Adriana Bruggeman. (eds). 2004. Indigenous Water Harvesting Systems in West Asia and North Africa. ICARDA, Aleppo, Syria, vi+173 pp. En.

ISBN: 92-9127-147X

Cover: Indigenous water-harvesting systems in West Asia and North Africa.

Headquarters
International Center for Agricultural Research in the Dry Areas (ICARDA)
P.O. Box 5466, Aleppo, Syria
Tel.: (+963) (21) 2213433, 2225112, 2225012
Fax: (+963) (21) 2213490, 2225105, 5744622
E-mail: ICARDA@cgiar.org
Website: http://www.icarda.cgiar.org

Foreword

ICARDA launched a regional initiative on "On-Farm Water Husbandry in West Asia and North Africa (WANA)" in 1996. The objective of the program was to improve the rainwater-use efficiency in the drier environments through the integration of appropriate water-harvesting techniques and the conjunctive use of rainfall and other available water resources in the agricultural systems in the region. Egypt, Iraq, Jordan, Libya, Morocco, Pakistan, Syria, Tunisia, and Yemen participated in the project. The key themes of the project were:

1. Water use in the prevailing farming systems, the role of indigenous knowledge and end-users' perception and participation
2. Water resources and capture potential
3. Options for optimum use of water

Since the theme on indigenous water-harvesting systems was the focus of the participating countries, the project teams in member-countries developed studies on indigenous water-harvesting systems in their countries, the role these systems played in the past and the potential for their use in modern agriculture. A review of the country papers pointed to the need for systematically collecting and collating information on indigenous knowledge on soils, crops, water resources and socioeconomics, as part of a national inventory for potential development of water-harvesting systems and their integration into the *badia* ecosystems. One of the key findings of these studies, reported in this volume, is that traditional techniques are often most sustainable and environmentally friendly. The study teams recommend that these techniques be the basis for planning modern water-harvesting systems. Indigenous knowledge on water harvesting should be a part of an integrated land and water resources management approach, and should include improvements in agronomic practices and capacity building of farming communities.

The benefits of water harvesting are not only of economic value but also have social and environmental importance. The responsibility for the success of these projects should not be left to the farmers alone, but rather it should be a national responsibilty. There is a clear need to increase support to research on water harvesting systems and to ensure that improved techniques are widely adopted in the dry areas.

The aim of this volume is to encourage researchers and policy-makers to document and incorporate indigenous knowledge into their project proposals, feasibility studies, implementation plans and project assessments, and to take indigenous knowledge and practices into account in all activities affecting local communities. We hope the information provided here will be useful in learning from the past experience of farmers and making use of it in today's agriculture.

Prof. Dr Adel El-Beltagy
Director General

Acknowledgements

The editors would like to acknowledge the contributions of the teams of the countries that participated in the "On-Farm Water Husbandry in WANA" initiative. Thanks are also extended to Surendra Varma for his editorial touches to the final draft and supervising production, and his colleagues at ICARDA's Communication, Documentation and Information Services (CODIS), especially Wafa Meskine for layout and typesetting, and George Chouha for cover design and assistance with graphics. We are also grateful to Piero d'Altan at ICARDA's Geographical Information Systems (GIS) Lab for his final touches to some of the maps provided by the teams. We would like to thank SCRIPTORIA Academic English Editing and Writing Services for assistance with the editing of the document. Funds for this work were provided by the German Federal Ministry for Economic Cooperation and Development (BMZ).

Photo Credits

All photos were provided by the authors of the chapters. Photos for chapter 1 were taken by Theib Oweis, except for those on pages 5 and 8, which were provided by Akhtar Ali. Photos on pages 34, 43, 130, 131, 133 and 134 were also taken by Theib Oweis. Photos on pages 82, 83, 86 and 87 were provided by Piero d'Altan.

Contents

Chapter One

The Role of Indigenous Knowledge in Improving Present Water-Harvesting Practices

Theib Oweis, Ahmed Hachum and Adriana Bruggeman
Natural Resource Management Program, International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Background

There are various definitions of the term 'indigenous knowledge'. One such definition is: 'the unique, traditional, local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area' (Grenier 1998). Indigenous knowledge is also defined as 'the basis for community-level decision making in areas pertaining to food security, natural resources management, health, education and other vital socioeconomic activities' (Gorjestani 2001). It is a key element of the social capital of the poor, and constitutes their main asset in their effort to gain control of own lives (Gorjestani 2001).

Indigenous knowledge (also referred to as 'traditional' or 'local' knowledge) is based on experience, and is often tested over centuries and adapted to local culture and environment. Indigenous knowledge is dynamic and changing, and is an important part of the lives of the poor. It is inherent in food security, in human and animal health, education, and natural resource management.

Indigenous knowledge is, therefore, a cumulative body of knowledge ('know-how'), practices and manifestations maintained and developed by peoples with long histories of interaction with their natural environment. It is the basis for local-level decision making in many aspects of their life, especially for the poor, and provides problem-solving strategies for communities (World Bank 1998).

The dry areas of West Asia and North Africa (WANA) are very rich in traditional, ancient water-harvesting systems. These must have been built on a sound foundation of indigenous knowledge. Such traditional knowledge should be utilized in order to develop new practices, or to improve the efficiency of existing ones. Building on indigenous knowledge can be particularly effective in helping us reach the poor, since indigenous knowledge is often the only asset they control and is certainly one with which they are very familiar.

Indigenous knowledge helps to increase the sustainability of development efforts, because the integration of indigenous knowledge encourages mutual learning and adaptation which, in turn, contributes to the empowerment of local communities. Since efficiency, effectiveness and sustainability are key determinants of the quality of development work, there is a clear economic case for the harnessing of indigenous knowledge. Early indications point to significant improvements in the quality of development projects if indigenous knowledge is given leverage in the form of modern technology (Gorjestani 2001).

There should be no confusion of the terms 'knowledge' and 'information' or 'technology' and 'practice'. Where knowledge is related to accumulated community experience, information could only be a set of data on a specific situation or experiment. Knowledge and information are needed in order to develop useful technologies. Individuals have, over time, developed innovative technologies and practices that are based on indigenous knowledge. This is still happening today. Indigenous knowledge is a continuous source of innovative ideas, which are developed into both technologies and practices. However, the technologies and practices developed may not be as relevant when used under different conditions or at different times.

Although indigenous knowledge has proven its validity over the centuries, there are instances where scientific validation may be required before a practice based on indigenous knowledge is shared beyond its original context and location. Indigenous knowledge should, however, be used to help in the development of innovative solutions to the problems of a society. Such innovative solutions may be needed because existing contextual arrangements may not be applicable to the specifics of transposed indigenous knowledge. Indigenous knowledge is preserved through oral tradition and demonstration, and most often emerges gradually rather than in distinct increments.

One important characteristic of indigenous techniques is that, generally, they are sustainable and environmentally friendly. A good example of this is the *qanat* (a well-known indigenous technique in WANA) which is used to tap groundwater and transport it to the surface. The tunnel gradient of the *qanat* intersects the water table, and water flows out by means of gravity, without pumping or the aid of any mechanical device. If the surface of the groundwater (water table) drops, due to lack

The outlet of the qanat *in Shallalah Saghirah in northern Syria, which supports the village with sustainable water flow for domestic and agricultural use round the year.*

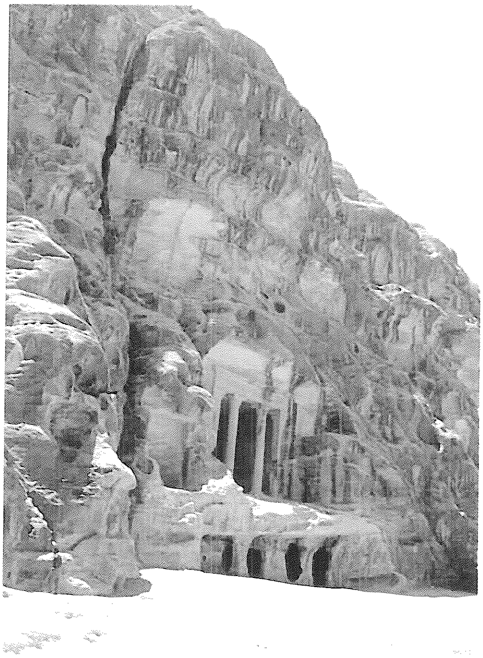
of replenishment or recharge, the outflow rate of the *qanat* decreases proportionally. Therefore, the *qanat* does not force more water out of the aquifer than the latter can safely yield, clearly demonstrating that sustainability is integral to such indigenous and environmentally friendly techniques.

The History of Water Harvesting

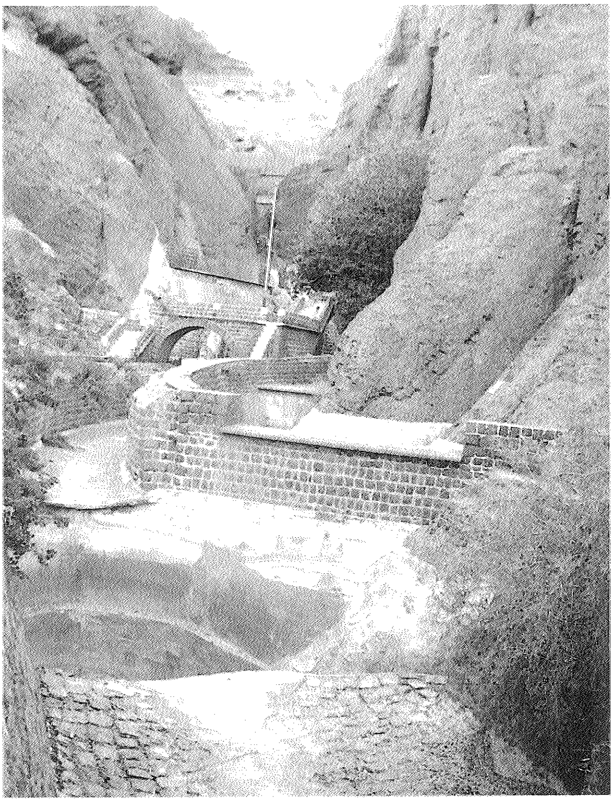
Life, as we know it, is not possible without water. Water is valued because it sustains life. Since the dawn of civilization, man has worked to make water serve him. He has been able to create gardens within deserts by means of intricate irrigation systems. However, when glistening salt covered the fields of ancient Babylon, the Hanging Gardens collapsed with it. Throughout history, man has struggled to survive in areas with limited water resources. The findings of numerous archaeological investigations, made all over the world, strongly indicate that man has long devised ways and means of harvesting (capturing and storing) rainwater, for use on crops or for supplying water to humans and animals.

Historically, agricultural methods using surface runoff and rainwater-harvesting techniques were first practiced extensively in WANA. Water-harvesting techniques are believed to have originated in Iraq, the cradle of agriculture, over 5000 years ago (Falkenmark et al. 2001). Water harvesting was also used in India and China more than 4000 years ago (Prinz 1996). Runoff originating from rainfall over a surface was collected and used for various purposes. To provide for future human water needs, such systems contained a storage facility to regulate the use of the collected runoff water. With the aid of water harvesting, farmers had practiced agriculture in areas with an annual rainfall of only 100 mm. The main reason for the development of water-harvesting techniques was the fact that alternative sources of water for drinking and irrigation were not available: it was then not possible to pump underground water reserves.

In southern Jordan, there are indications of early water-harvesting structures which, it is believed, were constructed over 5000 years ago (Oweis et al. 2001). Evidence also exists that simple water-harvesting structures were used in southern Mesopotamia as early as 4500 BC.



Water-harvesting reservoirs dug in the rocky mountains of Al Baida, near Petra in southern Jordan, over 5000 years ago.



The Sahārīj near Aden, southern Yemen was built in the first millenium 3000 years ago and still harvests rain water from the stony slopes and store for domestic use in the Kratter city.

Runoff agriculture in the Negev desert can be traced back as far as the 10th century BC. In Yemen, a system, dating back to at least 1000 BC, diverted runoff water in order to irrigate 20 000 ha, thereby producing agricultural products that may have fed as many as 300 000 people. In southern Tihama (Yemen) runoff agriculture was traditionally used for sorghum production, while in Baluchistan (Pakistan) the *Khuskaba* and *Sailaba* systems were applied in ancient times, and are still in use today (Oweis et al. 2001).

Before the Roman era, water-harvesting techniques were applied extensively in North Africa. Archaeologists have revealed that the wealth of the 'granary of the Roman Empire' was largely based on runoff agriculture (Oweis et al. 1999). In Morocco's Anti-Atlas region, a great variety of harvesting techniques still exist. In Tunisia, the *Meskat*, the *Jessour* and the *Mgoud* water-harvesting systems have a long tradition, and are still practiced today. In Egypt, the north-west coast and the northern Sinai areas have a long tradition of cistern use and *wadi-bed* runoff cultivation.

There is uncertainty as to why most of these water-harvesting systems were abandoned. Possibly the conveyance systems became clogged with silt, or were destroyed by heavy floods caused by exceptional storms. Or, possibly, the associated cropped land became degraded as a result of salinity. It has also been claimed that the technological innovations of the 20th century (which have allowed groundwater to be lifted, and large water conveyance and distribution systems to be built) have caused a decline in those ancient systems. It has also been speculated that some form of political instability, or perhaps climatic change in the area, forced the abandonment of these systems (Falkenmark et al. 2001).

Examination of ancient water-harvesting systems has revealed that they possessed two main features. Firstly, they were extremely flexible. Secondly, they were remarkably enduring. Their flexibility is demonstrated by their easy integration with other resource-use systems, as well their widespread adoption by diverse cultural groups in various parts of the world. Their enduring qualities are reflected by the antiquity of their use and their capacity to persist in the face of abrupt social change.

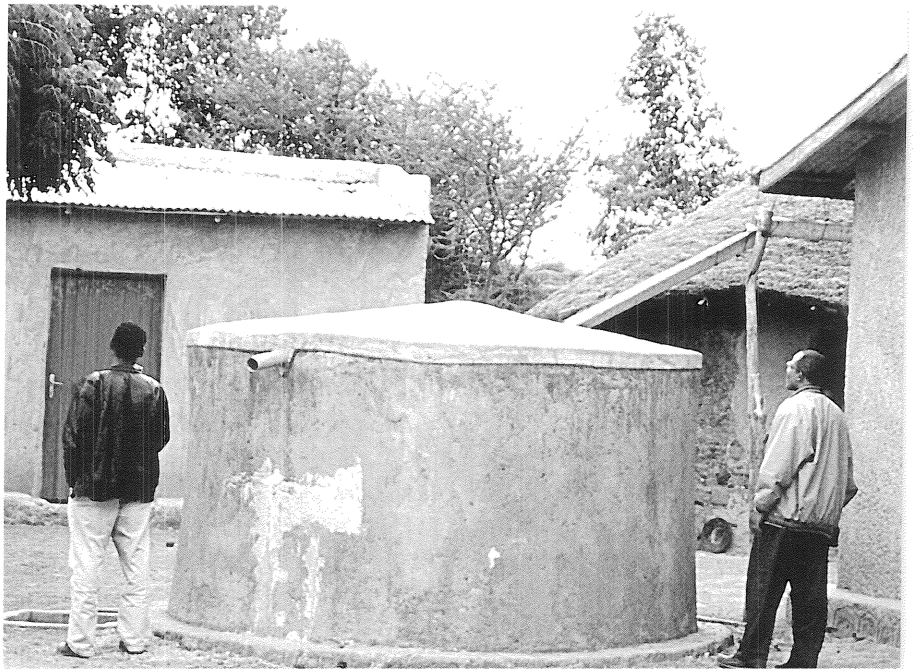
Apart from the modern water-harvesting techniques that have been recently introduced into the region, all the indigenous water-harvesting systems used in WANA evolved over the centuries, according to the dictates of agro-ecological and socioeconomic factors, and because of modifications made as a result of the experience gained by people in each country. The similarity of the techniques used in most countries in WANA is no more than a reflection of similarities in terms of their climates, edaphic conditions and socioeconomies.

Revived Interest in Water Harvesting in Dry Areas

In the past, in many places, water harvesting was the only method by which people could obtain water. The survival of communities was based on it. Therefore, people adopted these systems, which had previously been developed by others, and used them very successfully.

With technological development during the industrial age, it became possible to access water from remote areas through long and intricate conveyance systems and by pumping groundwater. This reduced dependence on water harvesting in many areas. However, with water scarcity increasing in the drier environments, the need to utilize rainwater is increasing.

A recent change has been the growth of political interest, in many countries, in promoting the increased agricultural use that is being made of areas with a low or erratic rainfall. Naturally, agricultural development, whether at the scale of an individual farm or a whole country, takes place first on the best land. When there is a need to increase agricultural production, efforts are usually directed towards maxi-



Rooftop rainwater harvesting is an ancient practice for domestic and livestock use. In many areas, like this one in Ethiopia, people still use it as the only source of water.

mizing production in areas with the best potential. However, as demand increases for products derived from the land (for food, fuel, shelter and clothing) it is necessary to make increasing use of land which is less suitable for agriculture, or of land in less favorable climatic zones.

In the past, agricultural research and development has placed emphasis on making the best use of good soils and good climates, with little attention being given to marginal environments. This has resulted in a lack of information about less favored dry areas. In the dry regions, fewer soil surveys have been undertaken to show what resources are available, and less research has been conducted on the physical and chemical properties of soils, to show their capabilities and identify any problems.

The two key features that adversely affect agriculture in drier areas are low and unreliable rainfall. These two factors are linked, and this compounds the problem: variability increases as mean rainfall decreases. Low rainfall is the cause of several constraints. Indeed, cropping may either be impossible, or only possible if special techniques are used (such as fallows, or furrows) to collect rain.

One of the main reasons for the opening up of areas previously considered too dry for arable farming has been the development of 'new' techniques (such as improved water-harvesting techniques). Early water-harvesting techniques made it possible to cultivate arid and semi-arid areas which might otherwise not have supported farming or permanent settlements. Their capacity to make the difference between effective agricultural occupancy and less intensive non-agricultural land use has been widely recognized.

The revival of interest in water harvesting is attributed to huge problems that have accrued due to long periods of drought since the 1970s, as well as to the current acute water shortage in the region and to an increasing demand for food and fiber as the result of a population explosion. Also, the use of modern technologies for water abstraction and diversion, particularly from groundwater aquifers, is damaging in its over-exploitation of limited natural resources. These practices severely endanger the sustainability of such development. Indigenous techniques of water control and utilization are, by their nature, environmentally friendly and thus sustainable.

Ancient water-harvesting techniques are rapidly being plucked from antiquity. However, the reuse of old knowledge is not only a question of technology and engineering (Oweis et al. 1999). Water harvesting is a practice related to local community needs and is vulnerable to changes in local ecologies. The transition from a top-down, imposed agricultural development approach, to the progressive adoption of a community-based participatory approach is favored as the most effective, promising strategy with regard to the development and implementation of a wide range of farm water-harvesting techniques all over the WANA region.

However, an evaluation of the adequacy of water harvesting must recognize its vulnerability to seasonal fluctuations in rainfall. Water harvesting was not foolproof and could result in crop failures. This fact must have compelled ancient cultivators to integrate their water-harvesting practices with other water management techniques. However, the possible shortfalls of such techniques are outweighed by their potential usefulness, as there is a wide range of evidence available to show that the natural resources of the arid and semi-arid regions are suffering increasing damage as they face increasing demands and pressures.

Water resources in WANA are very limited. What is more, demand for water in all sectors is growing rapidly as a result of population increases and improved standards of living. Because of this, the water situation is becoming critical in many countries of the region, which are falling far below the water poverty limit. ICARDA is taking the lead and assuming responsibility by responding to this situation: several initiatives now underway are aimed at improving the efficiency with which existing water resources are utilized, as well as searching for new ones (Oweis and Hachum 2003).

How Indigenous Knowledge Can Help

Water is the natural resource which most limits development in the dry areas. In addition to being scarce, water is poorly distributed in such areas and often comes in intense bursts, resulting in surface runoff and uncontrolled rill and gully water flow. Due to uncontrolled runoff, the land is deprived of its share of rainwater and growing plants endure periods of severe moisture stress. This significantly reduces yield, if any is produced.

The rainwater that runs off the land joins streams, and may cause substantial gully erosion. If not intercepted, it flows into depressions where it often loses its good qualities and evaporates. Rainwater productivity is extremely low in the WANA areas. Intervention, in the form of the capture and efficient use of rainwater, is vital if agricultural production and farmers' incomes are to be improved and desertification in these areas is to be combated (Oweis et al. 1999).

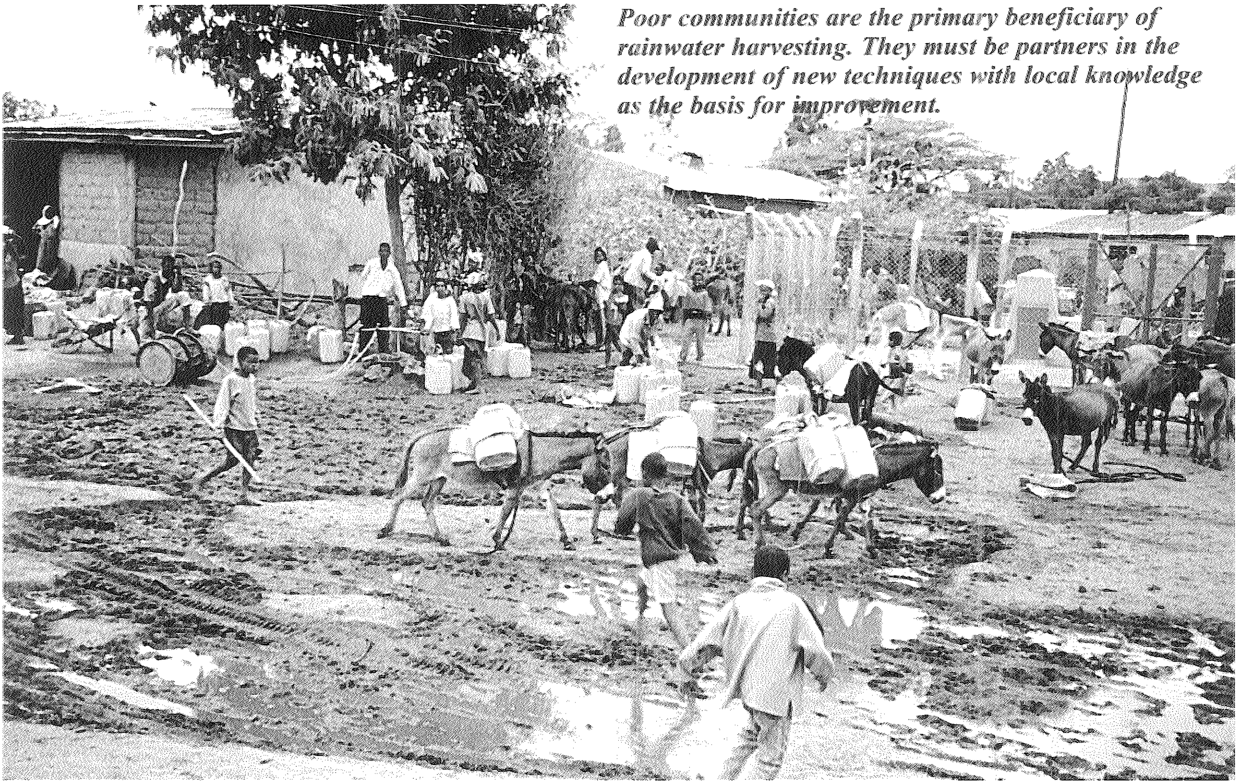
Water harvesting is based on the principle of depriving (naturally or artificially) part of the land of its share of rain (which is usually not used productively) and adding it to another part. This brings the amount of water available to that land closer to the crop's water needs, and so permits economically viable agricultural production. For example, a field receiving 200 mm of annual rainfall cannot normally produce an economically viable crop. If the rainfall on one half is diverted to the other half, then the second half will have a total of 400 mm, which is enough to support economically viable agricultural production. Of course, in reality, only a portion of this water may be harvested easily and at a low cost. Such concentration of rainwater is called water harvesting, and we define this here as 'the process of concentrating precipitation through runoff and storing it for beneficial use.'

When harvesting water, hillsides may be treated to stop runoff and soil erosion. Intervening structures built on the slope collectively recharge the area's groundwater; causing the water table in the wells to rise. Seasonal runoff from the developed catchment significantly decreases. Most of the rainwater is captured and used beneficially to increase plant production and improve the livelihoods of the poor in such areas. Therefore, water harvesting is particularly advantageous in the following cases:

- In dry environments, where low and poorly distributed rainfall normally makes agricultural production impossible. Provided other production factors such as soils and crops are favorable, water harvesting can make farming possible despite the absence of other water resources.
- In rainfed areas, where crops can be produced, but with low yields and a high risk of failure. Here, water-harvesting systems can provide enough water to supplement rainfall and so increase and stabilize production.
- In areas where the water supply for domestic and animal production is not sufficient. These needs can be satisfied with water harvesting.
- In arid land suffering from desertification, where the potential for production is being lost because of a lack of proper management. Providing water to these lands through water harvesting can improve the vegetative cover and can help to halt environmental degradation.

The specific benefits listed above lead to many other indirect but tangible socioeconomic gains. These include the following: (1) stabilization of rural communities; (2) reduced migration of rural people to cities; (3) use and improvement of local skills and (4) improvements in the standard of living of millions of poor people living in drought-stricken areas.

However, the problem we face is that of encouraging the adoption of these systems by farmers and communities. Many cases show that, once a project is



Poor communities are the primary beneficiary of rainwater harvesting. They must be partners in the development of new techniques with local knowledge as the basis for improvement.

implemented, it is difficult to maintain farmers' interest. Indigenous knowledge could help in making these systems more attractive to people. Adoption criteria should include issues such as the biophysical preconditioning of system function, as well as socioeconomic considerations, market issues, land tenure, legislation and human capacity. Water harvesting is a good example of rural development in which indigenous knowledge is blended with external knowledge and investment.

There are several reasons for the lack of enthusiasm of farmers and communities show towards water harvesting:

- The benefits obtained by implementing water-harvesting techniques are more indirect than direct. Indirect benefits include environmental, social and national benefits, whereas direct benefits are only felt by the farmer. However, it is not possible to justify projects based only on direct benefits.
- Land ownership in many areas does not help this type of development.
- Government policies are not enough to encourage this type of development. Usually only passive measures are taken to protect the environment, with no progressive means of implementing them to help communities increase their income. For example, most policies currently in place in the region prohibit the plowing of *badia* land as a safety measure against desertification and land degradation.
- Though water harvesting is a low-external-input technology, it still requires some input in terms of construction and maintenance.

Relevant Water-Harvesting Systems in WANA

As water harvesting has been practiced for many millennia in most dry areas of the word, a large number of different techniques have been developed. Most of the techniques are intended to provide water for irrigation purposes, while others are concerned with human and animal water consumption. Some techniques may have different names in different regions. Others may have similar names but, in practice, are completely different. However all water-harvesting systems must have the following three components:(1) The catchment area, which is the part of the land that contributes some or all of its share of rainwater to another area outside its boundaries. The catchment area can be as small as a few square meters or as large as several square kilometers. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road. (2) The storage facility, which holds runoff water from the time it is collected until it is used. Water can be stored in surface reservoirs, subsurface reservoirs (such as cisterns), in the soil profile (such as soil moisture), and in groundwater aquifers. (3) The target area, which is where the harvested water is used. In agricultural production the target of such systems is plants or animals, while in domestic use it is the human beings or the enterprise and its needs.

There are several classifications of water-harvesting methods, mostly based on the type of use or storage; but the method most commonly used is based on the size of the catchment. A simplified classification is shown in Fig.1.1.

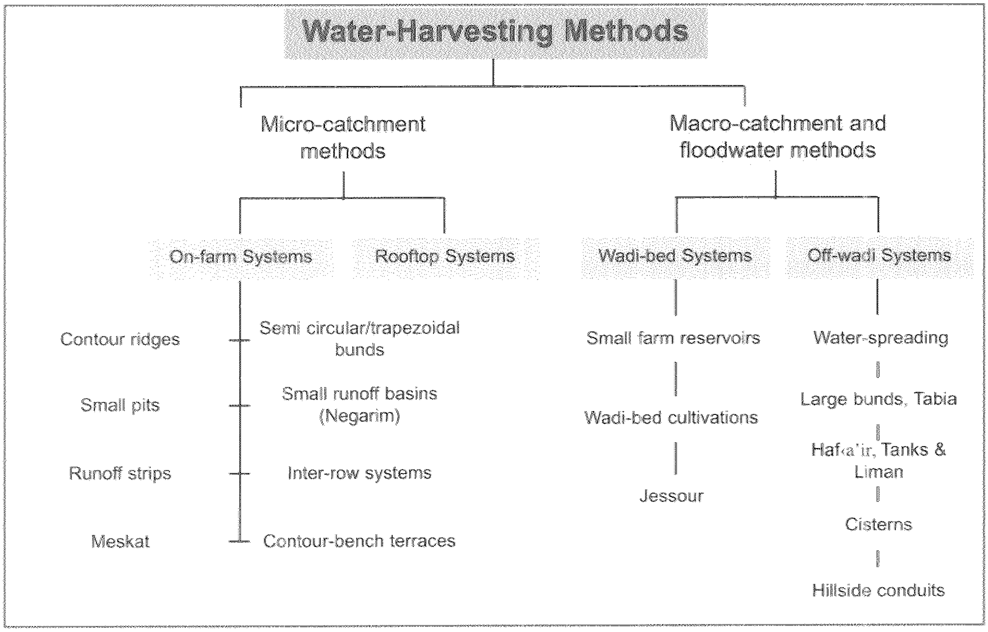


Fig. 1.1. Classification of water-harvesting systems. After Oweis et al 2001.

Micro-catchment Systems

Micro-catchment systems are those in which surface runoff is collected from a small catchment area where sheet flow prevails over a short distance. Runoff water is usually either applied to an adjacent agricultural area (to be stored in the root zone and used directly by plants) or stored in a small reservoir for later use (Fig. 1.2). The target area may be planted with trees, bushes or with annual crops. The size of the catchment ranges from a few square meters to around 1000 m^2. The catchment surface may be natural, cleared, or treated in order to induce runoff when soils are light, and can include the rooftops of buildings, and court-yards and similar impermeable surfaces.

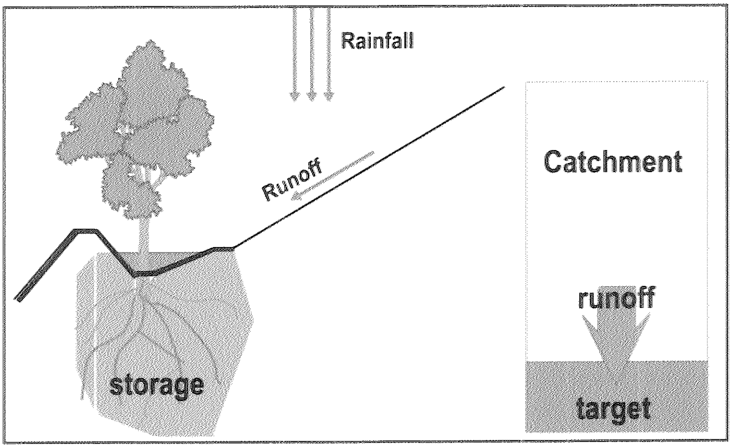


Fig. 1.2. Schematic of micro-catchment water-harvesting systems. After Oweis et al 2001.

Micro-catchment systems are simple in design and may be constructed at a low cost. Therefore, they are easy to replicate and adapt. They have a higher runoff efficiency than the macro-catchment systems, and usually do not need a water conveyance system. Soil erosion may be controlled and sediment directed to settle in the cultivated area.

There exist micro-catchment techniques suitable for use with any slope or crop. The farmer has, within his farm, control over both the catchment and the target areas. This is not usually possible in the case of macro-catchment systems.

All the components of the system are constructed within the boundaries of the farm. These components are usually used for agriculture and are simple, low in cost and practical. However, the catchment in this system occupies part of the farm area, and only in drier environments will a farmer accept the allocation of part of his farm to the catchment. These systems generally require continuous maintenance, with relatively high labor input. The most important micro-catchment water-harvesting systems in the dry areas of WANA are discussed below.

Contour ridges

These are bunds, or ridges, usually constructed along the contour line at an interval of between 5 and 20 m. A one- to two-meter strip upstream of the ridge is cultivated: the rest constitutes the catchment. The height of the ridges varies according to the slope and the expected depth of the runoff water retained behind it. The bunds may be reinforced by stones when necessary. This is a simple technique, which can be implemented by the farmers themselves. Bunds can be formed manually, using animal-driven equipment, or by tractors fitted with suitable implements. Ridges may be constructed on a wide range of slopes, from 1% to 50%.

Contour ridges are one of the most important techniques for supporting both the regeneration of and new plantations of forage, grasses and hardy trees on mild to steep slopes in the steppe (*badia*). In the semi-arid tropics, they are used for the arable cropping of sorghum, millet, cowpeas and beans.

A special form of contour ridge may be constructed on gentle slopes using stone bunds (i.e., permeable structures). These only slow down sheet flow, allowing increased infiltration. If earth is excavated and added to the upstream side, it acts as an impermeable contour ridge. In the semi-arid tropics, this system is sometimes combined with other techniques (such as the *zay* system—see 'Small pits' below) or with *in-situ* water conservation techniques (such as the tied-ridge system). These systems can only be used if stone is available nearby.

Contour ridges supporting shrubs at ICARDA research station, Tel Hadya, northern Syria.

Semi-circular and trapezoidal bunds

Semi-circular and trapezoidal bunds usually consist of semi-circular, crescent or trapezoid earthen bunds facing in the direction of maximum slope. They are created with a spacing sufficient to allow a catchment area large enough to provide the required runoff water for the plants behind the bund. Usually, they are built in staggered rows.

Semi-circular bunds are suitable for fruit trees and shrubs in the drier environments.

The diameter or the distance between the two ends of each bund varies between 1 and 8 m and the bunds are 30 to 50 cm high. Cutting soil immediately upstream creates a slight depression in which runoff is intercepted, to be stored in the plant root zone. Soil cut upstream increases the slope and hence the runoff coefficient. This allows the technique to be used on flat terrains, but it can also be used on slopes up to 15%. The technique is mainly used for rangeland rehabilitation or fodder production, but can also be used to grow trees, shrubs and, in some cases, field crops (e.g., sorghum) and vegetables (e.g., watermelons).

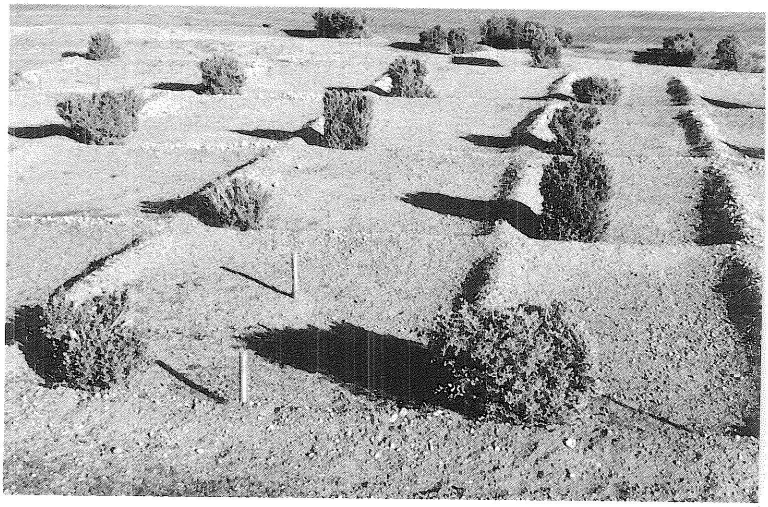
Small pits

Pitting is a very old technique, mainly applied in Western and Eastern Africa, though it has been adopted in some WANA areas. The pits are 0.3 to 2.0 m in diameter. The most famous pitting system is the *zay* system used in Burkina Faso. This form of pitting consists of digging holes 5–15 cm deep. Manure and grasses are mixed with some of the soil and put into the *zay*. The rest of the soil is used to form a small dike, downslope of the pit. Pits are used in combination with bunds to conserve runoff, which is slowed down by the bunds. By applying this system, much degraded agricultural land can be put into use again.

Small pits are being made in the Syrian badia *for reseeding of grasses and shrubs.*

Pits are excellent for rehabilitating degraded agricultural lands. However, labor requirements for the digging of the *zay* are high, and may constitute a large financial investment, not only in the first year but also in subsequent years. This is because the pits have to be restored after each tillage operation. A special disk-plow may be adjusted to create small pits for range rehabilitation.

Small runoff basins


Small runoff basin water-harvesting at ICARDA station, at Tel Hadya, in Aleppo, Syria.

Sometimes called '*negarim*', these runoff basins are small, and have a rectangular or elongated diamond shape. They are surrounded by low earth bunds, and are oriented so that the maximum land slope lies parallel to the long diagonal of the diamond, so that runoff can flow to the lowest corner, into which the plant is put. *Negarim* work best on smooth ground, and their optimal dimensions are 5–10 m in width and 10–25 m in length. They can be constructed on almost any slope, including very gentle ones (1–2%); but, on slopes of more than 5%, soil erosion may occur: bund height should then be increased. They are most suitable for growing tree crops such as pistachio, apricots, olive, almonds and pomegranates, but may be used for other crops, too. When used to grow trees, the soil should be deep enough to hold sufficient water for the whole dry season.

Runoff strips


Runoff strips water-harvesting supporting cereals and legumes at research station at Tel Hadya, Aleppo, Syria.

This technique is applied on gentle slopes and is used to support field crops in drier environments (such as barley in the *badia*), where production is usually risky or has a low yield. In this technique, the farm is divided into strips which follow contour lines. One strip is used as a catchment while the strip downstream is cropped. The cropped strip should not be too wide (1–3 m), while the catchment width is determined with a view to providing the required runoff water to the cropped area. The same cropped strips are cultivated every year. Clearing and compaction may be undertaken to improve runoff.

Contour bench terraces

Contour bench terraces are constructed on very steep sloping lands, and combine soil-and-water conservation and water-harvesting techniques. Cropping terraces are usually built to be level. Supported by stone walls, they slow down water and control erosion. They are supplied with additional runoff water from steeper, non-cropped areas between the terraces. The terraces are usually provided with drains to safely release excess water. They are used to grow trees and bushes, but are also used for field crops.

Ancient contour bench terraces supporting coffee and* qat (Catha edulis) *trees in the mountains of Yemen.

Good examples of this technique are provided by the historic bench terraces in Yemen. Since they are constructed in steep mountain areas, most of the work is done by hand (manual labor). They therefore involve high construction and maintenance costs.

Rooftop systems

Rooftop and courtyard systems collect and store rainwater from the surfaces of houses, large buildings, greenhouses, courtyards and similar impermeable objects. Most of the rain can be collected and stored. Farmers usually avoid storing the runoff provided by the first rains in order to ensure cleaner water for drinking. If water is collected from soil surfaces, the runoff has to pass through a settling basin before it is stored.

The water collected using this technique is used mainly for drinking and other domestic purposes, especially in rural areas where there is no tap water. Extra water may be used to support domestic gardens. It provides a low-cost water supply for humans and animals in remote areas. Although this technique is used mainly for domestic purposes, it can also be used in agriculture. Rainwater may be harvested from the greenhouse roof and used to irrigate the plants within.

Macro-catchments and Floodwater Systems

Macro-catchment and floodwater-harvesting systems are characterized by the use of runoff water collected from a relatively large catchment (Fig. 1.3). Often the catchment is natural range, steppe land, or a mountainous area. Catchments for these systems are mostly located outside farm boundaries, where farmers have no control over them.

Macro-catchment systems are sometimes referred to as systems that involve 'water harvesting from long slopes' or 'harvesting from an external catchment'. The predominance of turbulent runoff and channel flow in the catchment water in macro-catchment systems contrasts with the sheet or rill flow that is found in micro-catchments.

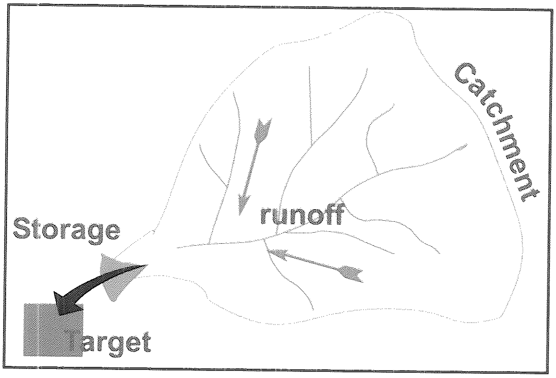


Fig 1.3. Schematic diagram of a typical macro-catchment water-harvesting system. After Oweis et al. 2001.

Generally, runoff capture—per unit area of catchment—is much lower than for micro-catchments, ranging from a few percent to 50% of annual rainfall. Water is often stored in surface or subsurface reservoirs, but may also be stored in the soil profile for direct use by crops. In some cases, water is stored in aquifers: in effect, this acts as a recharge system. The cropping area is either terraced on gentle slopes or located on flat terrain.

One of the most important problems associated with these systems involves water rights and the distribution of water, both between the catchment and cultivated areas and between various users in the upstream and downstream areas of the watershed. The best solution to all these problems is to plan the interventions made within an 'integrated watershed development' approach.

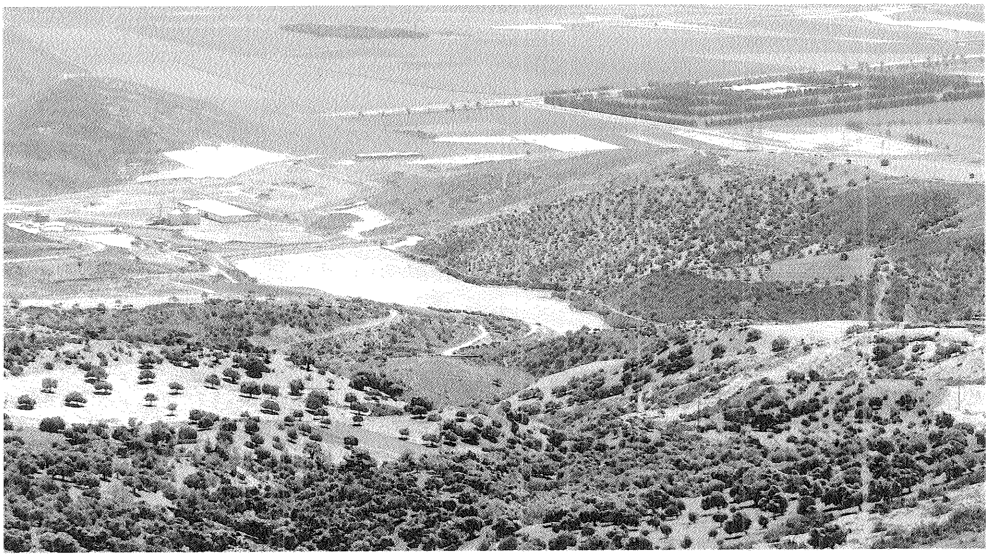
Large macro-catchment systems are called 'floodwater-harvesting systems'. Based on the location of the target area relative to the *wadi* bed, two types of macro-catchment and floodwater systems are distinguished: *Wadi*-bed systems and off-*wadi* systems.

Wadi-bed systems

In the *wadi*-bed (the bed of an ephemeral stream) system, the *wadi* bed is used to store water, either on the surface (by blocking the water flow) or in the soil profile (by slowing down the flow and allowing it to infiltrate the soil). The *wadi*-bed systems discussed below are those found to be the most suitable for the dry areas of WANA.

Small farm reservoirs

Individual farmers or groups of farmers who have a *wadi* passing through their lands can build a small dam, if a suitable location exists, to store some or all of the runoff water in the *wadi*. The water can subsequently be used to irrigate crops, or for domestic and animal consumption. These reservoirs are usually small, but



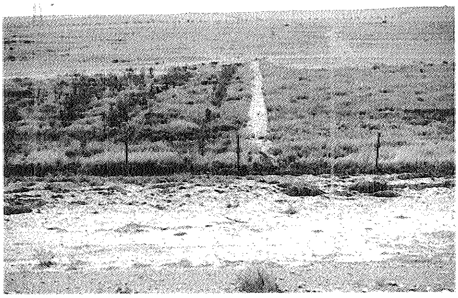
Small farm-water-harvesting reservoir for supplemental irrigation of field crops in Turkey.

may range in capacity from 1000 to 500 000 m^3. Assistance may be needed from an engineer to plan, design and build the dam.

The most important aspect of this system is the provision of a spillway with sufficient capacity to allow for the excessive peak flows that may pass through the *wadi*. Most of the small farm-reservoirs built by farmers in the rangelands (*badia*) have been washed away, either because they lacked spillway facilities or because their spillway capacity was insufficient.

Small farm-reservoirs are very effective in the *badia* environment. They can supply water to crops and livestock, thus improving and stabilizing the livelihood of local communities. Moreover, the benefits to the environment are substantial.

Wadi-bed cultivation



A* wadi *bed system in the Jordan* badia *called* 'marab' *supported by stone walls for fruit trees and rangeland.

Cultivation is very common in *wadi* beds with slight slopes. Due to slow water velocity, eroded sediment usually settles in the *wadi* bed and creates good agricultural lands. This may occur naturally or as the result of the construction of a small dam or dyke across the *wadi*, in order to slow the flow velocity and allow soil sediment to settle. For preference, *wadi* cross walls should be made permeable, out of stone or gabions, and should be no higher than one meter. This technique is very commonly used with fruit trees (such as figs, olive, and date palm) and other high value crops. This is because the soil in a *wadi* bed is usually fertile and a water supply is reasonably certain. The technique can also be helpful for improving rangelands on marginal soils.

The main problems associated with this type of water-harvesting system are the costs of building and maintaining the walls. Another problem, which has recently appeared in some WANA areas with increased development in the catchment area, is that of less runoff water reaching the *wadi* beds. This has resulted in most of the downstream cultivation areas becoming water-stressed, and has necessitated the development of an integrated watershed development plan.

Jessour

Jesr is an Arabic term given to the widespread indigenous use of walls built across relatively steep *wadis* in southern Tunisia. The walls are usually high, since the slope is steep. They are made either of earth or stone, or of both combined, and always have a spillway—usually made of stone. Over a period of years, while water is stopped by these walls, sediment settles and accumulates, creating new land which is planted with figs and olives, but which may also be used for other crops.

This system is similar to *wadi*-bed cultivation, except that it is practiced on steep *wadi* beds and includes a spillway to release the excessive water. Usually, a series of *Jessour* are placed along the *wadi*, which originates from a mountainous catchment. These systems require maintenance to keep them in good condition. Since the importance of these systems for food production has declined recently, maintenance has also been reduced and many such systems are losing their ability to function.

Jessour ***in southern Tunisia trap both runoff water and eroded soil but require maintenance to continue supporting high quality figs and olives.***

Off-wadi systems

In off-*wadi* systems, the harvested rainwater running in the *wadi* is applied outside the *wadi* bed. The system may include structures intended to divert the water in the *wadi* away from its natural course and into nearby areas which are suitable for agriculture (floodwater systems). Or, the system may function by collecting rainwater from catchments outside the *wadi* bed (macro-catchment systems). The following are the most important off-*wadi* techniques:

Water-spreading systems

The water-spreading technique is also called 'floodwater diversion' and entails forcing part of the *wadi* flow to leave its natural course and then conveying it to nearby areas, where it is applied to support the crops already growing there. This water is stored solely in the root zone of the crops. That is, it supplements rainfall. The water is usually diverted by means of a structure that raises the water table in the *wadi* bed in order to allow flow to spread, by gravity, on one or both sides of the *wadi* as directed by a levee, which should run a little off the contour and away from the *wadi* path.

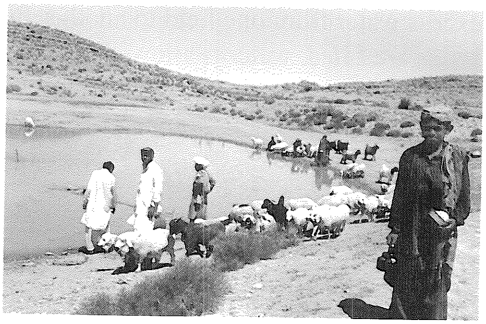
Water spreading structure in northern Tunisia provides supplemental irrigation water for wheat and other winter field crops.

Large bunds

Also called '*tabia*' in Tunisia, the large bund system consists of large, semi-circular, trapezoidal or open 'V' shape earthen bunds with a 'length' (the distance between the tips of each bund) of about 10–100 m and a height of 1–2 m. These structures are often aligned in long staggered rows facing up the slope. The distance between adjacent bunds on the contour (i.e. between their adjacent tips) is usually around half the length of each bund. The tips of the bunds should be protected against erosion, as water often flows around them. Large bunds are usually constructed using machinery; only rarely are they constructed by hand. They are used to support trees, shrubs, and annual crops in WANA, but also support sorghum and bulrush (pearl) millet in sub-Saharan Africa.

As large semi-circular bunds can store large quantities of water, they may break under extreme rainstorm events. Therefore, a method to control overflow has to be included. The period most critical to the bunds' stability is that immediately following construction, before their structure is fully consolidated. Breaks must be repaired immediately. As these systems are not traditional, it may be difficult to persuade farmers to adopt them.

Tanks and hafā'ir



Hafā'ir in western Sudan where water is very scarce and people and livestock depend on the harvested water collected in winter for the summer consumption.

Tanks and *hafā'ir* usually consist of earthen reservoirs, dug into the ground in gently sloping areas that receive runoff water either as a result of diversion from *wadi*s or from a large catchment area. The so-called 'Roman ponds' are indigenous tanks usually built with stone walls. The capacity of these ponds ranges from a few thousand cubic meters in the case of the *hafā'ir*, to tens of thousands of cubic meters in the case of tanks. Tanks are very common in India, where they support over 3 million ha of cultivated lands. In the WANA region, *hafā'ir* are the more common and are mostly used to store water for consumption by humans and animals. They are common in Sudan, Jordan and Syria.

Cisterns

Cisterns are indigenous subsurface reservoirs with a capacity ranging from 10 to 500 m^3. They are basically used for human and animal water consumption. In many areas they are dug into the rock, as is the case in Jordan and Syria. They are usually small in capacity. In northwest Egypt, farmers dig large cisterns (200–300m^3) in earth deposits, underneath a layer of solid rock. The rock layer forms the ceiling of the cistern, whereas the walls are covered by an impermeable plaster. Modern concrete cisterns are being constructed in areas where a rocky layer does not exist.

In this system, runoff water is collected from an adjacent catchment or is channeled in from a more remote one. The first rainwater runoff of the season is usually diverted away from the cistern, in order to reduce pollution. Settling basins are sometimes constructed to reduce the amount of sediment; however, farmers usually also clean their cisterns (either once a year or every other year). A bucket and rope are usually used to draw water from these cisterns.

The cisterns remain the only source of drinking water for humans and animals in many dry areas; the role they play in maintaining rural populations in these areas is a vital one. In addition to their more usual domestic purposes, cisterns are now also used to support domestic gardens. The problems associated with this system include the cost of construction, the cistern's limited capacity, and influx of sediment and pollutants from the catchment.

Hillside-runoff systems

In Pakistan, this technique is also called *sylaba* or *sailaba*. Runoff water flowing downhill is directed to flat fields, at the foot of the hill, by small conduits, before it joins *wadis*. Fields are leveled and surrounded by levees. A spillway is used to drain excess water from one field to another further downstream. When all the fields in a series are filled, water is allowed to flow into the *wadi*. When several feeder canals are to be constructed, distribution basins are useful. This is an ideal system with which to utilize runoff from bare, or sparsely vegetated, hilly or mountainous areas.

Conclusion

Building on the foundations of available traditional knowledge is the most reliable approach for the successful socioeconomic development of poor, local communities in the dry areas of WANA. The potential of indigenous water-harvesting practices is enormous. The cases and technologies mentioned here demonstrate that improvements increase the quality and productivity of crops and of land as available water increases. The productivity of rainwater in the drier environments can be substantially increased when an appropriate water-harvesting technique is implemented.

The successful blending of available indigenous knowledge with modern technology is one of the immediate challenges facing efforts aimed at developing sustainable and environmentally friendly agricultural production systems. It is strongly recommended that such blending and intervention form part of any plan for integrated land and water resources development and that such a plan takes into consideration all necessary technical, agricultural, socioeconomic and institutional aspects and inputs.

References

Falkenmark, M., P. Fox, G. Persson, and J. Rockstrom. 2001. Water harvesting for upgrading of rainfed agriculture: problems analysis and research needs. Stockholm International Water Institute, Stockholm, Sweden.

Gorijestani, N. 2001. Indigenous knowledge for development: opportunities and challenges. World Bank, Washington DC, USA.

Grenier, L. 1998. Working with Indigenous Knowledge: A Guide for Researchers. International Development Research Center, Ottawa, Canada.

Oweis T., A. Hachum and J. Kijne. 1999. Water harvesting and supplemental irrigation for improved water-use efficiency in the dry areas. SWIM Paper 7. International Water Management Institute, Colombo, Sri Lanka.

Oweis, T., D. Prinz and A. Hachum. 2001. Water harvesting: indigenous knowledge for the future of the drier environments. ICARDA, Aleppo, Syria. 40 pp.

Oweis, T., A. Hachum. 2003. Improving water productivity in the dry areas of West Asia and North Africa. Pages 179–198 in Kijne, W.J., Barker, R., Molden, D. (Eds.): Water Productivity in Agriculture: Limits and Opportunities for Improvement. Wallingford, U.K.: CABI Publishing.

Prinz D. 1996. Water harvesting – history, techniques and trends. Z. F. Bewasserungswirtschaft 31: 1, p 64–105.

World Bank. 1998. Indigenous knowledge for development: a framework for action. Knowledge and Learning Center. World Bank, Washington DC, USA.

Chapter Two

Water-Harvesting Systems in Tunisia

Nétij Ben Mechlia[1] and Mohamed Ouessar[2]
[1]Institut National de Recherche Agronomique de Tunisie (INRAT), Tunis;
[2]Institut des Régions Arides (IRA), Médenine, Tunisia

Introduction

Located in North Africa, Tunisia has a total land area of 16.4 million ha. Of this, the cultivable area is about 4.8 million ha, while forests and esparto grass (*alfa; Stipa tenacissima*) cover 1.7 million ha, and 3.7 million ha are used for grazing. In 1996, 34% of the cultivable area was planted with cereals, 29% with olive trees, 12% with fruit trees, 6% with forage crops, 3% with vegetables, 2% with pulses, and 2% with industrial and miscellaneous crops; 12% was left fallow (Min. Agr. 1996). The ratio of irrigated land to arable land is presently around 7%. Potentially this figure could reach 9%. This low ratio reflects the scarcity of water throughout the country.

The population of Tunisia has been estimated to be 9.2 million (1996) and is growing by 2.1% annually. Agriculture plays an important role in the economy, despite its relative decline during the last three decades (as a result of rapid growth in other sectors, especially industry). Agriculture provided 24% of the gross national product in 1972 and 8% of the gross national product in 1996. Agricultural exports declined from 40% to 8% over the same period, during which agricultural imports also fell from 20% to 9%. Agriculture is, however, responsible for about 30% of national employment.

Because of chronic water deficiencies, a wide variety of relatively small hydraulic techniques have been introduced over many centuries to make the land productive, irrespective of its geographical location. In their diversity, indigenous practices involving the use of runoff water to supplement rainfall deficiencies seem to be consistent with long-run climatological features. Within a sub-humid environment (550-800 mm annual rainfall), rainfall meets the water requirements of most winter crops; therefore, water harvesting involves the collection and storage of surface water in reservoirs and ponds for deferred use during the summer season. In semi-arid regions (400-550 mm annual rainfall), some annual crops (such as cereals and Mediterranean-type tree species) are grown extensively. These can give sustainable production on deep soils. Sloping areas, however, are characterized by shallow soils, and need specific management in order to retain runoff water. Terraces and embankments are the most common techniques used to enhance agricultural production in such areas.

More sophisticated systems have been developed in the arid zone (150-400 mm annual rainfall). In the central and southeastern parts of the country, where there are large areas of sloping land, micro-catchment techniques have been used to capture runoff, while spate irrigation from *wadis* is commonly used on the central plains of Tunisia.

Historical records show that a flourishing system of agriculture was created in arid Tunisia through the development of highly sophisticated soil and water conservation works (Baldi 1965). Degradation of the ecosystem and subsequent desertification processes, observed in many areas since the turn of the 20th century, were not triggered by a major climatic change, as some hypotheses may lead us to believe. Rather, they were the result of exploitative human activities (Hamza 1987).

To reduce natural resource degradation, independent Tunisia devoted 25% of its agricultural investment to reforestation and to soil and water conservation during the 1960s. This percentage dropped to 10% in the early 1970s and to 5% in the late 1970s.

At that time, an attempt to prevent water runoff on farmlands through the creation of barriers made of earth and vegetation was not very successful, due to the disinterest of, and hence poor maintenance by farmers. By the same token, overgrazing undermined an attempt to control gully erosion by planting grass, shrubs and trees. These were major reasons for a decline in budgetary allocations to the soil and water conservation sector.

Budget allocations to such projects also decreased as a result of the government's orientation towards the construction of a large hydraulic infrastructure (e.g., dams and water conveyance networks), dictated by development plans which sought higher production and productivity. Therefore, the maintenance of small-scale and traditional techniques was overlooked in many regions. At the same time, emigration and rural exodus resulted in land being abandoned, which accelerated the process of degradation. These factors, coupled with the occurrence of heavy rainfall, caused many traditional structures to be damaged, or completely washed away. Meanwhile, tremendous population growth and the rapid development of many water-consuming sectors resulted in accelerated competition for water resources.

The dilemma of attempting to increase food production with little allocated water made the mobilization of all available water resources and the improvement of water use efficiency inevitable. As a result, the late 1980s witnessed a revival of interest, at many levels, in traditional soil and water conservation techniques. The role of water harvesting has also been fully recognized in all regional agricultural development plans. However, in contrast to the general attitude assumed during the 1960s, a strong emphasis is now placed on the participatory approach. Similar trends, in terms of a reconsideration of the importance of indigenous water-harvesting techniques, seem to be occurring in other regions with similar ecological conditions, particularly in the Middle East and Western Asia (Mainguet 1991; Oweis et al. 1999; Oweis et al. 2001*)*.

This document describes the water-harvesting systems that are still in use in Tunisia. It presents, first, the various agro-ecological zones of the country, in which the agricultural sector depends heavily on rainfed farming. It then highlights the basic natural and historical backgrounds of the various water-harvesting techniques and describes their adaptation to local environmental and social conditions.

Background

Tunisia can be divided into three major natural regions: the northern, central, and southern zones (Karray 1979). The northern zone is separated from the central zone by a branch of the Atlas Mountains called the Dorsale (Fig. 2.1). It covers 25% of the country's land area and is characterized by fertile plains stretching from the Kroumirie and Mogod mountains to the foothills of the Dorsale. Rainfall in the northern zone is relatively high. It varies from 400 to 800 mm in the agricultural areas and reaches a maximum of 1500 mm in the northwest corner of the Kroumirie forests.

Being the extreme eastern part of the Saharan Atlas, the Dorsale is composed of a fragmented series of the country's highest peaks—Châambi (1544 m), Semmama (1314 m), Zaghouan (1295 m) and Sidi Abderrahman (637 m)—arranged in a southwest-northeast transect from Kasserine to Cap Bon.

In the north, smaller mountains form the Tell (which is composed of the high Tell, Khroumerie and Mogod). The Medjerdah, the only perennial river in the country, is embedded in the valleys of this area, along with some ephemeral streams. The dominant natural vegetation is relatively dense oak forest. Agriculture is based on rainfall and on irrigation using water collected in dams and hill lakes. The northern zone produces cereals, fruits, milk, meat and vegetables.

The central zone (15% of the country) is located between the Dorsale and a series of salt lakes (*chotts*), which form its southern border (Fig. 2.1). It receives between 200 and 400 mm of rainfall and is used, agriculturally, to grow olive trees, cereals, and as pasture. Traditionally, this zone is subdivided into three agro-ecological regions: the High Steppes, the Low Steppes, and the Sahel.

The High Steppes, consisting of plateaus of more than 400 m elevation, are dominated by esparto grass. They are drained by the famous, intermittent and turbulent *wadis* of the central zone (Sidi Aïch, Marguellil, and Zeroud) which subsequently cross large plains located in the Low Steppes areas and, finally, either come to rest within saline depressions (*sebkhas)* or flow into the Mediterranean Sea. In the Low Steppes, rainfed farming based on cereal cultivation and sheep rearing predominates, alongside the development of newly irrigated areas which are served by groundwater wells. The third agro-ecological zone of central Tunisia is the Sahel, where the landscape is dominated by rolling hills and by many small villages. In this area micro-catchment systems are widely used within olive tree plantations.

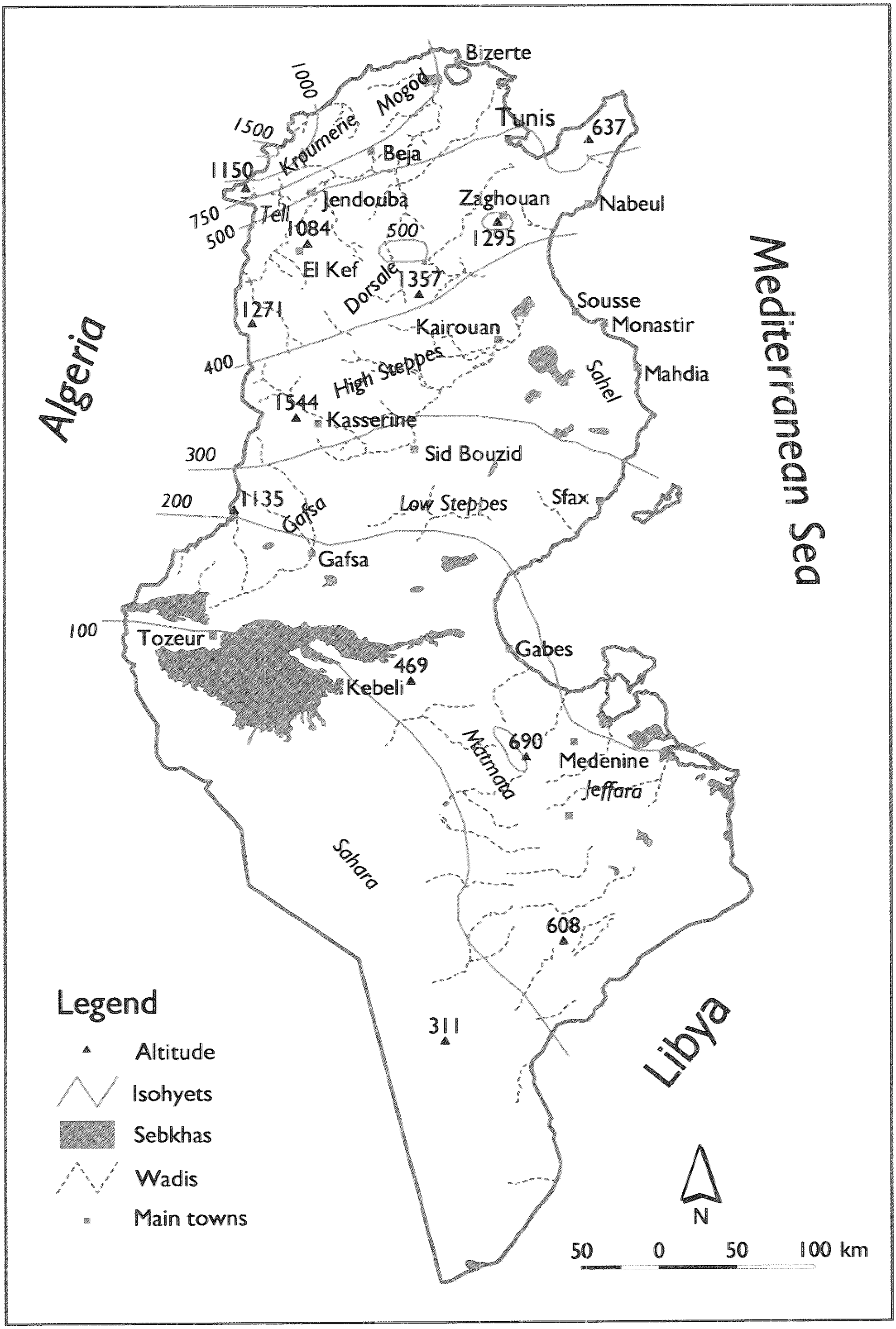


Fig. 2.1. Agroecological zones of Tunisia.

Southern Tunisia can also be divided into many sub-regions. The Dahar is a calcareous plateau of 400 to 600 m in elevation, dissected by small *wadis* and ending in the east in a *cuesta* (landform with an inclined upland slope and a relatively steep escarpment descending abruptly from its crest). The Jeffara, which is a large plain made up of crusted quaternary deposits, stretches between the Matmata mountains and the littoral (coast). Rainfall increases from 100 mm in the lowlands to 200 mm in the mountains. The area's natural vegetation consists primarily of degraded arid rangelands species. Besides some rainfed farming and irrigation in the oases, livestock husbandry is the main agricultural activity. The region of Gafsa is an area of *chotts* and *sebkhas,* with a series of mountains in a west–east orientation. The Sahara, found in the most southerly part of the country, is a xeric zone dominated by sand dunes.

The climate of Tunisia is Mediterranean, influenced by the caprices of the Sahara climate. Semi-arid, arid, and desert climates cover more than two-thirds of the country. The country's rainfall is known for its unpredictability, combining scarcity with the tendency to fall in torrents. It is also highly variable, both over time and in space. This variability increases when moving from north to south. The total amount of rainfall is estimated to be 35 billion m^3 annually, distributed unequally between the three major ecological zones. Seventeen percent of the country, located in the 400 to 1500 mm rainfall zone, receives 41% of the total amount of rain. The area between the 200 and 400-mm isohyets constitutes 22% of the country and receives 29% of the total rainfall. Finally, the arid region in the south (not including the Sahara), which receives less than 200 mm of rain, constitutes 61% of the country, but receives only 30% of annual rainfall (Ben Mechlia et al. 1996).

The mean annual renewable water resources of the country are estimated to be 4.6 billion m^3, which may be subdivided into 2.7 billion m^3 of surface water, 1.2 billion m^3 of water held in confined aquifers (deep groundwater) and 0.7 billion m^3 of water held in unconfined aquifers (shallow groundwater). Approximately 70% of this potential resource is mobilized at present. Agriculture is the largest water-consuming sector (using 84% of water consumed), followed by domestic use (13%). Industry, tourism and various other sectors make use of the remainder (Mamou 1997).

Most agricultural systems are based on dry farming, with the cultivation of cereals and olive trees being the dominant agricultural activities. The raising of livestock is also very important in all regions, and is practiced by 70% of farmers. Water harvesting ensures the best use of winter rains. Use of this technique is, therefore, essential to improve the yield of cereals and olives and enhance rangeland production within the country.

Indigenous Water-Harvesting Systems

An Overview

A comprehensive survey of traditional hydraulic works in the *Maghreb* countries was carried out by El Amami (1982). This document, written in Arabic, was followed by a second document, written in French, on Tunisia (El Amami 1984). These manuscripts cover all the local small-scale irrigation techniques used in North Africa, with particular attention paid to Tunisia. The English term 'water harvesting' was not specifically used by these reports to describe the indigenous systems of runoff water capture and use. The term was, in fact, only recently introduced into North Africa, the people in these countries being far more conversant with the French language. The terminology used in these reports refers to water-harvesting techniques as 'small hydraulic structures or systems'. However, the techniques described exhibit the three main characteristics of water harvesting listed by Boers and Ben-Asher (1982): (1) they are applied in arid and semi-arid regions, (2) they depend upon local water, and (3) they are relatively small-scale operations. El Amami's fundamental works (1982; 1984) have triggered increased awareness of the potential indigenous technologies have in terms of drought mitigation. Since the works were published, a large number of studies have been made of the methods used to induce, collect, store and conserve local surface runoff for agriculture in arid and semi-arid regions. A compilation of these techniques was recently produced by Ennabli (1993).

Undoubtedly, the various water-harvesting techniques (which are used on approximately one million hectares within Tunisia) are considered to be an integral part of the country's national heritage. Not only do these techniques contribute to the country's wealth by increasing agricultural productivity and by enhancing natural vegetation, they play a key role in the protection of its natural resources (Min. Agr. 1958) and in the maintenance of social equilibrium in the different regions.

The main water-harvesting techniques encountered in the country (Fig. 2.2) can be subdivided into three major groups: (1) runoff water harvesting that makes use of runoff as it is collected, thus eliminating the need for storage—included among such systems are the related micro-catchment techniques called *meskat* and *jessour*; (2) floodwater harvesting and spreading or spate irrigation using diversion dykes (*mgoud*); and (3) runoff water collection and storage in reservoirs of variable capacities, which provides drinking water for people and animals, as well as water for irrigation.

Meskat

Meskat is a very ancient runoff water-harvesting technique practiced in the Sahel region of the Tunisia, the landscape of which is dominated by a rolling topography (Fig. 2.2). Slopes vary between 3% and 10% and sandy loam soils, with good

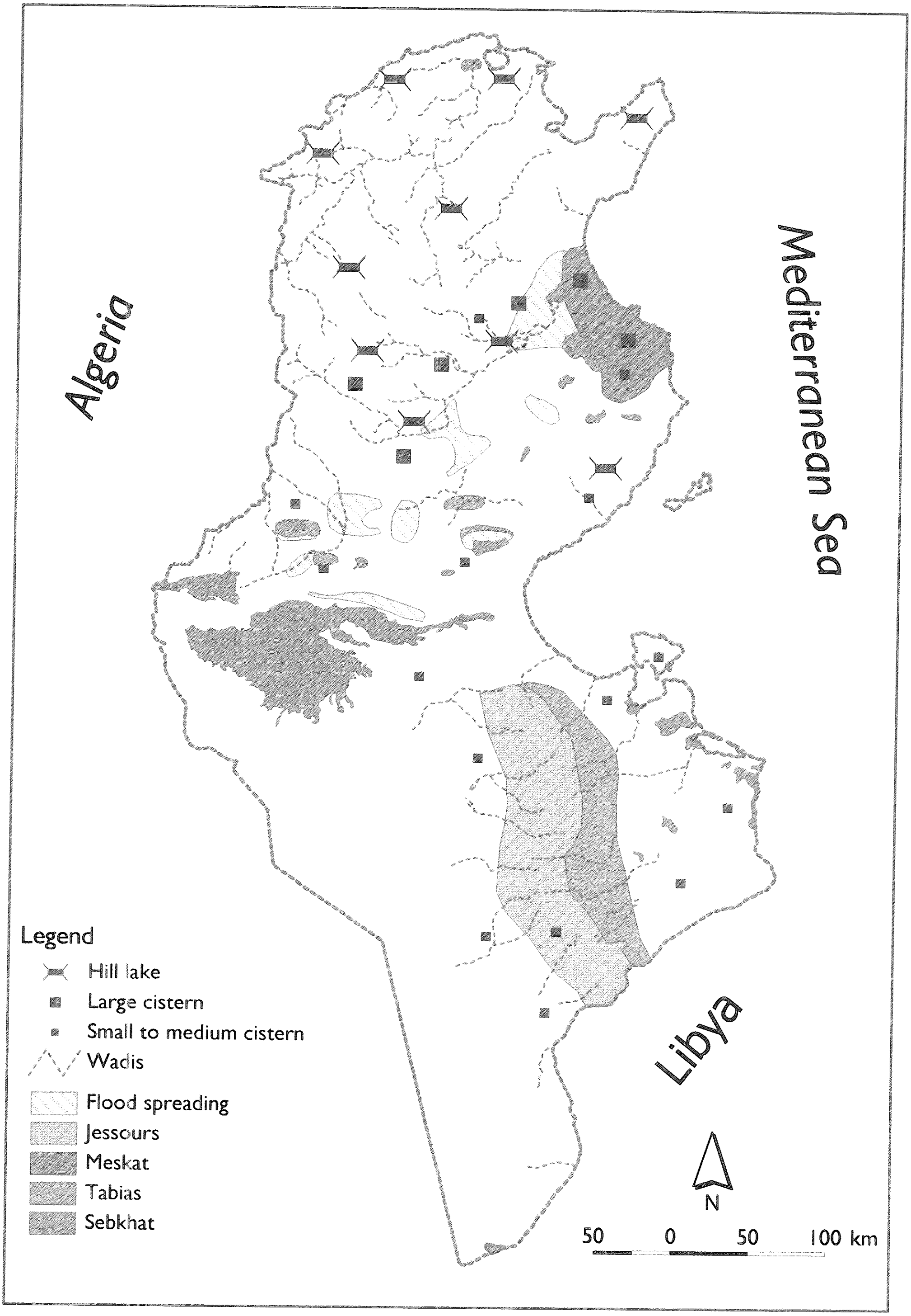


Fig. 2.2. Geographical distribution of water-harvesting techniques in Tunisia.

infiltration rates and water retention capacities, predominate in this region. In fact, only the runoff area in this system is locally known as *meskat:* the target or 'run-on' area is called *mankaa*. The cultivated areas are formed by one or several compartments, bounded by an earthen embankment. They are conjoined by spillways. This micro-catchment system covers 300 000 ha (El Amami 1982) and still supports millions of productive olive trees.

Hydrological studies during the late 1970s confirmed the efficacy of this technique with regard to erosion control and the enhancement of the water supply to olive plantations (El Amami and Chaabouni 1982; Ben Khlil 1983). These studies showed that originally (at the beginning of the 20th century) the ratio of the surface areas of the collection area and the infiltration basin was frequently higher than 2. In later years, because of population pressure, this ratio dropped sharply in many areas, to about 0.7 in the mid-20th century (El Amami 1984).

Later studies tried to explain the rationale behind the *meskat*/*mankaa* ratio variations. For instance Toumi (1986) and Snane et al. (1991) argued that, with an average annual runoff coefficient of 20%, this system is adapted to heavy rain and that a productivity of 60 kg/tree could be obtained with a ratio of 1.5. On the basis of these assumptions, Ennabli (1993) also claims that this value represents the limit beyond which the efficiency of the system and its hydraulic equilibrium would be threatened. Similarly, other studies tried to relate embankment characteristics to the amounts of runoff that storms of different frequencies (i.e., return period or probability of occurrence) may produce.

These studies, in spite of their usefulness, have serious shortcomings: they simply address those aspects of the *meskat* that El Amami (1982; 1984) had already extensively studied. Also, the many reports and papers which have been produced in both the national and international press present the *meskat* as a mere

A meskat *system, supporting olive trees in central Tunisia.*

hydrological system when in fact, if it is to be adopted in other areas, it must be considered as an integrated production system. However, despite the promise it showed, the extension of this system to other areas of Tunisia did not have the expected outcome.

Many factors underlie the *meskat* system's success. Four of these factors are agricultural: (1) the land must have gentle slopes never exceeding 16%; (2) the soil should be of the loamy-sand type, being more than 1-m deep, and having good infiltration rates (2-12 cm/hr) and a high water-holding capacity; (3) plantations in the run-on areas should only consist of olive trees; and (4) the runoff area can be used for grazing and can, therefore, contribute to the farmer's income. With regard to the social and institutional aspects of such systems, the following facts are worthy of mention: (1) *meskat* are developed on private lands, (2) there is legislation to protect one's right to runoff water, (3) embankments are constructed to ensure that all rainwater captured will be kept within the farm.

The rationale of using *meskat* to grow olive trees exclusively is explained by the growing and fruiting habit of this species and by the fact that the biomass such trees produce in addition to their fruit can be used as a green fodder. The biological cycle of olive trees takes place over two years. At different phases, shoot growth may respond positively to any rainfall. Young buds, moreover, may develop into flowers or into shoots, depending on the moisture conditions. Adding to these properties the tree's high capacity for drought resistance, it can be concluded that the species is exceptionally well-adapted to use with the water-harvesting techniques of the *meskat* and the *jessour* systems.

Jessour

Jessour is an ancient runoff water-harvesting technique widely practiced in the arid highlands (Fig. 2.2.), which are dominated by outcroppings of calcareous formations and depositions of quaternary calcareous silt (loess). Average annual rainfall ranges from 100 to 200 mm, but annual rainfalls of 80 and 700 mm have been observed. About 400 000 ha are covered by *jessour*, particularly in the Matmata mountain chain (El Amami 1984). This technique was described in detail by Abi El Abbes Naffoussi, who died in 1110, in his book "Land rights" (cited by Ben Ouezdou et al. 1999).

Arranged in the form of a *gradoni* (a series of contour ditches used mainly for growing trees), the *jessour* generally occupy runoff watercourses (*talwegs*). In fact, *jessour* is the plural of *jesr*, which is a hydraulic unit made of three components: the *impluvium*, the terrace and the dyke. The *impluvium* or the catchment is the area which collects and conveys runoff water. It is bounded by a natural water divide line (a line that demarcates the boundary of a natural area or catchment, so that all the rain that falls on this area is concentrated/drains towards the same outlet; any rain falling outside of this line does not contribute to the runoff of this area). Each unit has its own *impluvium*, but can also receive excess water from upstream units. The terrace or cropping zone is the area in which farming is prac-

***Jessours** in the Matmata mountains of southern Tunisia supporting olives, figs and date palms.*

ticed. It is formed progressively by the deposition of sediment. An artificial soil will then be created, which can be up to 5 m deep close to the dyke. Generally, fruit trees (e.g., olive, fig, almond, and date palm), legumes (e.g., pea, chickpeas, lentil, and faba bean) and barley and wheat are cultivated.

In *jessour*, a dyke (*tabia, sed, katra*) acts as a barrier used to hold back sediment and runoff water. Such dykes are made of earth, and are equipped with a central and/or lateral spillway (*masref* and/or *manfes*) and one or two abutments (*ktef*), assuring the evacuation of excess water. They are trapezoidal and measure 15-50 m in length, 1-4 m in width and 2-5 m in height. In old units, the dyke is consolidated with a coating of dry stones to overcome the erosive effects of water wave action on the front and back of the dyke. The spillway is made of stones arranged in the form of stairs, in order to dissipate the kinetic energy of the overflow. The runoff/cultivated area ratio is estimated to be around five (El Amami 1984); although higher values have been encountered (Chahbani 1990; 1996). The watershed of the Oued Fessi, between Tataouine and Ben Gardane on the Tunisian-Libyan border, is a typical example. This 99 000 ha area is located in the 400 to 600 m high hills of Tataouine, and has an annual rainfall of around 100-150 mm/yr. In this area there are approximately 35 000 *jessour*. The concentration of runoff water allows crops to benefit from a water supply equivalent to 300-500 mm/yr in the target areas.

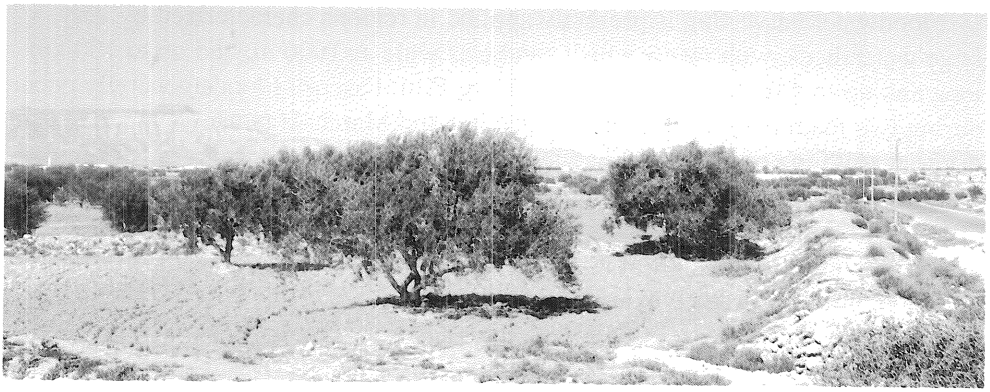
Though the *jessour* technique was developed for the production of various agricultural commodities, it now also plays three additional roles: (1) water table recharge, via runoff water infiltration into the terraces, (2) flood control and therefore the protection of infrastructure and towns built downstream, and (3) wind erosion control, by preventing sediment from reaching the plains, where the wind is very active.

Despite its importance, this technique is facing problems as a consequence of socioeconomic change leading to the system being inadequately maintained. Emigration and non-agricultural activities play an important role in income generation in the region. As agriculture becomes very much less important in terms of family earning capacity, less land is farmed. This leads the progressive abandonment of *jessour* farming in the mountains and to the establishment of tree crops and cereals in the downstream zone, at the expense of the best rangeland. The abandonment of *jessour* agriculture is accelerated by a lessening of community cohesion, which makes the necessary integrated and simultaneous treatment of an entire runoff unit increasingly difficult to implement, and which means that the construction of terraces must be mechanized, which is an extremely expensive undertaking for individual farmers.

Recent research has indicated that the formation of watershed associations and co-operatives would facilitate the adaptation of management systems to the newly established social and economic context (Laffat et al. 1997). Also, some solutions to specific engineering problems have been proposed to protect the existing structures (Chahbani 1990; 1996; 2000). Other studies have addressed the improvement of the geotechnical properties of earthen dykes constructed by machine (Mtimet 1992; Mellouli 1996; Rabboudi and Ouessar 1999).

Tabia

The *tabia* technique is similar to the *jessour* system used in the foothill and piedmont areas. It is considered to be a relatively new technique, developed by mountain dwellers who migrated to the plains. Alaya et al. (1993) have reported that the ancient remnants of *tabias* have been found in the region of Gafsa. The system has been adopted by people living in the neighboring foothills and plains



Newly constructed* tabias *in southern Tunisia.

of the central and southeastern regions (Jeffara) of the country, following the transformation of their pasture to cultivated fields (Fig. 2.2).

The *tabia* runoff water-harvesting technique is widely practiced in central Tunisia. *Tabias* are usually installed on the piedmont, where the slope does not exceed 3% and where the soil is relatively deep. *Tabias*, like *jessour*, are comprised of a dyke (50-150 m in length, 1-1.5 m in height), a spillway (central and/or lateral) and an *impluvium*. *Impluvium*/cropped area ratios vary from 6 to 20. The differences between the *tabia* and the *jessour* systems are that the former contains two additional lateral bunds (up to 30 m long) and sometimes a small flood diversion dyke (*mgoud*) (Alaya et al. 1993). Fruit trees and annual crops are commonly grown using *tabia*. Besides their water-harvesting qualities, *tabias* also have a positive effect on soil erosion and groundwater recharge.

Nasri et al. (2002) reported in a study of the hydrological processes of the *tabia* system in central Tunisia (Bou Hedma) that this traditional technique reduced the total surface runoff from the catchment to, essentially, zero. They also concluded that this water-harvesting system significantly reduced surface runoff peaks within the catchment, which reduces the hazard of erosion. They found that a cultivated area of about 5% of the total area of the catchment could be supplied by harvested water corresponding to eight times the amount of each rainfall event above 20 mm.

Floodwater Harvesting

Floodwater-harvesting systems divert the total, or a portion, of the floodwater carried by *wadis* to neighboring cultivated fields, so providing natural irrigation. The remnants of such systems, together with many still-functioning units, can be found in the central region of the country (e.g., Gafsa, Sidi Bouzid, Kairouan, Enfidha; see Fig. 2.2). It seems that this technique has been practiced since Roman times, and may even have been practiced in the pre-Roman period. However, El Amami (1984) believes that the arrival of the Arabs, who brought with them from Yemen immense experience of similar environments, was behind the adoption and the perfection of this technique on a large scale.

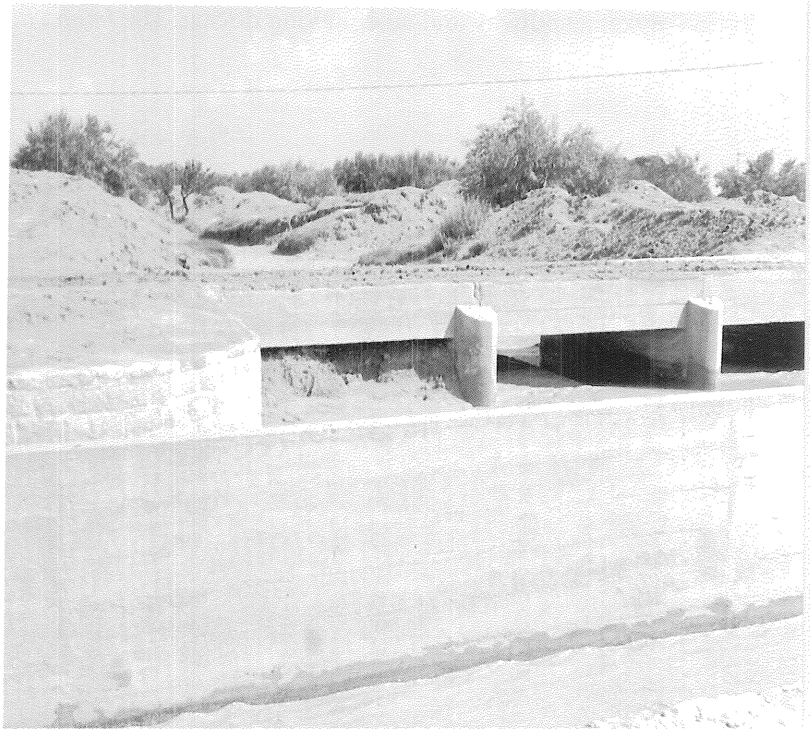
Floodwater harvesting is presently applied in regions characterized by very large watersheds, with *wadis* which can be as wide as 1000 m, and up to 100 km long and up to 4 m deep (e.g., Zeroud, Merg Ellil, Esserg). Floods generally occur during two main periods: September-October and March-May. However, they can occur at any time of the year. The yield of sediment from the *wadis* is very important for fertilizing the soil (Ennabli 1993). Mean annual rainfall ranges between 200 and 400 mm. Hénia (1993) found that this region has the most variable rainfall regime and the highest rainfall intensity of all Tunisia's regions (more than 300 mm/d recorded maximum).

In general, this artificial flooding system has three components, namely: a diversion dam, a distribution network, and cropped fields. The diversion dam is normally made of earth and acts as a kind of fuse or safety mechanism (by breaking down in the event of very intense floods). Recently, gabion and reinforced concrete have come to be widely used to build such structures.

The distribution network consists of open trapezoidal canals, which decrease in cross sectional area downstream. As with irrigation networks, this distribution network consists of primary, secondary, tertiary, etc. canals. The slope is normally gentle, except at the partition points (in order to avoid sedimentation and the silting up of the network). However, clearing/cleaning the system, to remove silt, should be undertaken at least once a year, during the summer. The fields in this system are generally flat, rectangular and delimited by an earthen embankment, in order to retain up to 1 m of water. The crops grown using this system are, mainly, cereals, fruit trees, spices, and legumes.

In the case of the natural water spreading systems, there is no need for the construction of diversion structures. In this case, the system is composed of a small-catchment water-harvesting system, whereby gullies emerging from neighboring mountains (alluvial fans) directly feed the fields below. Examples are provided by the Mbazaat (Gafsa) and Chereb (Djerid) *wadi* cropping systems, which are generally used for cereal cultivation.

In the absence of sufficient quantitative data on flood frequency, river discharge and sediment yield, the design of floodwater harvesting systems continues to rely on empirical models (Nagaz 1991). Abaab et al. (1994) recommended that a technical guide be prepared for flood-spreading networks and that their different impacts be assessed. As a first step towards that objective, Chérifi et al. (1995) proposed some changes to the design of this system, including (1) the installation of diversionary dykes at the narrowest points (constrictions), (2) the use of canals with a uniform



Flood-spreading construction across Wadi Margellail in central Tunisia.

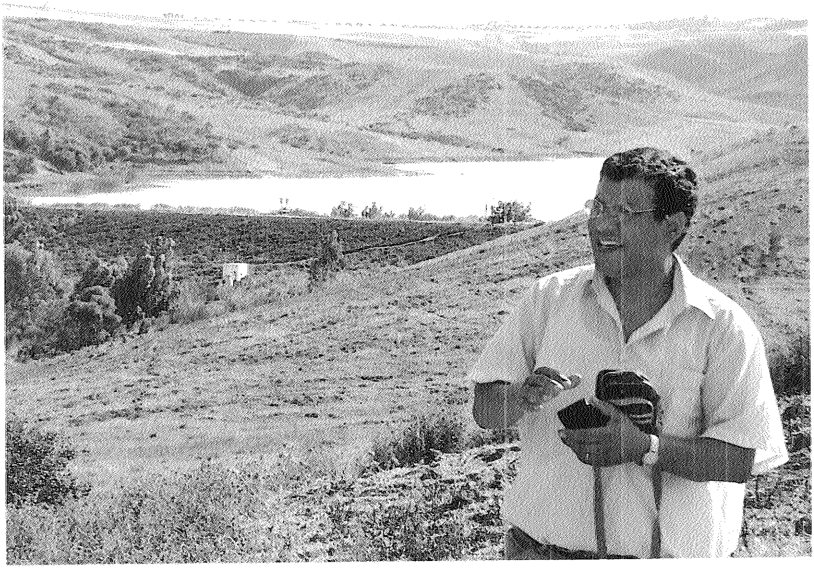
longitudinal slope, (3) the construction of spillways using reinforced concrete, and (4) the application of the 'rate theory' for hydraulic calculations.

Flooding techniques are a very efficient means of flood control and groundwater table recharge, especially in areas where, with the development of irrigated fields with motorized wells, declines in piezometric-level (groundwater pressure) are an increasing concern (Yahyaoui and Ouessar 1999; Abaab et al. 1994). It is estimated that the spreading of runoff waters could mobilize as much as 25 million m^3 of water per year (Mamou 1997). In fact, this technique has been widely adopted in central as well as in southern Tunisia, within the framework of the National Strategy for Water Resources Mobilization (Min. Agr. 1990a; b).

Hill Reservoirs

Construction of small earth dams has triggered the development of new agricultural systems, which can be classified as falling between rainfed and irrigated systems. The hill reservoir runoff water collection system was introduced to Tunisia at the beginning of the 19th century. The hill reservoirs, or *lacs collinaires* as they are called locally, are used in areas where runoff usually occurs on saturated land. Collection of excess water for irrigation and other purposes is therefore practiced during the 'wet' season. Hill reservoirs were first installed in the sub-humid regions of Bizerte and the Marguellil basin. By the end of the 1980s, these reservoirs were extended into semi-arid regions (Fig. 2.2). At present, 500 hill lakes are in operation out of a planned 1000, with an estimated overall capacity of 500 million m^3 (Min. Agr. 1990b; Alouani 1997).

A hill lake system is comprised of a small dam, a collection area, a reservoir, a dyke, a spillway and an emptying device. The *impluvium* is a watershed with a



A hill reservoir for supplemental irrigation of winter crops in El-Kamech, northern Tunisia.

drainage area of 100 to 2000 ha. Runoff water is stored in a reservoir with a capacity of 10 000 to 350 000 m^3. The dyke is made of compacted earth with slopes that vary from 2.5:1 to 3:1 upstream and from 2:1 to 2.5:1 downstream. Dykes are between 5 and 12 m and 100 and 300 m wide.

Built at 1 to 2 m below the dyke crest, the spillway ensures the evacuation of floodwater. A pipe outlet pierces the dyke, in order to allow water to enter and leave. An analysis of 400 hill lakes constructed between 1992 and 1996 has shown (1) that average construction costs are US$1.6 /m^3 storage capacity and (2) that the ratio between the runoff area and the storage capacity decreases from 4.5 to 1.5 when rainfall increases from 300 to 600 mm.

In addition to the environmental and recreational roles they play (protection of dams from silting, flood control, water table recharge, parks, etc.), hill lakes are intended to contribute to the development of small-scale irrigation schemes and to provide water for animals in remote mountainous areas. Although they are more costly than traditional techniques, they have the advantage of increasing farming options (such as providing the means for both full and supplemental irrigation and for the raising of livestock).

Irrigation from hill lakes has specific features: (1) it is directly related to the runoff water collected in the reservoir; (2) it is practiced on soils which have different slopes and levels of exposure; and (3) it is extremely dependent on local conditions for its profitability. Hill lakes enrich the hydraulic network of the country. They ensure the mobilization of an appreciable amount of water in areas where, because of physical and economic constraints, a heavy hydraulic infrastructure cannot be installed. However, in addition to their vulnerability to variable rainfall, silting-up of the reservoir presents a major problem with regard to the use of this system. If this recently introduced technique is to ensure sustainable development schemes, thorough analysis is needed during the site selection phase (Talineau et al. 1994; Mekki 1999).

Cisterns

Cisterns were traditionally used to provide drinking water. In the cistern system, runoff water is collected and stored in stone-faced underground cisterns, of various sizes, called *majel* and *fesquia*. It is estimated that a tank with a capacity of 35 m^3 can meet the annual water needs of a family and its livestock (Ennabli 1993). Small private and communal cisterns (5 to 200 m^3) and big cisterns (up to 70 000 m^3) can be found throughout the water-deficient zone south of the 400-mm isohyet (Fig. 2.2).

Basically, a cistern is a hole dug in the ground and lined with a gypsum or concrete coating, in order to avoid vertical and lateral infiltration. Each unit consists of three main parts: the *impluvium*, the sediment settlement basin, and the storage reservoir. The *impluvium* is a sloping piece of land delimited by a diversion channel (*hammala*). In flat areas, where it is possible also to exploit floods

A **fesquia** ***providing drinking water to people and animals in central Tunisia.***

via a diversion dyke, one also finds artificially paved runoff areas. A small basin before the entrance of the cistern allows the sedimentation of runoff loads. This improves stored water quality and reduces maintenance costs. Big cisterns have, in addition to the storage compartment, a pumping reservoir from which water is drawn.

Ennabli (1993) claimed that this technique was used to collect and distribute spring water in both Roman and pre-Roman times. Carthage received its drinking water from the Djebel Zaghouan, *via* an aqueduct 50 km long. This water was collected in a cistern with a volume of 50 000 m^3. The same procedure was followed in other large towns (such as Kef, Sbeitla, Tebourba, and Sousse). The collection of rainwater accelerated with the arrival of the Arabs.

More than 200 big cisterns can be found in the central region of the country. The most famous one is Aghlabit, in Kairouan, which was built in the 19th century, and which has a total capacity of 58 000 m^3. The use of cisterns also contributed to the development of large-scale livestock husbandry in areas where groundwater is not available, because of constraints connected with quantity or quality. It was estimated, during the 1990s, that 10 to 16 million m^3 of water per year could be mobilized using this type of hydraulic infrastructure (Ennabli 1993).

Nasri (1993) reported that, in the rangelands of Dahar, the selling of cistern water is a widespread and popular practice, especially during the summer months. While studying a micro-catchment in the region of Beni (Khedache), Sghaier and Chahbani (2001) found that water from the cisterns was not being fully exploited. Through a cost–benefit analysis simulation, they showed that there is great potential for improving the farming system and for increasing the income earned from *jessour*-based agriculture, by practicing supplemental irrigation and/or small scale, full irrigation under greenhouses using cistern water.

Summary and Prospects

Rainfed farming in Tunisia is, and will remain, an important component of the country's agricultural production system. Its productivity is, however, severely limited by chronic rainfall deficits. One way to support the sustainability of such a vulnerable system is by increasing the water supply. Water-harvesting techniques, at present, cover about one million hectares and efficiently support rainfed agriculture.

Crossing the country from north to south, one can easily observe that each agro-ecological zone is characterized by specific water and soil management practices. Hence, in northern Tunisia, embankment techniques appropriate to that area may be seen in many fruit-growing areas, in addition to the hundreds of hill reservoirs. *Meskat* micro-catchments have allowed olive tree orchards to be developed on the rolling land in the Sahel region. In central Tunisia, spate irrigation or *mgoud* techniques are commonly used in areas bordering the big *wadis*, while in the southeastern region, *jessour* are used to capture the runoff from the Matmata mountain chain. Hill lakes and both large and small cisterns (*fesquia* and *majel*) also contribute to the storage and exploitation of rainwater. Other techniques (bunds, cordons, basins, dry-stone diversion weirs and gabion check dams) are also commonly used.

The water-harvesting techniques are well adapted to the physical and social environment in which they are used. These techniques have various functions, such as water supplementation, flood prevention, water table recharge and water and wind erosion control. Because of these functions, the economic profitability of their use and maintenance should be considered on a national scale, without overlooking the problem and benefits specifically associated with each. A long-term strategy is required to handle a consideration of such on a national scale. Observation suggests that the solution lies in convincing the relevant populations that the protection of the environment improves agricultural production. This can only be done by improving the well-being of the local population, by providing alternatives to some of the current, low-profit methods of cultivation. The best strategy is to increase livestock and crop production by improving water-use efficiency. The specific measures taken to achieve these objectives will depend on the type of water-harvesting system being used.

With regard to the *jessour*, emigration and the increased use of non-agricultural activities to provide an adequate income are causing a progressive abandonment of farming in the mountains. Moreover, the establishment of tree crops and cereals in the downstream areas occurs at the expense of the best rangelands. Measures are needed to convince the local population that *jessours* are the basis of agricultural activity in this southern, hilly, area of the country. The successive arrangement of the *jessour* demands collective maintenance in order to reduce the intensity of runoff and to facilitate the collection of rainwater.

Hill reservoirs enrich the country's hydraulic network. They ensure the mobilization of a sizeable amount of water in areas where a large-scale hydraulic infrastructure cannot be implemented because of environmental and economic constraints. The strategic role of these reservoirs must be reinforced, in order to face growing competition for water resources.

There is some awareness, at the decision-making level, that abandonment of these small irrigation structures will lead to situations that will be increasingly difficult to control (such as accelerated erosion in the mountains and the wastage of water on the plains and the piedmonts). Attention should therefore be given to the need to convince farmers that maintenance of the system they use will increase the productivity of their crops and the value of their land. In order to succeed, new actions/programs must attract popular participation. To do this, projects must be orientated towards development. In arid areas, for instance, to combat the deterioration of soils and natural vegetation, operations may aim to slow (through dune stabilization and the adoption of new techniques for working the land) the speed with which sand encroaches upon plantations, land planted with cereals, and rangeland. This could be achieved through the introduction of appropriately located windbreaks, which take account of the prevailing wind direction. These windbreaks would be built by constructing *tabias* parallel to rows of shrubs. Reseeding with sand-tolerant plant species would also be required.

A decline in the amount of mobilized water allocated to agriculture renders the practice of water harvesting essential, in that this process will fill the present water deficit. The widespread presence of hydraulic structures helps to slow down the flow of runoff water, encourages infiltration and limits flood damage on the plains. The performance of old structures needs to be improved. The near complete lack of research in this area is forcing farmers to make improvised changes to their systems in response to emerging, changed, social conditions. But, there still exist numerous technical problems which can only be solved through research. Specific mention should be made of the importance of

- methods of improving runoff collection systems,
- data concerning the major crops that can be established in arid regions,
- new materials that could be used in surface tanks and small dykes, and
- the choice of suitable cultivation and farming methods.

Full implementation of the ongoing national strategy concerned with natural resource development would mean that one million hectares of land would be subject to conservation measures and that most accessible water would be mobilized (Min. Agr. 1990a;b). More attention must now be paid to the need to assess the impact of combining old and new water-harvesting techniques (Sghaier and Chahbani 2001; Yahyaoui and Ouessar 2000). On the basis of local know-how, and in order to ensure sustainable agricultural development of the dry regions, future management methods must better fit the current socioeconomic context (Chahbani 1997; Laffat et al. 1997).

References

Abaab, A., A. Balde, M. Dabre, L. Dhiabi, M. N'diaye, E. Saumon and T. Tangara. 1994. Valorisation et gestion des eaux d'épandage de l'oued El Fakka à Sidi Bouzid (Tunisie). International Center for Development Oriented Research in Agriculture ICRA), Wageningen, the Netherlands.

Alaya, K., W. Viertmann and Th. Waibel. 1993. Les tabias. Imprimerie Arabe de Tunisie, Tunis, Tunisia. 192 pp.

Alouani, B. 1997. [The Tunisian experience in the realisation of small dams and hill lakes.] In Arabic. Unpublished report, Ministère de l'Agriculture, Tunis, Tunisia.

Baldi, C. 1965. Climatologie et bioclimatologie de la Tunisie centrale. FAO, Rome, Italy.

Ben Khlil, K. 1983. Technique de construction des *meskats* du Sahel de Sousse. Centre de Recherche en Génie Rural (CRGR), Tunis, Tunisia.

Ben Mechlia, N., M. Masmoudi and Ch. Laroussi. 1996. Water saving opportunities in the Mediterranean: Tunisia case study. Pages 41-58 *in* Proceedings of the 16th Congress on Irrigation and Drainage, Sustainability of Irrigated Agriculture Workshop on 'Water Saving and Sustainable Irrigated Agriculture in the Mediterranean Region' (A. Hamdy ed.). CIHEAM-MAI, Bari, Italy.

Ben Ouezdou, H., M. Hassen and A. Mamou. 1999. [Water laws and hydraulic management in southern Ifrikia in the middle ages.] In Arabic. Based on the manuscript "Land rights" of Abi El Abbes Naffoussi (died in 1110). Centre de Publication Universitaire, Tunis, Tunisia.

Boers, Th.M. and J. Ben-Asher. 1982. A review of rainwater harvesting. *Agricultural Water Management* 5: 145-158.

Chahbani, B. 1990. Contribution à l'étude de la destruction des jessour dans le Sud Tunisien. *Revue des Régions Arides* 1: 137-172.

Chahbani, B. 1996. Nouvelles méthodes pour le dimensionnement des ouvrages de petite hydraulique dans le centre et sud tunisien. *Revue des Régions Arides* 9: 33-46.

Chahbani, B. 1997. Les acquis de la recherche dans le domaine de la conservation optimale des eaux du ruissellement dans les régions arides du centre et sud tunisien. Proceedings of the international seminar Acquis Scientifiques et Perspective pour un Développement Durable des Zones Arides, *Revue des Régions Arides (numéro spécial):* 77-92.

Chahbani, B. 2000. New techniques for the control of and valorization of runoff water in arid regions. UNU Desertification Series No. 2, 124-137.

Chérifi, K., S. Baccouche and M. Hammami. 1995. Irrigation par épandage des eaux des crues. *Revue de l'INAT* 10(2): 1-13.

El Amami, S. 1982. The traditional hydraulic structures in the Maghreb. ACSAD, Damascus, Syria. 35 pp. + Annexes.

El Amami, S. 1984. Les aménagements hydrauliques traditionnels en Tunisie. Centre de Recherche en Génie Rural (CRGR), Tunis, Tunisia. 69 pp.

El Amami, S. and Z. Chaabouni. 1981. Les aménagements hydrauliques traditionnels (Meskat et Jessours): Moyens de lutte contre l'érosion. Paper presented at Deuxieme Colloque Arabe sur les Ressources en Eau. 21-27 Sept, Rabat, Morocco. ACSAD, Damascus, Syria.

Ennabli, N. 1993. Les aménagements hydrauliques et hydro-agricoles traditionnels en Tunisie. Imprimerie Officielle de la République Tunisienne, Tunis, Tunisia. 255 pp.

Hamza, A. 1987. La problématique de la dégradation des terres en Tunisie. Paper presented at Séminaire sur le Productivité des Terres Agricoles en Tunisie. INAT, 27 et 28 Avril.

Hénia, L. 1993. Climat et bilans de l'eau en Tunisie: Essais de régionalisation climatique par les bilans hydriques. Publication de l'Université de Tunis I, série Géographie, Tunis, Tunisia. 391 pp.

Karray, R. 1979. Relief, géologie, hydrogéologie et géomorphologie. Pages 5-16 *in* Atlas de Tunise (M. Fakhfakh, ed.). Editions Jeune Afrique, Tunis, Tunisia.

Laffat, F., M. Ouessar and K. Azaq. 1997. Pour un partenariat dans la rehabilitation des jessour en zones arides: Cas du bassin versant d'Oued Kef-Chern (Douiret, Tataouine). Proceedings of the international seminar Acquis Scientifiques et Perspective pour un Développement Durable des Zones Arides. *Revue des Régions Arides (numéro spécial)*: 465-473.

Mainguet, M. 1991. Desertification: Natural Background and Human Mismanagement. Springer-Verlag, Berlin, pp. 234-241.

Mamou, A. 1997. Développement des ressources en eau en Tunisie: situation actuelle et perspectives. Unpublished report, Minsitère de l'Agriculture. Tunis, Tunisia, 30 pp.

Mekki, I. 1999. Etude intégrée du bassin versant d'un lac collinaire et de l'exploitation de l'eau collectée pour l'irrigation. Mémoire de fin d'étude du cycle de spécialisation de l'INAT. INAT, Tunis, Tunisia. 57 pp.

Mellouli, H. 1996. Modification des caractéristiques physiques d'un sable limoneux par les effluents (les margines*)* des moulins à huile d'olive: Incidence sur l'évaporation. Thèse de Doctorat, Université de Gent, Belgique. 255 pp.

Min. Agr. (Ministère de l'Agriculture). 1958. Terre de Tunisie. Bulletin No. 6. La lutte contre l'erosion. Publication du Secretariat d'Etat a l'Agriculture, Ministère de l'Agriculture, Tunis, Tunisia. 108 pp.

Min. Agr. (Ministère de l'Agriculture). 1990a. La stratégie nationale de la conservation des eaux et du sol (1991 - 2000). Ministère de l'Agriculture, Tunis, Tunisia. 29 pp.

Min. Agr. (Ministère de l'Agriculture). 1990b. La stratégie nationale des ressources en eau (1991 - 2000). Ministère de l'Agriculture, Tunis, Tunisia. 35 pp.

Min. Agr. (Ministère de l'Agriculture). 1996. farm surveys, Direction Generale de la Planification et du Developpement Agricole. Ministère de l'Agriculture, Tunis, Tunisia

Mtimet, A. 1992. Les loess sahariens et l'amélioration de leurs propriétés géotechniques: Cas des Matmata et de leurs bordures (Tunisie). Pages 387-400 *in* L'aridité une Contrainte au Développement (E. Le Floc'h, M. Grouzis, A. Cornet and J.C. Bille, ed.). Didactiques/ORSTOM, Paris, France.

Nagaz, K. 1991. Protection contre les inondations de la ville de Sidi Bouzid: Impacts du transport solide. Mémoire de fin d'études, ESIER, Tunis, Tunisia.

Nasri, S., J. Albergel and R. Berndtsson. 2002. Hydrological processes in macrocatchment water harvesting in the arid regions of Tunisia: The traditional system of Tabia. Submitted to Journal of Hydrology.

Oweis T., A. Hachum and J. Kijne. 1999. Water harvesting and supplemental irrigation for improved water use efficiency in the dry areas. SWIM Paper 7. International Water Management Institute, Colombo, Sri Lanka.

Oweis, T., D. Prinz and A. Hachum. 2001. Water harvesting: indigenous knowledge for the future of the drier environments. ICARDA, Aleppo, Syria. 40 pp.

Raboudi L. and M. Ouessar. 1999. Effets de la margine sur la stabilisation des digues des jessour et des tabias. *Revue des Régions Arides* 11: 24-36.

Sghaier, M. and B. Chahbani. 2001. Simulation on improvements of the traditional jessour systems and their impact on farm income in arid zones of Tunisia: case of the micro-watershed of Ksar Jouamaa (in press).

Snane, M.H., M. Toumi and Z. Chaabouni. 1991. Un modèle d'optimisation des pluies pour les oliveraies. *Sécheresse* 2(1): 12-16.

Talineau, J.C., S. Selmi and K. Alaya. 1994. Lacs collinaires en Tunisie semi-aride. *Sécheresse* 5(4): 251-256.

Toumi, M. 1986. Modèle d'analyse fréquentielle des termes du bialn hydrique pour le dimensionnement des ouvrages CES - Application aux Meskat. Mémoire de fin d'études du cycle de spécialisation. INAT, Tunis, Tunisia.

Yahyaoui, H. and M. Ouessar. 2000. Abstraction and recharge impacts on the ground water in the arid regions of Tunisia: Case of Zeuss-Koutine water table. UNU Desertification Series No. 2, 72-78.

Chapter Three

Indigenous Water-Harvesting Systems in Jordan

Abed Al-Nabi Fardous(1), **Awni Taimeh**(2) **and Moh'd Jitan**(1)
(1) National Center of Agricultural Research and Technology Transfer (NCARRT), Amman, Jordan. (2) Faculty of Agriculture, University of Jordan, Amman, Jordan

Introduction

It is widely acknowledged that water scarcity is one of Jordan's most pressing national problems. Not only is water security crucial for Jordan's agricultural development, it is also essential for assuring the well-being of its domestic and industrial sectors. The limited amount of available water resources in Jordan made the people realize the importance of water-harvesting techniques as long ago as the Roman and Byzantine era. Archaeologists have found widespread evidence of such practices as the collection of rainwater from the surfaces of rocky land, roofs, and watersheds. The collected water was stored in natural reservoirs, cisterns, pits excavated from rock, and wells.

Available surface water and groundwater resources in Jordan are, respectively, about 880 and 200 million m^3. The total area of Jordan is around 89 206 km^2. About 94% of this area receives less than 200 mm of annual rainfall; almost 72% of the country receives less than 100 mm/yr. The total amount of annual rainfall received is approximately 8.6 billion m^3. It is estimated that more than 90% of this is lost to evaporation (WAJ 1998). This indicates the importance of water harvesting for Jordan.

It is important to review the historical development of water-harvesting practices, and thus gain knowledge from traditional experience, if we are to improve the efficiency of existing systems. The objective of this paper is to present an overview of indigenous water-harvesting systems in selected sites in Jordan. Old indigenous water-harvesting techniques have been described and documented, and such documentation can be used as a guideline by engineers and farmers for field applications. The socioeconomic impacts of water-harvesting practices, as well as environmental factors for each site, are also highlighted here.

Background

Indigenous water-harvesting techniques in Jordan were developed by people living under arid and semi-arid conditions. Under these conditions, rainfall is low and occurs only over a short period in the year. For these people, available surface water was the only source of water: no alternative water source was available to them for drinking and irrigation.

Because agriculture was the major economic activity of early Jordanian society, human labor and other types of inputs were invested in agriculture, and therefore in the collection of runoff water. The building of water-harvesting structures, the cleaning and smoothing of runoff catchments and the maintenance of canals and reservoirs were labor-intensive work.

The options for developing additional sources of water in Jordan are limited. The most promising one entails the utilization of flash floods that occur in the eastern part of Jordan or the capture of rainfall water in the highlands, which would otherwise be lost, using appropriate water-harvesting techniques.

In Jordan, about 80% of the total amount of the country's precipitation falls over arid areas that receive less than 200 mm of annual rainfall. The amount of water involved is estimated as being, on average, 4.0 billion m^3/yr. Most of this water flows either into salt sinks, such as the Dead Sea, or into the desert, where it is lost by evaporation. A very limited amount percolates into the ground and recharges groundwater resources. Therefore, it is imperative that such water losses be converted into a useful stored resource (either in the soil profile or in surface and subsurface reservoirs) which can subsequently be usefully used.

Agriculture using surface runoff and rainwater-harvesting techniques was extensively practiced in Jordan as long as 4000 years ago. Archaeological investigations have found that farmers in Jordan cultivated land in areas with an annual rainfall of 100 mm. Floodwater from *wadis* with ephemeral flow were also routed through channels and spread to flat areas with deep soil.

That water-harvesting techniques developed in Jordan is a fact which is not questioned; the evidence of these techniques appears in many locations. There are indications of early water-harvesting structures being constructed in sites more than 4000 years old. Pools, *hafā'ir* (earthen tank dug into the ground with a capacity of a few thousand cubic meters) and cisterns have been found in most ruins and archaeological sites in the country. Some of these structures are still in good working order, such as the Roman pools near Ma'daba, Mwaggar, Ajloun, and the Nabataean dams and cisterns. Water was delivered to Petra (capital of the Nabataean kingdom) from rain harvested from the surrounding mountains. This

Roman water pond hafā'ir still in use in northern Jordan.

water was channeled and piped to the city during winter and stored in cisterns and excavated rock reservoirs for domestic use during the rest of the year. Rainfed agriculture outside the cities was also supported by harvested water.

Different water-harvesting techniques can be found in Jordan, depending on the climate, topography, and soil type of the area considered. In the arid desert area (Umm Al-Jimal), deep cisterns and pools were used to provide drinking water for both people and animals. In marginal areas, large pools were used for supplemental irrigation and the watering of animals. In mountainous terrain, reservoirs dug into the rock have been found in Shoubak, Tafilah, Ajloun, Karak, and around Amman. Cisterns of different forms, depending on the soil type, were used for domestic use; such cisterns can be found in almost all rural areas.

The most productive period in Jordan's history began with the arrival of the Nabataeans, late in the third century BC. Runoff farming continued throughout Roman rule and the Byzantine era. Water harvesting reached its peak during the Islamic era, during which water control structures, used to support agriculture and provide drinking water, were under the supervision of the state. During this period, water management (including the management of floodwater) was regulated and water rights were legislated for.

Indigenous Water-Harvesting Systems

A survey has been conducted that covered most of the ancient water-harvesting sites and locations in Jordan. The survey was carried out in cooperation with the Regional Agriculture Research Centers of Al-Shoubak and Ramtha. Site visits and data collection effectively started in June 1996. Several ancient locations were investigated, namely Ajloun, Unjoraeh, Ibleen, and Ibbeen (in the north), Petra, Al-Byddah, Ma'an, and several sites at Al-Shoubak (in the south), Mafraq, Umm Al-Jimal, Umm Al-Quttain, Amra, Al-Khalidieh and Safawi (in the east), and Ma'daba near Amman (in the west). For each location, the following information was collected:

- Longitude, latitude, and elevation
- Historical information (date and reason for site establishment)
- Current situation and status of the site
- General information about the location concerned with catchment, use and users
- Soil type, structures, rock types and vegetation cover
- Sketches of the site and/or location.

About fifty sites were visited and described. Schematic figures and diagrams for the system components and site layout were also drawn. Fig. 3.1 shows the location of the ancient water-harvesting sites visited in the survey. These ancient systems are classified, in this report, into the following: cisterns, water ponds and *hafā'ir* , water conservation works, and wells. Appendix A summarizes the information collected in the survey. A brief description of each site, along with a description of the water-harvesting system used, is also given.

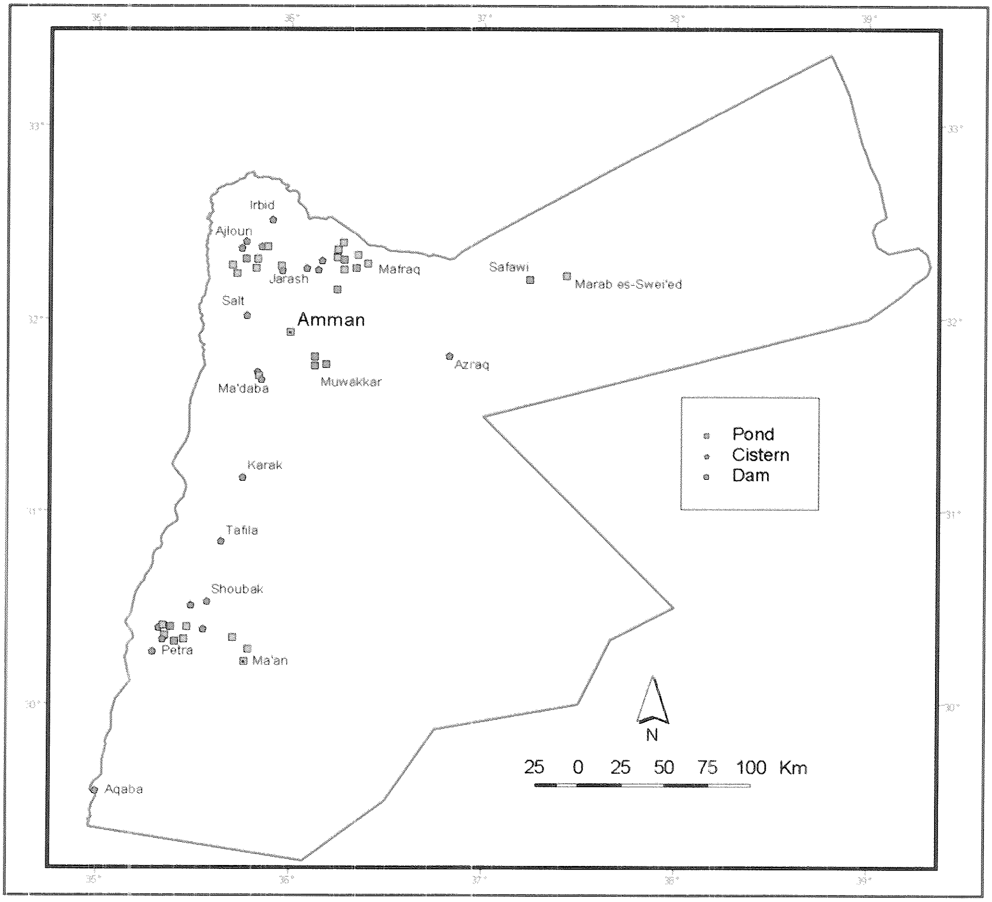


Fig. 3.1. Location of the ancient water-harvesting sites visited in the survey.

Cisterns

Collecting rainwater from roofs or impervious catchment areas and channeling it into cisterns is a technique that was practiced by individuals in rural areas until only a few decades ago. This used to be a common practice, used to provide water for household purposes and for consumption by animals. However, due to urbanization and the provision of tap water to most villages, this practice has gradually been abandoned.

The diversion channel and the entrance of a Roman cistern in northern Jordan.

The typical cistern used for water storage is an oval tank dug into the ground to a depth of 3 to 12 m. Such cisterns have a capacity of 60 to 200 m^3. Construction begins by digging a cylindrical hole in the soil until the parent material is reached. Such holes are 1 m in diameter and are protected by masonry work. An oval cistern is then excavated from the rock. The inside of the cistern is then plastered with a cement and sand or lime and sand mortar.

Water Ponds and *Hafā'ir*

The storing of water in large surface reservoirs or ponds is a technique practiced in many parts of Jordan. The water harvested in this way is used either for full or supplemental irrigation, or for other purposes, such as domestic uses (by the Bedouin), and the watering of livestock. The surface reservoirs or *hafā'ir* are trapezoidal. Their walls are protected by riprap (a stone lining), while their bottoms are usually lined with concrete, or another impermeable material, to reduce seepage.

Water is channeled to such reservoirs by building a weir across the *wadi,* in order to raise the water level. When the reservoir is full, the water flow to the reservoir automatically stops. The channel to the reservoir is provided with a head gate, to allow the flow of water to be controlled. At the beginning of the rainy season the control gates are kept closed, to prevent the first rush of floodwater from entering the reservoir.

Harvested water is used for irrigation and, sometimes, to water animals. The water is bailed or pumped from the reservoir using a hand pump or a motor pump. is recommended that such reservoirs be equipped with a graded sand filter if

A water harvesting pond used by the Bedouins to water their animals in northern Jordan.

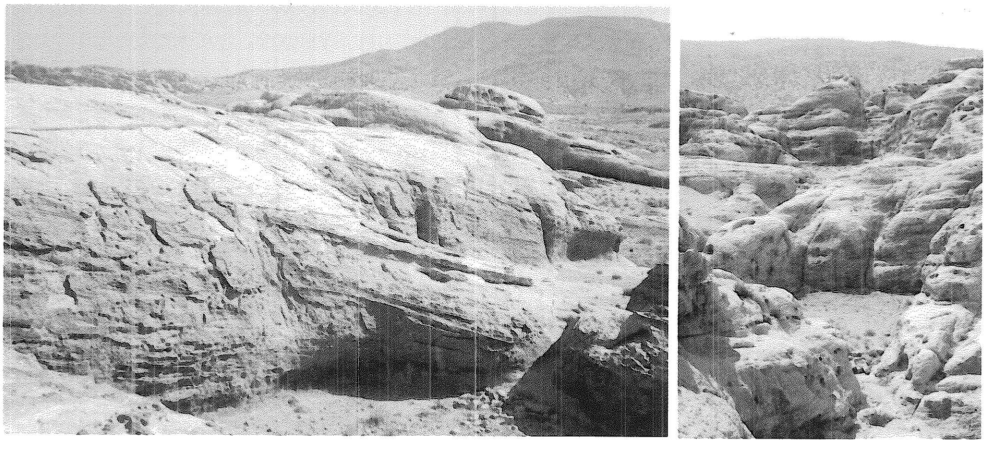
they are to be used to provide water for livestock. The following sites have been visited and described: the Al-Da'janieh, Unizeh, Abu Al-Ra'ah and Ain Mulghan ponds at Ma'an; the Al-Byddah rock excavated ponds, the Petra pond, the Paleston pond, and the Fouram pond at Wadi Mousa; the Ibben ponds, the Al-Rabbad Castle pond, the Al-Barahmeh pond, the Al-Makatti Jimal pools, the Amra pools, the Sabha pools, the Manshieht Al-Qubblan pond, the Al-Dafyaneh pool, and the Umm-Al-Quttain ponds in Al-Mafraq.

Water Conservation Works

Water conservation works are used as water-harvesting and soil-conservation measures. The following practices have been used in several of the soil-conservation projects carried out in Jordan:

- earth banks
- *gradoni* terraces (contour ditches mainly used for growing trees)
- bench terraces
- contour stone terraces
- stone and reinforced concrete structures
- micro-catchments
- check dams.

In the survey, the following locations were visited and described: the Al-Byddah dams (several steppe dams) at Wadi Mousa; Al-Rabbad Castle at Ajloun; Abu Al-Ra'ah at Ma'an; the Al-Khalidieh dam, the Salameh Qutish dam and the Al-Ghadeer Al-Abiad dam, at Al-Mafraq; Marab Swai'ed, at Al-Azraq/Safawi; and an area where water spreading is practiced, at Al-Byddah, using stone terraces.



(a) *(b)*

A Nabataean dam and excavated spillway: (a) from upstream, (b) from downstream.

Wells

Historically, wells of different sizes and shapes have been used for water harvesting in Jordan. Among the visited sites (Appendix A) were the Kherbit Saleem wells (about 5 wells of different sizes), the Al-Rabbad Castle wells at Ajloun; the Al-Zawaidih and Al-Badieh wells (about 20 wells of different sizes) at Unjoraeh; the Kherbit Al-Qannas wells (about 30 wells) at Al-Shoubak; the Al-Makatti wells; the Al-Jia'a Rihab wells; and the Tall Hisban wells, near Ma'daba.

Some of the wells are carved into rock. Among the sites visited, the following are examples of such wells: the Al-Byddah wells (about 100 wells) at Wadi Mousa; the Al-Arayes well (three large square chambers carved out of rock) at Wadi Mousa; the Al-Rabbad Castle wells (about 20 wells) and the large cisterns known as Al-Sieh; the Dir Al-Yous at Ajloun; and the Petra wells, the Al-Amareen wells, the Wadi Araba wells, and the Seiq Bydda wells at Wadi Mousa.

Conclusions and Recommendations

A large part of Jordan is desert, and a significant amount of the country's rainfall is lost as a result of evaporation and runoff. If these resources were properly managed, with appropriate water-harvesting schemes being used to save 10% to 15% of the total amount of water currently being lost (about 6.6 billion m^3), Jordan would be able to increase groundwater recharge and double its agricultural production. It is anticipated that the amount of water harvested per year would be almost equal to the amount of water used in the country during 1994. In addition, if part of that harvested water were to be stored in appropriate, specially treated reservoirs, it could be used not only for agricultural production, but also for domestic and industrial purposes.

Different water-harvesting techniques (such as cisterns, *hafā'ir* and earth dams) were widely used in Jordan in the past. In an effort to encourage Jordanian farmers to adopt more productive and stable land-use systems, the Jordanian government, through organizations associated with the Ministry of Agriculture, initiated several programs for soil and water conservation. The aim of these programs is both to ensure the better utilization of Jordan's limited water resources and to improve and stabilize agricultural production. A number of these programs are described below.

The National Center for Agricultural Research and Technology Transfer and the University of Jordan have conducted several studies on the application and evaluation of water-harvesting practices under local conditions. Madanat (1988) has evaluated the performance of water-harvesting systems under three runoff-inducing treatments: natural, bare land; polyethylene sheeting; and paraffin wax soil surface sealant. These treatments were used on different contribution (catchment) areas. The results obtained showed that the runoff efficiencies of the polyethylene, paraffin wax, and natural soil treatments were 95%, 55% and 21%, respectively. In addition, the study concluded that stored available moisture in the soil profile reached a maximum of 83% of total available moisture during wet periods, and a minimum of 41% during dry periods for the different treatments.

During the early 1970s, the Ministry of Agriculture initiated a project for the development of the areas that depend on contour terracing as a water-harvesting technique for fruit tree planting (Jordan Highland Development Project). The project was financed by the FAO. Different water-harvesting techniques were implemented. The total area covered by the project was about 6000 ha.

At the end of the 1980s, the Zarqa River Basin Project was initiated. The aim of the project was the implementation of appropriate land uses, in order to prevent land degradation and the erosion of soils in that area. In addition, the project aimed to reduce the sediment load of water feeding the King Talal reservoir. A total area of 3000 ha was covered by the project.

Another project is underway at the Al-Hammad basin in the northeast of Jordan. In this project, *hafā'ir* and ponds are being built to provide harvested water for livestock, and good quality drinking water for the people living in that area.

Between 1985 and 1987, a research project (the Balama Project) was carried out at Wadi Al-Ddulyl. The results of this project indicated that a large amount of water could be collected or stored in the soil profile simply by using micro-catchment water harvesting. In addition, the technique was found to reduce soil erosion. Thus, it was found to be possible to retain a good fertile soil that had a relatively high organic matter content.

In 1985, an important project (the Muwaqqar Project) was started in eastern Jordan (30 km southeast of Amman). The aim of this project was to develop lands that receive 100-200 mm of annual rainfall. A second phase of this project (the Jordan Arid Zone Productivity Project) is being carried out as a joint venture between the Faculty of Agriculture, University of Jordan, and the European Union.

The above-mentioned projects indicate that water harvesting is indeed an important part of Jordan's research and development agenda.

Bibliography

Abujaber, R.S. 1995. Water collection in dry farming society. Department of Antiquities, V-5, Amman, Jordan.

Al-Labadi, A.M. and J. Abu-Mushrif. 1994. Water harvesting in Jordan: Existing and potential systems. p. 211–230. *In* Water Harvesting for Improved Agricultural Production, Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21-25 November 1993. FAO Water Reports 3. FAO, Rome, Italy.

Buol, S.W., F.D. Hole and R.J. McCracken. 1980. Soil Genesis and Classification. 2nd edn. The Iowa State University Press, Ames, Iowa, USA.

Fink, P.H. and G.W. Frasier. 1977. Evaluating weathering characteristics of water-harvesting catchment from rainfed-runoff analysis. *Soil Science Society of America Journal*

41: 618-622.

Frasier, G. 1994. Water harvesting/runoff farming systems for agricultural production. p. 57–71. *In* Water Harvesting for Improved Agricultural Production, Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21-25 November 1993. FAO Water Reports 3. FAO, Rome, Italy.

LaBianca, O.S. 1995. On site water retention strategies: Solutions from the past for dealing with Jordan's present water crisis. Studies in the History and Archaeology of Jordan, V. Amman, Jordan.

Lancaster, W. and F. Lancaster. 1995. The traditional systems of water conservation in the Eastern Badiya of Jordan. Studies in the History and Archaeology of Jordan, V.5. Amman, Jordan.

Madanat, L.O. 1988. Evaluation of a water-harvesting system efficiency in Al-Muwaqqar area. MSc thesis. University of Jordan, Amman, Jordan.

Mare, W.H. 1995. The technology of the hydrological system at Abila of the Deapolis. Department of Antiquities, V-5, Amman, Jordan.

Oleson, J.P. 1995. The origins and designs of Nabatean water supply systems. Studies in the History and Archaeology of Jordan, V.5, 1995.

Oweis, T. and D. Prinz. 1994. Identification of potential water harvesting areas and methods for the semi-arid regions of West Asia and North Africa: a proposal for a regional research project. p. 401–411. *In* Water Harvesting for Improved Agricultural Production, Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21-25 November 1993. FAO Water Reports 3. FAO, Rome, Italy.

Shatanawi, M.R. 1994. Water harvesting in Jordan and the region: present situation and future needs. p. 391–399. *In* Water Harvesting for Improved Agricultural Production, Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21-25 November 1993. FAO Water Reports 3. FAO, Rome, Italy.

Siegert, K. 1994. Introduction to water harvesting: some basic principles for planning, design and monitoring. p. 7–21. *In* Water Harvesting for Improved Agricultural Production, Proceedings of the FAO Expert Consultation, Cairo, Egypt, 21-25 November 1993. FAO Water Reports 3. FAO, Rome, Italy.

Taimeh, A.Y. 1988. Agriculture Production in the Semi-arid to Arid Land and Areas Suffering from Desertification. University of Jordan, Amman, Jordan.

United Nations Environment Program. 1983. Rain and storm-water harvesting in rural areas. Tycooly International Publishing, Dublin, Ireland.

WAJ (Water Authority of Jordan). 1998. Annual Report. WAJ, Amman, Jordan.

Appendix A. Basic information and brief descriptions of ancient water-harvesting sites in Jordan.

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
1	Al-Zawydeh wells	Ajloun/Umm Al-Khasheb village	About 200 years ago	To provide drinking water for use by laborers during the olive harvesting season	To provide drinking water for agricultural laborers	Wells, 5 m deep, 2 m in diameter at the top, and 6 m at the bottom, with a small catchment area of 20 m x 15 m
2	Al-Badieh wells	Unjoraeh	Roman era (AD 63-628)	To provide water for drinking and domestic uses	To provide water for drinking and for watering livestock	About 20 wells of different sizes (4-12 m deep, 2-10 m in diameter), located up a hill, some are connected. Small catchment area (4 m x 4 m) for each well
3	Ibbeen ponds	Ajloun	About 200 years ago	To provide water for animals	To provide water for construction purposes and for the watering of livestock	Three natural ponds (one totally demolished) exist within a popu lated area. Their size is about 100 m in length and 30 m in width. They are 2-3 m deep.
4	Al-Barahmeh pond	Ajloun	Roman era (AD 63-628)	To provide water for drinking and the watering of livestock	To provide water for the watering of livestock	The dimensions are 60 m x 30 m and it is 3-4 m deep, with more than 5 ha catchment area. It is in good shape.
5	Dir Al-Yous well and pond	Ajloun	Roman era (AD 63-628)	To provide water for drinking and recreational purposes	To provide water for the watering of livestock and drinking	An ancient Roman site consisting of a pond (15 x 15 m and 2-. 3m deep), and an adjacent well (2-4 m in diameter, and 5 m deep). The site is excavated in the rocks up a mountain.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
6	Kherbit Al-Qannas wells	Al-Fujyj/Al-Shoubak	Around AD 400	To provide drinking water to people going to Mecca on pilgrimage	Neglected	About 30 wells of various sizes (5-10 m deep). They were excavated in the limestone, each well has its own small catchment area (about 10 m in diameter) located near an old station built to serve the Muslim people going to Mecca.
7	Unizeh pond	Ma'an	During the Ottoman period (AD 1516-1918)	To provide water for a station on the Hijazi rail-road	To provide water for the watering of livestock	A pond near the highway from Amman to Aqaba, built of stone. Its dimensions are 20 m x 25 m, and it is 5-6 m deep.
8	Al-Da'janieh pond	Al-Hashimieh/ Ma'an	Nabataean period (BC 400-AD 63)	To provide water for a Nabataean security check point	To provide water for the watering of livestock	A pond built from rock: 50 m in length, 30 m wide, and 5-6 m in depth; it is in good condition.
9	Abu-Al-ra'a tunnels	Ma'an	Roman era (AD 63-628)	To provide water for agricultural purposes	Totally demolished; this structure requires professional investigation and renovation	Deep tunnels under the ground, about 10 km in length; only the surface manholes can be seen. At the tunnel's end (after 10 km) a pond appears and acts as a reservoir and a place from which water can be diverted to irrigated fields.
10	Ain Mulghan	Ma'an	Roman era (AD 63-628)	To provide water for drinking and the watering of livestock	To provide water for irrigation	Two small ponds (15 x 5 x 1.5 m) and a well (4 x 4 x 10 m), built as a reservoir to collect and save water provided by a spring.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
11	Al-Rabbad Castle pond	Ajloun	Roman era (AD 63-628)	To provide water for drinking and the watering of livestock	Used to provide water for the watering of livestock until 60 years ago	A big reservoir (17 x 28 m, and 9 m deep), built of stone, and used to collect water from a steppe (25% slope). It is neglected at present.
12	Al-Rabbad Castle wells	Ajloun	Roman era (AD 63-628)	To provide water for drinking	Neglected	Several cylindrical wells, built of stone and having an excellent hydraulic design. Some are excavated from rock. They are 8-9 m deep, and about 5 m in diameter. Some are rectangular (10 m x 5 m) and 5 m deep.
13	Al-Rabbad castle moat (water-filled security ditch)	Ajloun	Roman era (AD 63-628)	To provide water for use as a security measure-to prevent the invasion of the castle by providing a water barrier	A historical monument. Dry at present.	This large ditch (20m deep and 15-25 m wide), dug around the castle, was intended to be filled with water, acting as a water barrier against would-be castle invaders. The catchment area is the castle itself (about 0.5 ha).
14	Kherbit Saleem wells	Ajloun	Most are from the Roman era (AD 63-628), but some are newly established (several years ago)	To provide water for drinking, irrigation and the watering of livestock	Used by the owner of a farm to provide drinking water and water for livestock	Several pear-shaped wells (five), excavated from limestone rocks; the size ranges from small ones (3 x 4 x 3 m) to larger ones (8 x 7 x 8 m).

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
15	Al-Byddah wells	Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide water for drinking and the watering of livestock. The large ones were use to provide water for irrigation.	The good ones are still being used for watering livestock	About 20 wells have been excavated deep inside the rocks, most of them are cylindrical, with three different diameters (2 m at the opening, 4 m neck, and 6 m for the well itself). They are 8 m deep. The catchment area is part of the upper rocky mountains (and does not exceed 1000 m2); small canals (20 cm x 30 cm), also excavated from the rock, divert the water to the wells.
16	Wadi Al-Byddah dams	Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide water for irrigation. Some of this water used to refill drinking water wells.	Neglected	Several dams built in the mountains, some are natural and some are man-made (rock-excavated). The size of the dams ranges widely depending on the topography of the mountain (from 100 up to 1000 m3).The dams are built as a series from the top to the bottom, i.e. when the upper dam is full, the water runs, by gravity, through excavated canals to the lower ones. The catchment area is the upper bare rocks

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
17	Al-Arayes Well	Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide drinking water and water for watering livestock-through the collection of rain water from the surface of rocks	To provide water for the watering of livestock	A large reservoir excavated in the bottom of the mountain, consists of three large rooms (5 x 8 x10 m) each, with stairs for access, the total area is 15 x 20 m, with 10 m deep. The catchment area is the rock surface of the mountain (about 2000 m2).
18	Byddah ponds	Wadi Mousa	Nabataean era (BC 400-AD 63)	Irrigation	Neglected	Two ponds excavated in the rocks: one is 20 x 20 x 2 m, which collects water from the mountain; the other is 10 x 8 x 10 m which collects water from the surrounding area (about 0.2 ha).
19	Al-Petra reservoir	Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide drinking water and water for irrigation	Still being used to provide drinking water and water for irrigation	A small pond (5 x 4 m) and 3 m deep, built from stones, which acts as a reservoir down a spring stream. It holds the water and diverts it to Petra through buried tunnels. Some of this water is diverted to irrigate trees in orchards.
20	Tall Hisban	Madab	Roman era (AD 63-628), reconstructed during the 1990s	To provide drinking water	The site is being reconstructed by American Center for Oriental Research	A large reservoir built from stones; the reservoir is 8 m x 5 m and 4 m deep. At the same location two small pear-shaped wells are also found. The catchment area is about 0.2 ha.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
21	Palestone pond	Petra/Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide drinking water for the people living inside Petra	Neglected. A historical monument.	A pond excavated close to the base of a rocky mountain (the catchment area is the mountain). Its dimensions are 10 m x 8 m, and it is 1.5 m deep.
22	North Palestone dam and pond	Petra/Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide water for agricultural purposes	Neglected. Some trees are present indicating the system's efficiency.	A small dam built across a groove (a mountain waterway) to divert runoff water to a nearby pond (20 m x 15 m) and is used for agricultural purposes.
23	Petra wells	Petra/Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide drinking water	Neglected	Two square 'rooms' excavated inside the mountain (5 x 4 x 8 m deep), with 2 x 2 m front window opening. The catchment area is about 1000 m2.
24	Fourm pond	Petra/Wadi Mousa	Roman era (AD 63-628)	To provide drinking water and to serve as an emergency reservoir	Neglected	A pond built up from stones, 10 m x 18 m and about 2 m deep. The catchment area is about 0.5 ha.
25	Seiq Bydda well	Petra/Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide drinking water	Neglected	A cylindrical well (2 m in diameter and 4 m deep) excavated in the rocks. The catchment area is the cliff of a nearby mountain. The well is served by a 4 m x 4 m pond that is 1 m deep, and a sedimentation pond (1 x 1 x 1 m).

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
26	Al-Amareen dam and well	Petra/Wadi Mousa	Nabataean era (BC 400-AD 63)	To provide water for agricultural purposes	The dam was rebuilt by the owner of the land for irrigation but was not technically sound. The dam is still providing some water, but is not efficient.	Two dams were built in the groove (a mountain waterway) and a well was excavated in the rocks to obtaindrinking water. The excess water from the dam is delivered to this well. The catchment area of these dams is the slopes of the mountains.
27	Wadi Araba wells	Petra/Wadi Mousa	Roman era (AD 63-628)	To provide drinking water and water for livestock	The well is still used by Bedouins to water livestock and provide drinking water	The well is built up from stones (4 x 7 m; 8 m deep), it is open at the top (but used to be covered). The catchment area is about 0.3 ha with a 1 x 1 m sedimentation pond.
28	Al-Makattia wells and ponds	Ajloun/Ibbeen	Roman era (AD 63-628)	To provide drinking water and water for livestock	To provide water for livestock	Several wells, and small ponds excavated up a mountain. Some wells are pear-shaped, 4 m deep and with a 3 m bottom radius. The catchment area is small (1000-2000 m2).
29	Al-Makattia wells (Al-Jia'a)	Ajloun/Ibbeen	Roman era (AD 63-628)	To provide drinking water and water for livestock	To provide water for livestock	Pear-shaped and square wells with a adjacent square excavated pond. The wells are 2-3 m deep. The pond is 4 x 4m and 2 m deep. The catchment area is 0.5 ha.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
30	Al-Makattia ponds	Ajloun/ Ibbeen	Roman era (AD 63-628)	To provide water for livestock	To provide water for livestock	Excavated ponds similar to those built by the Nabataeans in the south.They are also equipped with silt traps. An adjacent well is also present at the same site.
31	Dew Traps	Ajloun/ Ibbeen	Roman era (AD 63-628)	To provide water for livestock	Neglected	Small catchment areas (1.5-2.5 x 1.5-2.5 m) of bare rock. Grooves are excavated into this small area with a slope down to a small reservoir (25 x 30 cm) that is 30 cm deep. This is enough to collect dew drops which can be used to water a small number of livestock in the early morning.
32	Samta pond	Ajloun/Samta Village	Roman era (AD 63-628)	To provide drinking water and water for livestock	Neglected	An excavated pond (10 m x 12 m) with a depth of 2-4 m according to the slope of the area adjacent to the pond. The catchment area is about 3000 m^2.
33	Sheen pond	Ajloun/Samta Village	Roman era (AD 63-628)	To provide drinking water and water for livestock	Neglected	An excavated pond (10 m x 15 m) with a depth of 2-3 m. The catchment area is about 5000 m^2.
34	Leestep pond	Ajloun/Samta Village	Roman era (AD 63-628)	To provide water for irrigation and livestock	Neglected	An excavated pond (25 m x 15 m) with depth 2- 5 m. The catchment area is about 1 ha.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
35	Rihab pond and wells	Al-Mafraq	Roman era (AD 63-628)	To provide water for irrigation and the watering of livestock (wells for drinking)	Neglected, though a few wells are being used for limited agriculture/domestic purposes.	A pool built up from stones, 52 x 40 m in size, 4-5m deep. Several wells (more than 20) are excavated near this pond.
36	Marabb Swai'ed	Al-Azraq	Natural	To provide water for agricultural purposes and animal grazing	To provide water for irrigating field crops and grazing	A natural depression, used for planting wheat and barley and for grazing animals.
37	Umm Al-Jimal pools	Al-Mafraq/ Umm Al-Jimal village	Roman era (AD 63-628)	Multi-purpose	Only the reservoir is used to supply water for drinking and other purposes.	The system is designed to collect surface water from upstream first into an excavated rock pond then into an underground reservoir (10 m x 4 m) that is 3 m deep. This is used for to supply drinking water. Then it is connected to a big pool (25 m x 35 m) that is 5 m deep, to provide water for various purposes.
38	Amra pond	Al-Mafraq/ Amra village	Roman era (AD 63-628)	Multi-purpose	Totally neglected	An old reservoir with irregular shape. It is neglected due to the death of civilians in the area as a result of drowning in the reservoir.

Appendix A. (Continued)

Site no.	Site name	District area	Date of establishment	Reason for establishment	Current uses	Site descriptions
39	Sabha pool	Al-Mafraq/ Sabha village	Rehabilitated by the Jordanian government during the late 1970s.	Multi-purpose	Used by villagers for livestock	A square pond (120 m in diameter with depth of 2-3 m). This was built by the government of Jordan to serve the villagers.
40	Manshiet Al-Qubblan pond	Al-Mafraq/ Al-manshie village	Rehabilitated by the Jordanian government during the late 1970s.	Multipurpose	Used by villagers for watering livestock.	A square pond (100 m in diameter with a depth of 2-3 m). It was built by the government of Jordan to serve the villagers.
41	Al-Dafyaneh pool	Al-Mafraq/ Al-Dafyaneh village	Roman era (AD 63-628)	Multi-purpose	Used by villagers for limited agricultural purposes.	A small square pond (50 m in diameter with a maximum depth of 2.5 m) was rebuilt by the Jordanian government to serve the local people.
42	Um-Al-Quttain large pool	Al-Mafraq/ Umm Al-Quttain village	Roman era (AD 63-628)	Multi-purpose	Used by villagers for limited agricultural and domestic . purposes	A big reservoir (50 m x 50 m; 10 m deep), used to collect water from upstream. The reservoir is well established and was rebuilt by the government of Jordan.
43	Umm Al-Quttain small pool	Al-Mafraq/ Umm Al-Quttain village	Roman era (AD 63-628)	Multi-purpose	Used by villagers for limited agricultural and domestic purposes.	A reservoir (25 m x 25 m; 8 m deep). The reservoir is well established and was rebuilt by the government of Jordan.

Chapter Four

Indigenous Water-Harvesting Techniques in Morocco

Mohammed Karrou and Mohammed Boutfirass
National Institute for Agronomic Research (INRA), Agronomy Department, Aridoculture Center, Settat, Kingdom of Morocco

Introduction

Water has always been an important component of societal development. Many of the powerful and sustainable civilizations of the past developed in areas where just enough water was available. These civilizations developed irrigation schemes and hence agricultural production, which was the main source of income. In dry areas, where water was scarce and where drought was more likely, people developed techniques for collecting and storing rainwater for domestic uses, the watering of livestock, and the irrigation of crops. Such water harvesting not only helped people survive drought, it also insured their well-being.

The main reasons for the development of water-harvesting techniques were that alternative sources of water for drinking and irrigation were not available, and the expertise needed to pump groundwater did not yet exist. Following the technological developments of the 19th century, however, small irrigation schemes and water-harvesting techniques received little attention—large irrigation schemes were encouraged instead. But, because of population growth during the 20th century and the appearance of new water uses (which have increased competition for the limited amounts of water available) more interest is now being shown in water-harvesting techniques, though mainly in arid and semi-arid areas.

In Morocco, both indigenous water-harvesting techniques and small irrigation systems are still used in many regions. Among the well-known water-harvesting systems in use in Morocco's arid and semi-arid areas are the *matfia* (cistern), which was introduced into the country by the Portuguese in the 16th century, when they colonized cities on the coast of the Atlantic Ocean, and the *rhettara* (*qanat*), an underground water-harvesting system developed during the period of the Almohad (AD 1147-1269).

Since the 1960s, the government of Morocco has encouraged large-scale irrigation. Although a major effort has been made in terms of the construction of dams, water resources are becoming more and more scarce. In addition to the problem of water scarcity, only 1.6 million ha of Morocco's 9.2 million ha of arable land show the potential for irrigation (1.3 million show potential for perennial irrigation and 0.3 million show potential for seasonal irrigation). Around 67% of the country's 7.6

million ha of rainfed cropland is located in arid and semi-arid zones, where the risk of crop failure, water losses through runoff and evaporation, soil erosion, and desertification are very high. Fig. 4.1 shows a map of the agroecological zones of Morocco.

To insure agricultural production and sustainability in the arid and semi-arid areas of Morocco, and to reduce the migration of rural people to the cities, new sources of water need to be found and sound techniques for water management need to be developed, in order to meet the demands of humans, animals, and plants. Rainwater is one of the potential, under-developed, water resources in such areas. One strategy for improving the efficiency with which rainwater is used is the development of adapted techniques for the collection and storage of runoff water. However, in order to adapt such technologies, it is important to first describe and evaluate the existing techniques. This will allow us to improve them and to propose other, more efficient, alternatives.

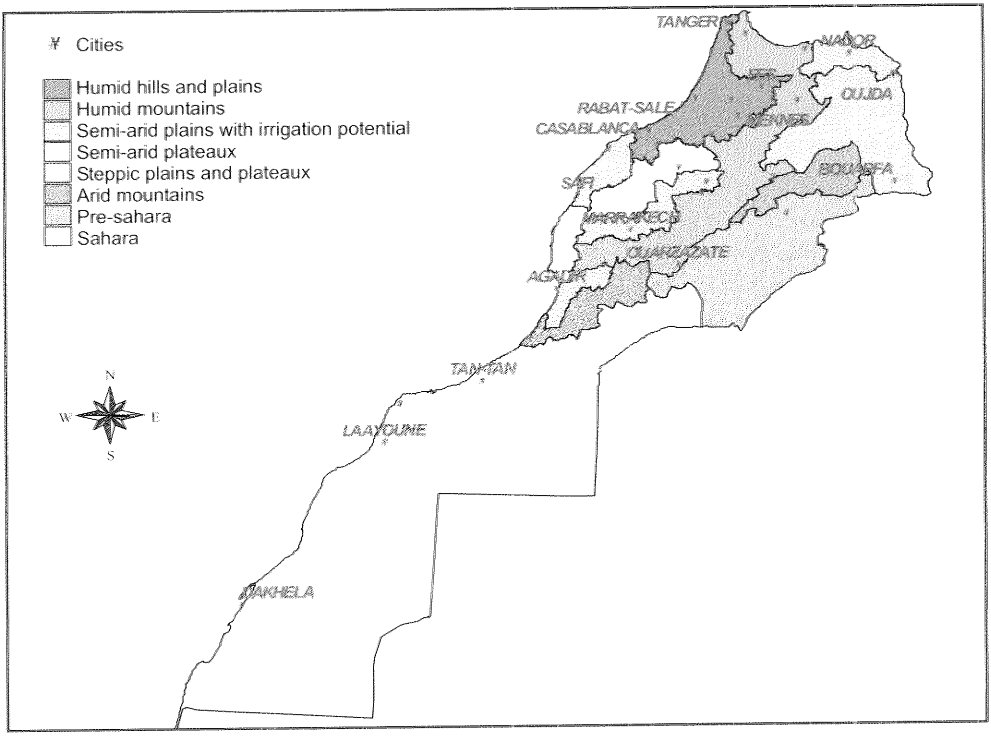


Fig. 4.1. Agroecological zones of Morocco.

Background

Morocco receives, on average, 150 billion m^3 of precipitation per year (Benazzou 1994). Its general rainfall pattern shows a decrease in rainfall both from the north to the south of the country, and from the west to the east. Annual rainfall varies, from 1500 mm in some regions in the north (Rif Mountains) to less than 50 mm in the south (Fig. 4.2).

The rainy season in Morocco occurs, in general, from November through April. Approximately 80% of the precipitation delivered returns to the atmosphere through evapotranspiration: only 30 billion m^3 (comprising infiltration and runoff water) is considered to be potentially 'useful' rainfall. This potentially useful water consists of 22.5 billion m^3 surface water and 7.5 billion m^3 groundwater (Benazzou 1994). The management of this resource, and of the associated hydraulic infrastructure (i.e., dams and reservoirs), currently allows only 10.9 billion m^3 of water to be used effectively (7.3 billion m^3 surface water and 3.6 billion m^3 of groundwater). In 1990, most of the water effectively used (92%) was used in agriculture, but more competition is expected from other sectors (domestic and industrial) in the future. Prediction studies indicate that by the year 2020 only 81% of this water will be used by agriculture (AGR 1995). What is more, water requirements will, by this time, be greater than the available water resources.

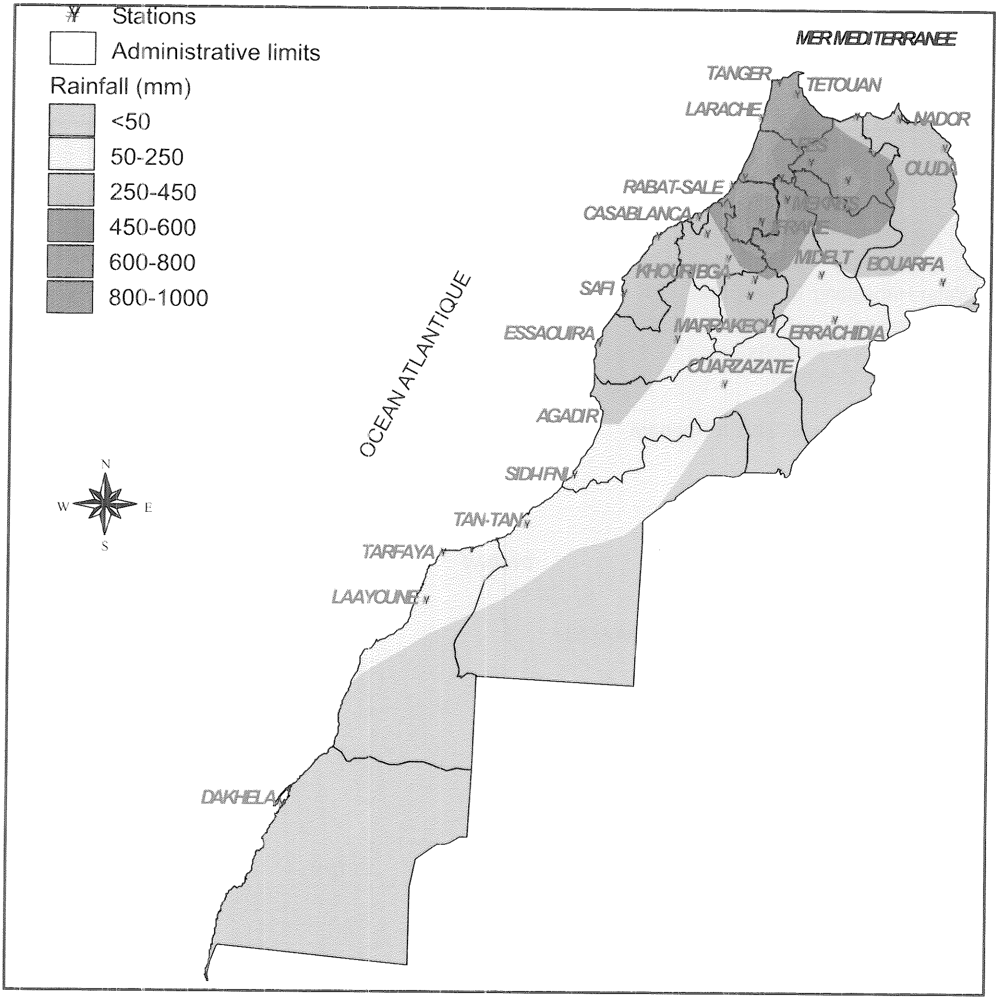


Fig. 4.2. Distribution of annual rainfall in Morocco.

Indigenous Water-Harvesting Techniques

Various water-harvesting systems are found in Morocco. The different techniques are discussed below, while Fig. 4.3 shows the distribution of water-harvesting techniques throughout the country.

Rhettaras

The *rhettara* is an underground handmade tunnel that functions as a channel. This channel conveys water from the aquifer to the surface of the ground, and follows a regular slope. A series of wells are dug along the length of the tunnel, to function as vertical access shafts for construction work, maintenance and cleaning (Fig. 4.4). The distance between the wells is usually 20 to 25 m. In regions where the tunnel does not lie as deeply below the surface, this distance is only 4 to 6 m. The first *rhettara* was built in 1071 on Marrakesh's Haouz Plain, and others were built during the 11th and 12th centuries. Very few are of recent construction.

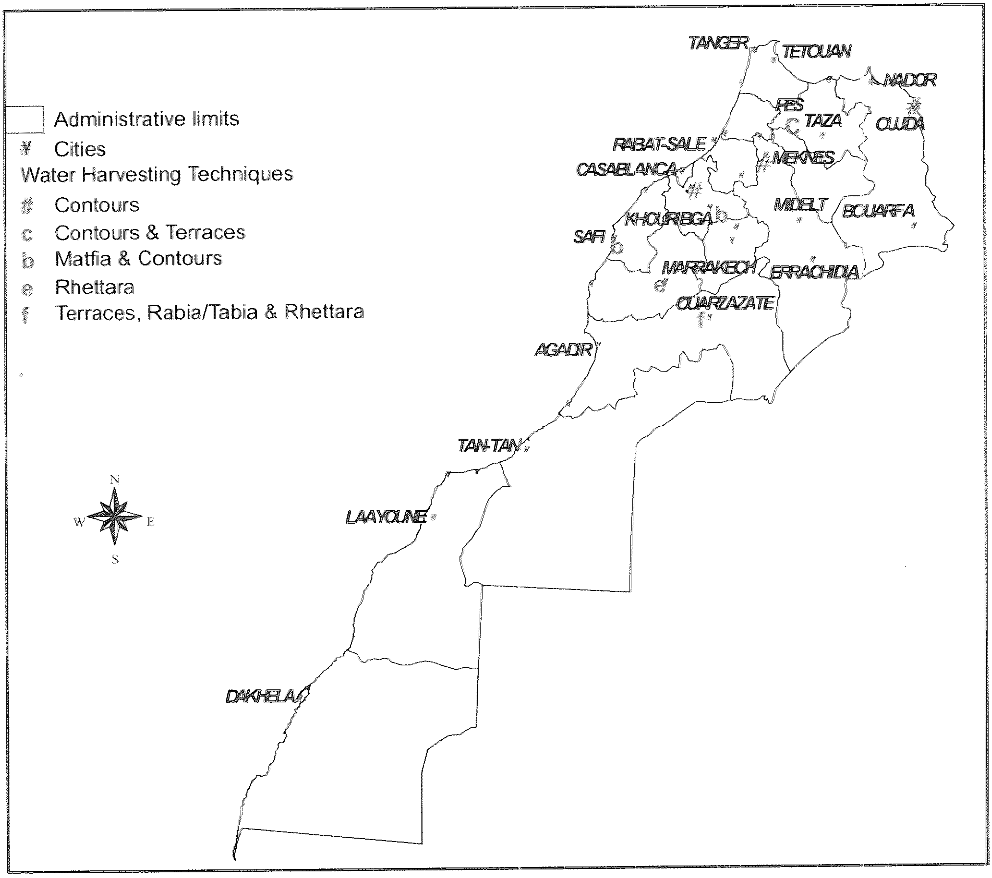


Fig. 4.3. Location of indigenous water-harvesting techniques in Morocco.

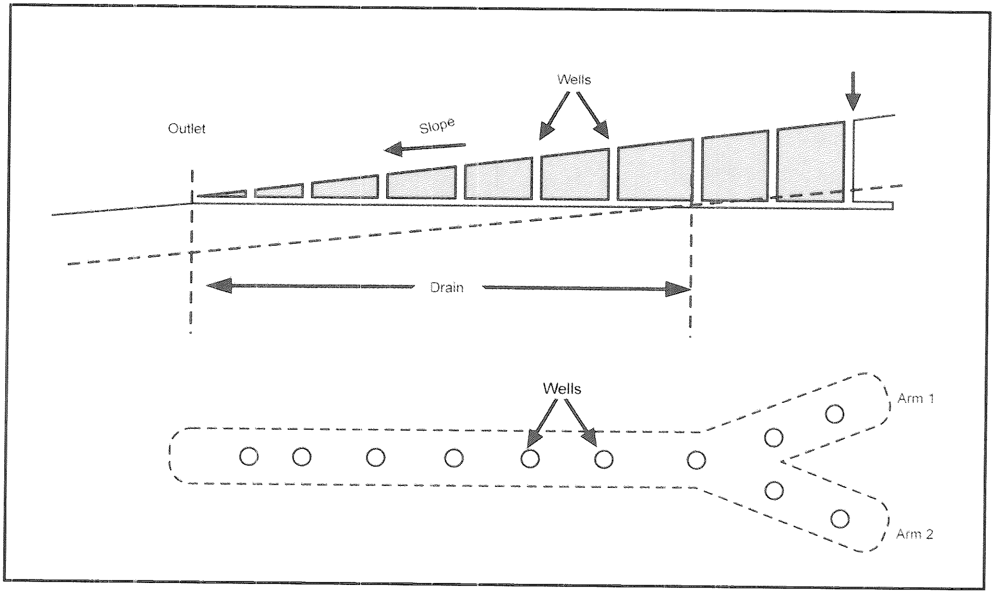


***Fig. 4.4. Schematic and plan view of a* rhettara.**

***A vertical access shaft in a* rhettara.**

There exist two types of *rhettaras*: those that are totally underground (10 to 20 m deep) and those that are 'open air', placed at a depth of less than 5 m. Most *rhettaras* have a single channel; however, some have two secondary 'arms' that convey water towards the main drain. *Rhettaras* vary in length, ranging from 15 m to more than 7000 m (depending on aquifer depth, the ground's surface slope, and the slope of the channel). When water flow is very low, the *rhettara* is augmented by a small water storage basin, in order to collect enough water to allow

An open-air rhettara.

A low-flow-rate rhettara *combined with a small storage basin for irrigation.*

the use of surface irrigation. The longest *rhettara* is 7090 m long and is located on Marrakesh's Haouz Plain (Pascon 1977).

In the Haouz region, where most *rhettaras* are found, more than 650 *rhettaras* were originally built nine centuries ago. These had a total length of 700 km, and a total continuous discharge of 3200 L/s, constituting 70% of the water withdrawn from the aquifer. This water was used to irrigate approximately 20 000 ha (Benbiba 1987) as well as for drinking. The discharge of a single *rhettara* varies between 1 L/s and 400 L/s, depending on the length of its tunnel, the catchment area and the linkage to the aquifer.

Presently, most *rhettaras* in Morocco are either dry or have been destroyed. Such decay is the result of many factors—such as lack of maintenance, the use of pumping systems, a drop in the levels of water tables (due to the intensive use of groundwater), and a drought which affected Morocco for many years.

Matfia

A *matfia* is an underground cistern used for rainwater storage. The system was introduced into the Atlantic Coastal region of Morocco by the Portuguese in the 16th century. *Matfias* are very common in the arid and semi-arid areas of south El Jadida, the Occidental High Atlas, and the Oriental and Souss regions. In these areas, surface water and groundwater are lacking: the only source of water is rain. Consequently, the communities have to harvest rainwater for domestic and animal uses.

Such systems are constructed on sloping sites, to encourage runoff and to channel water to the storage area. In the traditional system, water is harvested from the surrounding surface through natural streams and small compacted roads. Old *matfias* (Fig. 4.5) were dug on rocky sites or constructed from dirt and rocks. They are spherical, and have a limited storage capacity (5 to 12 m^3). In some

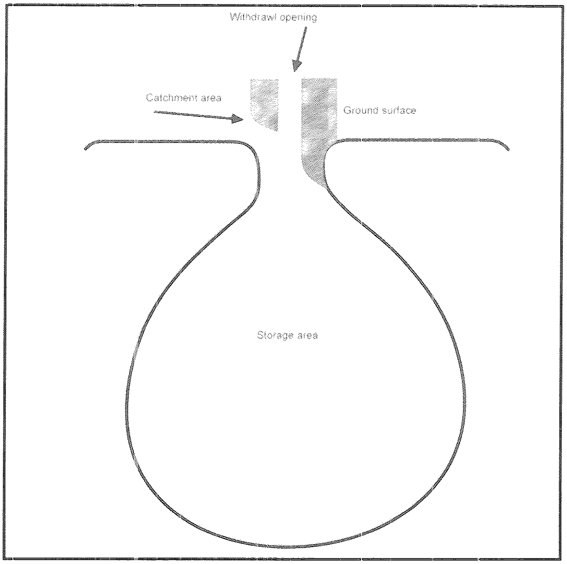
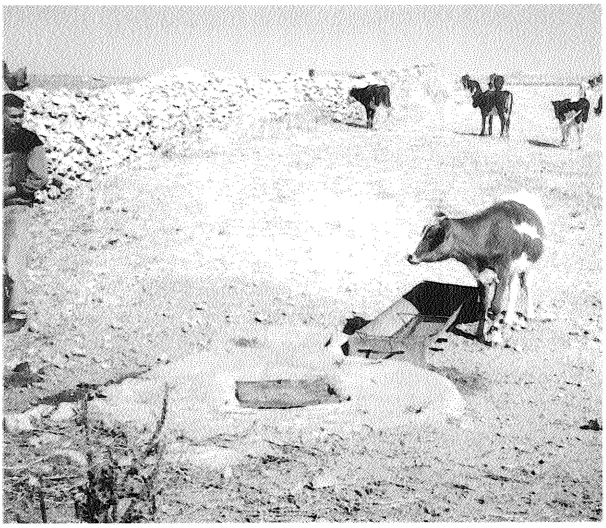
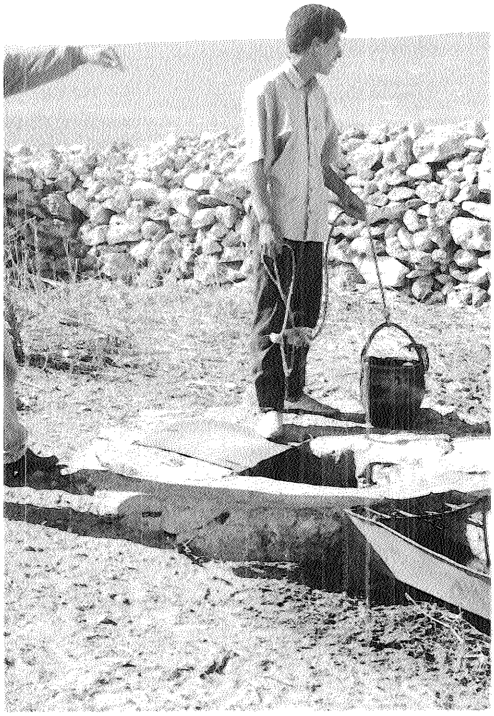


***Fig. 4.5. A schematic section of a traditional* matfia.**





Above: Bailing water out of a* matfia *with a bucket and rope.
Above left: A* matfia *used for watering livestock.
Left: Large* matfia *for collective use.

places (such as the El Jadida and Safi regions) a farmer can own more than ten such units. Some farmers can even afford to rent some of their units to others. More recently constructed *matfias* are made of concrete. In many places, in order to have clean drinking water, the *matfia* is fed with rainwater from the house roof via small metal pipes.

The maintenance and cleaning of *matfias* are very important tasks, as they ensure their sustainability; many cease to function because of lack of maintenance. Water quality is also a problem in the traditional system, because the catchment area is not well managed and the cistern is made of dirt. Therefore, the stored water is dirty and unhealthy. To address this, the Public Health Services advise users to treat the water before it is used.

Over the last few decades, public institutions have begun to invest in larger systems for collective use. The newly introduced system is rectangular and made of concrete, with standard storage capacities of 100 m^3, 150 m^3 and 300 m^3. The catchment area is also well treated with concrete. The design of the system is based on the following parameters (Nrhira 1994):

$$V = \frac{k \times P \times S}{1000}$$

where V is the storage capacity (m^3); S is the catchment area surface (m^2); P is the annual rainfall (mm); and k is the reduction coefficient (0.7 for hot regions and 0.8 for cool regions).

Contours, and Circular and Semi-circular Ridges

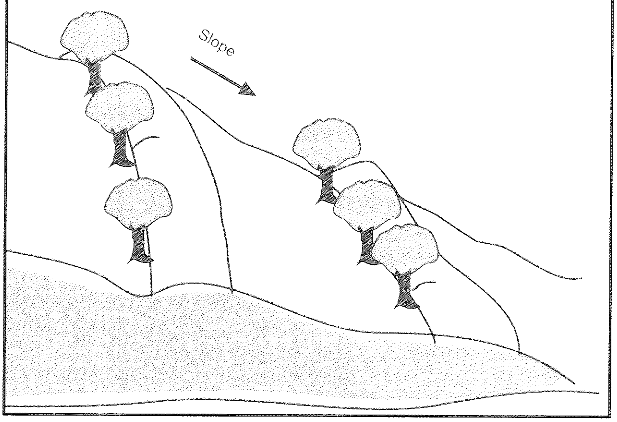
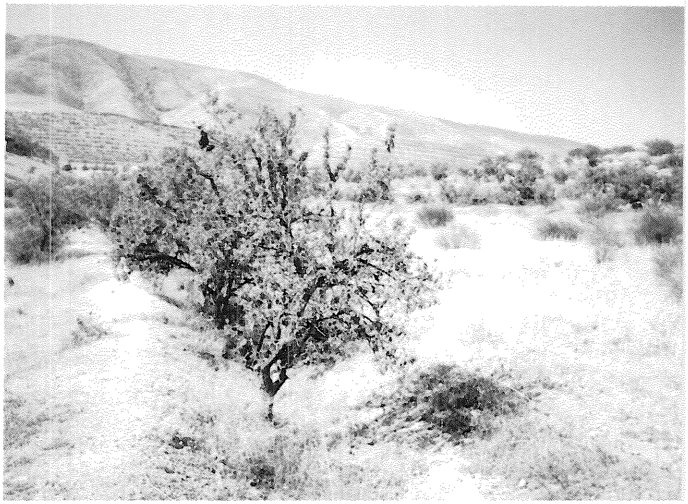


Fig. 4.6. A schematic representation of contour ridges.

The use of contours and circular and semi-circular ridges are techniques associated with trees or bushes in areas where irrigation water is only available either in very small quantities or not at all. Such ridges are used to stop runoff water and reduce erosion, as well as to ensure a supply of water to the trees. Traditional contours are made of earth or rock ridges and follow a design perpendicular to the slope. However, most of the time, they do not 'fit' the natural contour lines (Fig. 4.6).

Recently, the Forestry Service initiated a program which aims to protect land in arid, semi-arid and marginal areas from erosion and desertification. The program entails the planting of trees along ridged contours, following the contour lines of the area. However, the management of the catchment area in this system has not received sufficient consideration. In fact, in most cases, the catchment area is actually cultivated (e.g., planted with annual crops). Circular and semi-circular ridges are built around a single tree (Figs. 4.7 and 4.8). The design and the size of the system vary between regions of the country. These systems need to be well designed and maintained.



Contour ridges supporting trees in central Morocco.

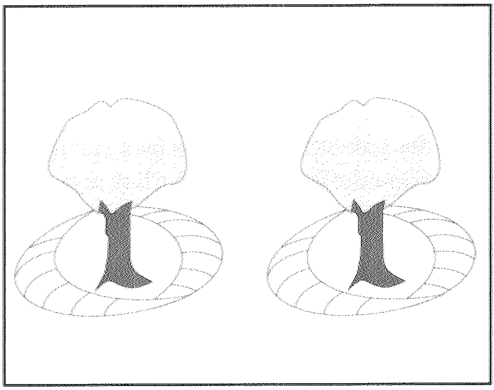


Fig. 4.7. A sketch of a circular-ridge system.

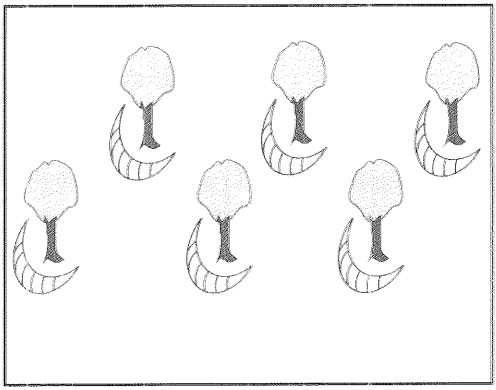
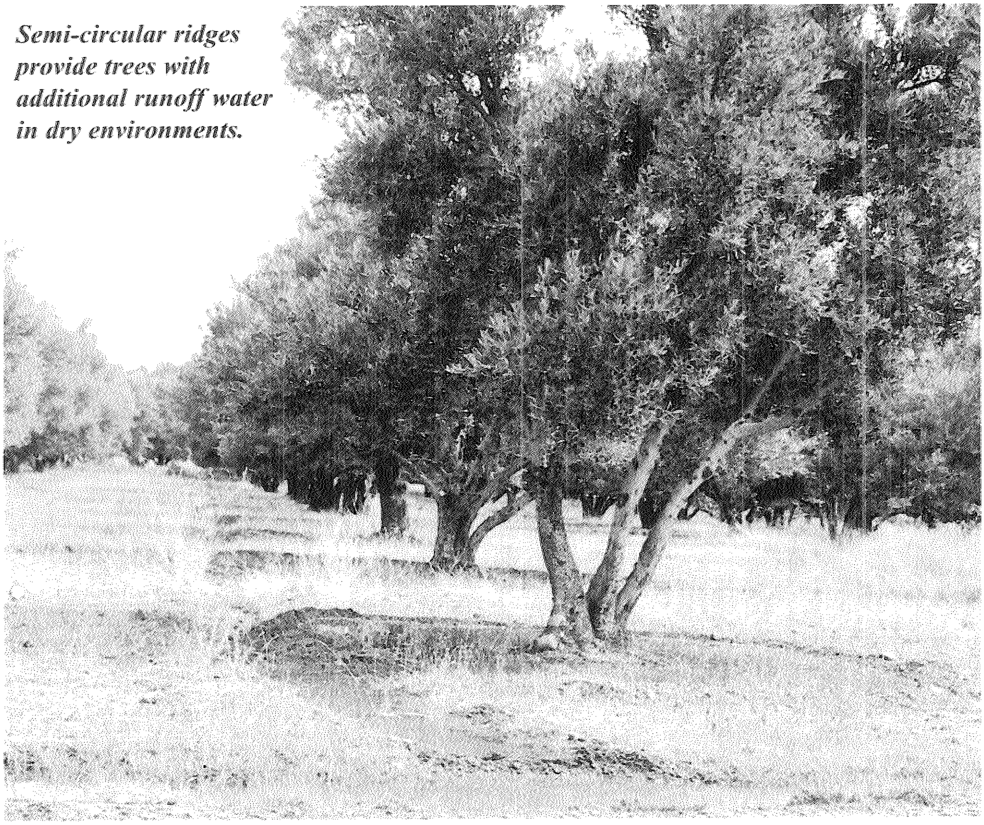


Fig. 4.8. A schematic representation of semi-circular ridges.



Semi-circular ridges provide trees with additional runoff water in dry environments.

Terraces

Terracing is the process of re-shaping sloping land into a series of nearly level 'steps' of suitable dimensions, which vary depending on their purpose and the site's conditions. A terrace system ensures that rainfall water is captured and stored by the soil. Erosion control and reduction is another major aim of terraces. In the Anti-Atlas mountain chain, this system represents the highest level of development in terms of agricultural technology (Kutsh 1983). Terraces are usually used to grow annual crops such as barley, wheat, and corn. In some cases, such terraces are surrounded by fruit trees.

On gentle slopes, which are only rarely completely flooded by the runoff from heavy rainfall, extensive terrace banks and wide, level steps are typical. On slopes with a medium gradient (15% to 25%), rainwater runs down to the next, lower, row of terraces via ramps which slope in opposite directions (Figs. 4.9 and 4.10).

Water harvesting and soil conservation terraces on steep slopes in Morocco.

Water harvesting and soil conservation terraces on gentle slopes in Morocco.

As a rule, rainwater from the upper slopes is allowed to flow straight down onto the terraced areas. To slow down the flow, various barriers (such as stone walls or banks) are constructed at the upper end of the system. The regular reinforcement of the base of the walls on their up-slope side is of great importance

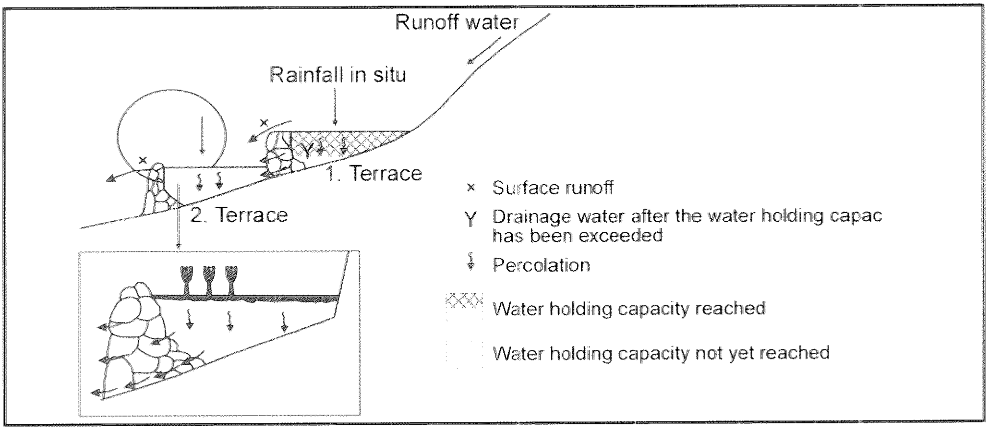


Fig. 4.9. A schematic section of a water-harvesting system on terraces.

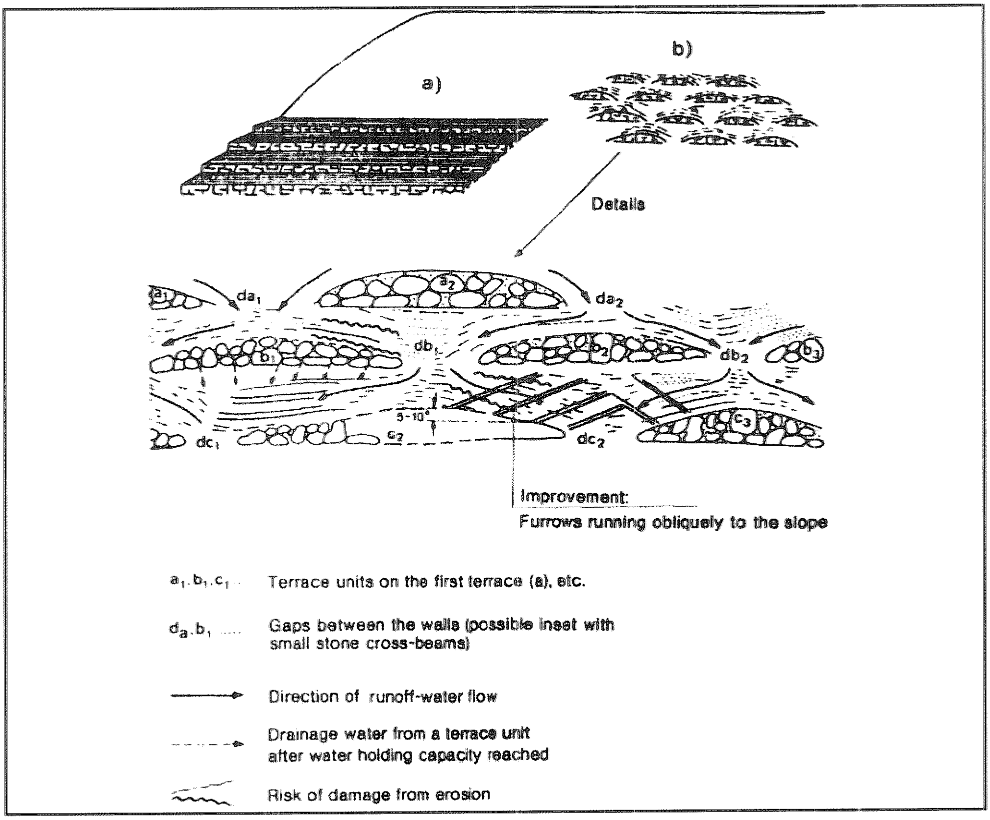


Fig. 4.10. A schematic description of terrace water-harvesting systems on (a) gentle slopes and (b) medium-steep slopes.

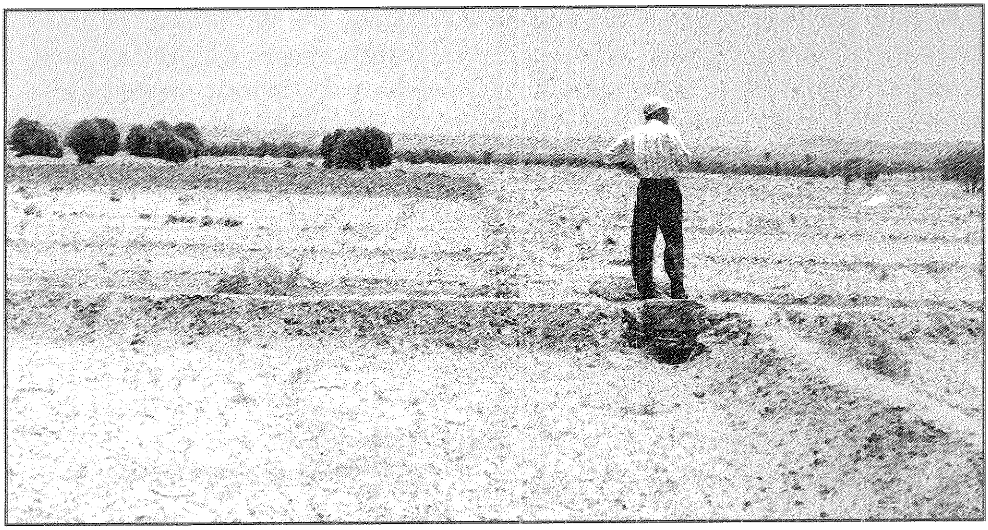
with regard to maintaining terraces on medium slopes. For this reason, the area between the foot of the wall and the soil slope is strengthened with stones, so as to increase the stability of the main structure of the wall. On many of the older terrace walls, damage (such as cracks or even breaches) can be seen. Such damage is probably the result of improper design and poor construction. Terraced sections concentrate water in the following ways:

- The precipitation that actually falls on the terraces is almost all directly absorbed into the terrace, which usually has a well-drained soil. When rainfall is exceptionally heavy, water flows over the surface and irrigates the lower-lying terraces or the valley floors.
- Surface runoff can occur on the uppermost terrace because of an imbalance between the inflow of water from the sloping water-harvesting area and the percolation potential of the terrace. The speed with which the water runs off is reduced by plowing furrows across the natural slope and by adding extra height to the banks.
- Drainage flow can develop when the water-carrying capacity of a terrace is exceeded. When this happens, water seeps through joints and cracks in the bank or filters through the base of the bank and then to the soil of the next terrace down.

Rabta and Tabia

Rabta and *tabia* are different names used to describe what is, in either case, almost the same technique. The technique is used to harvest floodwater or surface flow from large mountains during the rainy season. In the case of *rabta*, water from a nearby river in flood is channeled through drains (bounded by stone or earth walls) to a farmer's field. The field is generally divided into small plots surrounded by earth dikes or ridges 20 to 30 cm in height and interconnected by spillways. When the first plot is flooded, water moves to the next through the spillway, the process being repeated until all the plots are submerged. The concept is essentially the same for the *tabia,* the difference being that the plots used in the *tabia* system are situated at the foot of large mountains, which serve as the catchment area (Fig. 4.11). The inflow sources to the *tabia* are concentrated into one or more artificial or natural drain, and then diverted to the individual plots. The height of the surrounding earth dikes or walls may exceed 1 m.

Harvested water remains at the plot level until it has completely infiltrated the soil. The technique can supply enough water for a barley or wheat crop from sowing to harvest. However, fields that are cropped under this technique are often not properly leveled, which means that water infiltration is not uniform over the irrigated field. Also, the soils in the system are subject to erosion, due to the high speed at which the water enters the field, and plants can be damaged when heavy storms occur at unsuitable times during the growing season.



A rabta *water-harvesting system in Morocco.*

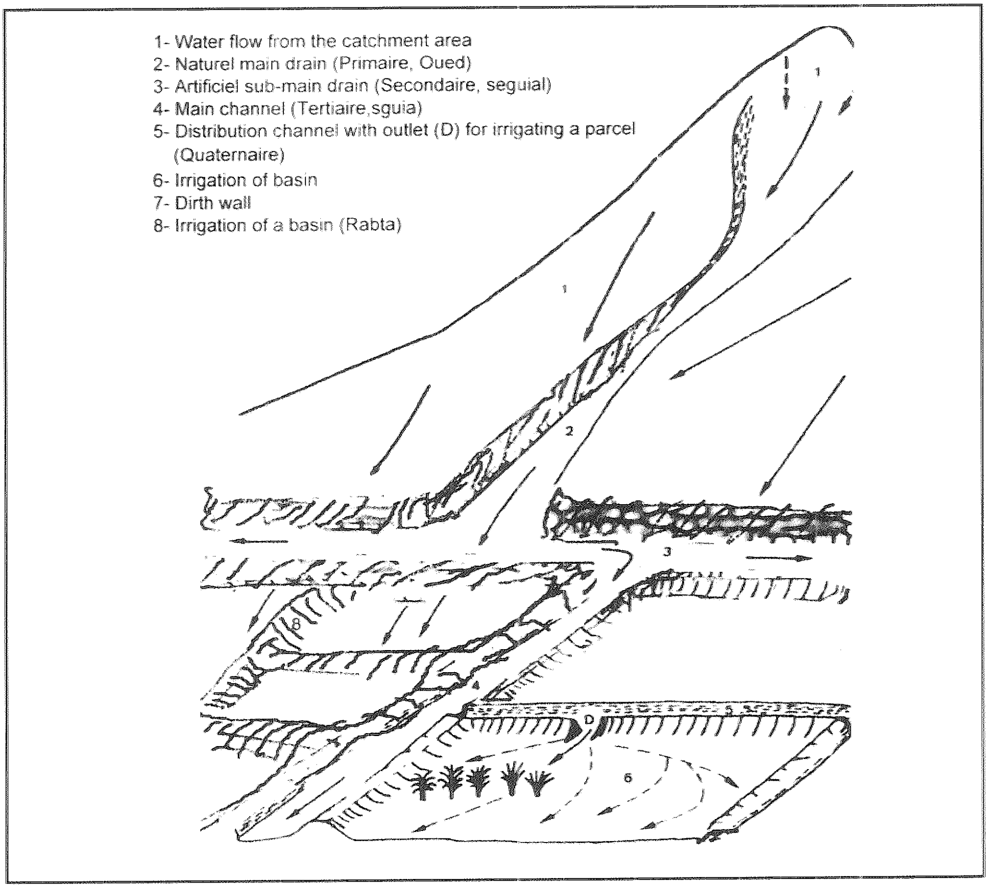


Fig. 4.11. Water harvesting using the rabta *system.*

Conclusion

Because of drought, which has become more frequent in the country, Morocco must develop and implement all currently available drought mitigation and water resource improvement techniques. Fortunately, the country's scientists and decision makers are aware of this situation. Water harvesting is one of the strategies that has been discussed at different levels and some projects have already been implemented. In fact, some large and well-designed *matfias* have already been constructed for public use in rural arid areas, while projects concerning the introduction of improved *tabias* have been undertaken in other places (such as Ouerzazat). However, with regard to the *tabia* system, there still remain some technical problems which need to be solved—such as issues of land property, water rights, the reconstitution of the arable land involved and the fertility of the *tabia*, which requires 3 to 4 years to recover, as this process entails digging up the arable land and moving the topsoil from the *tabia* during construction in order to make bunds).

In the case of the other water-harvesting techniques described in this study, the management of the catchment area and the design of the systems remain those traditionally used and have not been adapted. The government has initiated a program for the protection of *rhettara* in some areas (as they are culturally/historically important structures), and have forbidden the pumping of groundwater in the areas around them. In order to be more successful with regard to the harvesting of water for agricultural production, as well as in terms of environmental protection, a larger, integrated research and development program on water-harvesting techniques needs to be launched, in order to improve the existing systems and introduce new, better adapted ones. Such a program has to involve all partners, including the users, in order to insure the sustainability of the systems.

Acknowledgments

The authors wish to acknowledge the valuable contributions made by M. El Mourid, M. El Gharous and A. Laamari (scientists at INRA, Settat, during this study) with the surveys and gathering of the presented information. The authors would also like to thank H. Benaouda and C. Essadi, of the GIS Laboratory at INRA Settat, for producing the maps used here.

References

AGR (Administration du Génie Rural). 1995. Contribution de l'agriculture irrigué à la sécurité alimentaire. Note. Administration du Génie Rural, Ministère de l'Agriculture et de la Mise en Valeur Agricole (MAMVA), Rabat, Morocco.

Benazzou, C. 1994. L'eau le défit permanent. Collection Etudes et Recherches. Publications Panorama. Rabat, Morocco.

Benbiba, M. 1987. Les rhettaras du Haouz de Marrakech. *Eau et Developpement* 3: 38-42.

Kutsh, H. 1983. Currently used techniques in rain-fed water-concentrating culture. The example of the Anti-Atlas. *Applied Geography and Development*, 21: 108-117.

Pascon, P. 1977. Le Haouz de Marrakech. Tome Premier. CURS Rabat, CNRS Paris, INAV, Rabat. pp. 105-112.

Nrhira, A. 1994. La matfia ou citerne à eaux pluviales. *Eau et Developpement* 17: 38-43.

Chapter Five

Indigenous Water-Harvesting Techniques in Syria

George Soumi and Atef Abdel Aal
General Commission of Agricultural Research (Irrigation and Water Use)
Ministry of Agriculture and Agrarian Reform, Damascus, Syria

Introduction

Comprehensive and outstanding development in different fields, particularly in the sciences, was associated with the Abbasid Caliphate (AD 750-1258). This progress was embodied in monuments and antiquities, many of which are still prominent in Syria. In the context of this paper, the most important of these monuments and antiquities are the water structures and constructions found in Damascus, at Hama, on the banks of the Orontes, and in many other parts of Syria. The Arabs developed several techniques for the conveyance and lifting of water for different uses (such as irrigation and drinking). The achievements of Arab mathematicians and engineers (such as the Banu Musa brothers in the ninth century, Al-Khadhri in the thirteenth century and many others) also caused irrigation engineering to progress.

The water-harvesting techniques formulated to capture surface runoff resulting from rainfall reflected the environment in which they were used, and were correlated with the availability of surface water and groundwater for both human and agricultural uses as well as for animal husbandry. Therefore, this technology spread in old Syria in particular, which is considered a water-scarce area (i.e., the current Syrian steppe, Dara'a, and Al-Suweida).

The local inhabitants used special techniques to make use of groundwater near the soil surface—digging channels for hundreds of kilometers in order to provide water for agricultural purposes, as well as for drinking and the watering of animals in the area around Damascus (Al-Ma'damīyyah, Jayrūd, Al-Nasrīyyah, Al-Qaryatīn, Al-Salamīyyah, and Al-Khabūr). These channels are currently referred to as 'Roman channels'. However, the word 'Roman' is commonly used in Syria to describe old features—its use does not always mean that these features were constructed during the Roman period.

Background

Syria lies between the latitudes 32° and 37°N and the longitudes 36° and 42°E. The country is bordered on the north by Turkey, on the east by Iraq, on the south by Jordan and Palestine, and on the west by Lebanon and the Mediterranean Sea. It occupies 185,000 km^2, most of which is used for arable farming and animal husbandry (Table 5.1 shows land and irrigation water use in the country).

Table 5.1. Land use and irrigation water sources in Syria (1986-1999).

Land Use	Mean 1986-90	1995	1999
	--------	10^3 ha	--------
Cultivable land			
Exploited	5592	5502	5502
Not exploited	512	477	495
Total	6104	5979	5997
Non-cultivable land			
Pasture and rangelands	8132	8287	8265
Bushes and forests	608	493	546
Rocky and sandy areas, water bodies, roads, buildings	3676	3759	3710
Total	12 416	12 539	12 521
Exploited land			
Rainfed	3957	3893	3356
Irrigated	664	1089	1186
Fallow	971	520	962
Irrigated land			
Groundwater wells	319	686	705
Surface water - with pump	201	228	211
Surface water - without pump	144	175	270

Topography

Syria can be divided into four topographical areas, each with its own characteristics, as described below.

The coastal strip

The coastal strip is a 177-km long, narrow plain located between the Mediterranean Sea in the west and the coastal mountain chain in the east. It extends along the coast, from the Turkish border in the north to the Lebanese border in the south. The area constitutes 2% of the total area of the country and is highly cultivable, having fertile soil and ample water resources. Mean annual rainfall is more than 600 mm. The coastal strip is characterized by many valleys that descend from the coastal mountain ranges.

The coastal heights

The coastal heights consist of mountain ranges which extend across the Lebanese border and have a mean width of 32 km. They form a line parallel to the coast, and form a natural barrier that protects the interior from the effects of humid west winds. The coastal heights are characterized by heavy rain (1000–2000 mm/yr), and some parts of them are covered with snow in winter. These ranges are interrupted by cultivable hilly plains and sandy valleys, most of which have extremely steep sides.

The interior plains

The interior plains lie behind the coastal mountain ranges, which separate them from the direct effect of the humid west winds. This area is characterized by low rainfall (250–350 mm/yr) and consists of vast plains surrounded by some hills. Soil depths range from 10 to 200 cm. The interior plains represent the most important agricultural areas in the country, and include the plains of Damascus, Homs, Hama, Aleppo, Al-Hassakeh and Dara'a.

The steppe

The steppe lies in the southeastern part of the country, extending westwards from Iraq. It consists of a large plain with a mean height of 250 m above sea level. In the east, the Euphrates River crosses the Syrian steppe. The steppe is considered a grazing area, having a mean annual rainfall of less than 200 mm.

Hydroclimatic Conditions

General climatic status

Because of the climatic conditions of the Mediterranean Sea basin, Syria has two main seasons, a moderate winter tending to coldness, and a summer which is hot in interior areas, but temperate in elevated areas (see below). The summer is arid and dry with little or no cloud cover. The spring and autumn are short and overlap the other seasons. As explained above, topographical features divide the country into different hydroclimatic zones.

Temperature is affected by several factors—such as latitude, topographical features, altitude, remoteness from the sea and the movement of air masses (both in terms of their general rotation and their different cycles). January is the coldest month of the year, while July and August are the hottest. Thermal rate changes can be classified regionally as follows:

- Coastal region—temperatures range between 12°C in winter and 20-26°C in summer.
- Mountainous areas—in comparison with the other areas, temperatures are lower in summer and winter, because of the higher elevation.
- Interior plains—temperatures range between those of the coastal region and those of the steppe.
- Steppe region—daily temperatures range between 6 and 8°C in January and between 26 and 32°C during July and August.

Rainfall

The total volume of Syria's annual rainfall is estimated to be about 50 billion m^3, which represents 55% of the total annual water supply of the country. Rain is not a dependable resource, because of the large temporal and spatial variations which occur in distribution. The distribution of the country's average annual rainfall is presented in Table 5.2. Fig. 5.1 shows the isohyets for Syria.

Based on mean annual rainfall, the country is divided into five stabilitzation zones, as presented in Table 5.3 and Fig. 5.2. These zones are used for agricultural planning.

Table 5.2. Distribution of average annual rainfall in Syria.

Rainfall mm	Land area km^2	Area of the country %
more than 1000	9 250	5
1000-500	37 000	20
500-250	46 000	25
250-100	74 000	40
less than 100	18 500	10

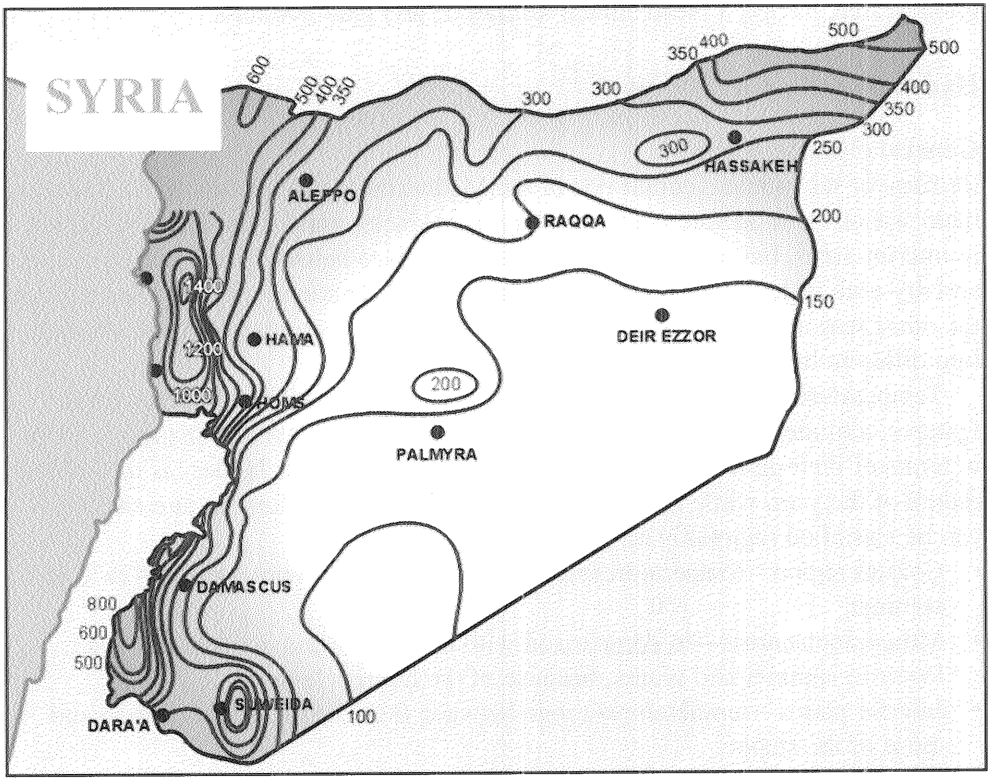


Fig. 5.1. Rainfall distribution in Syria (mm/yr).

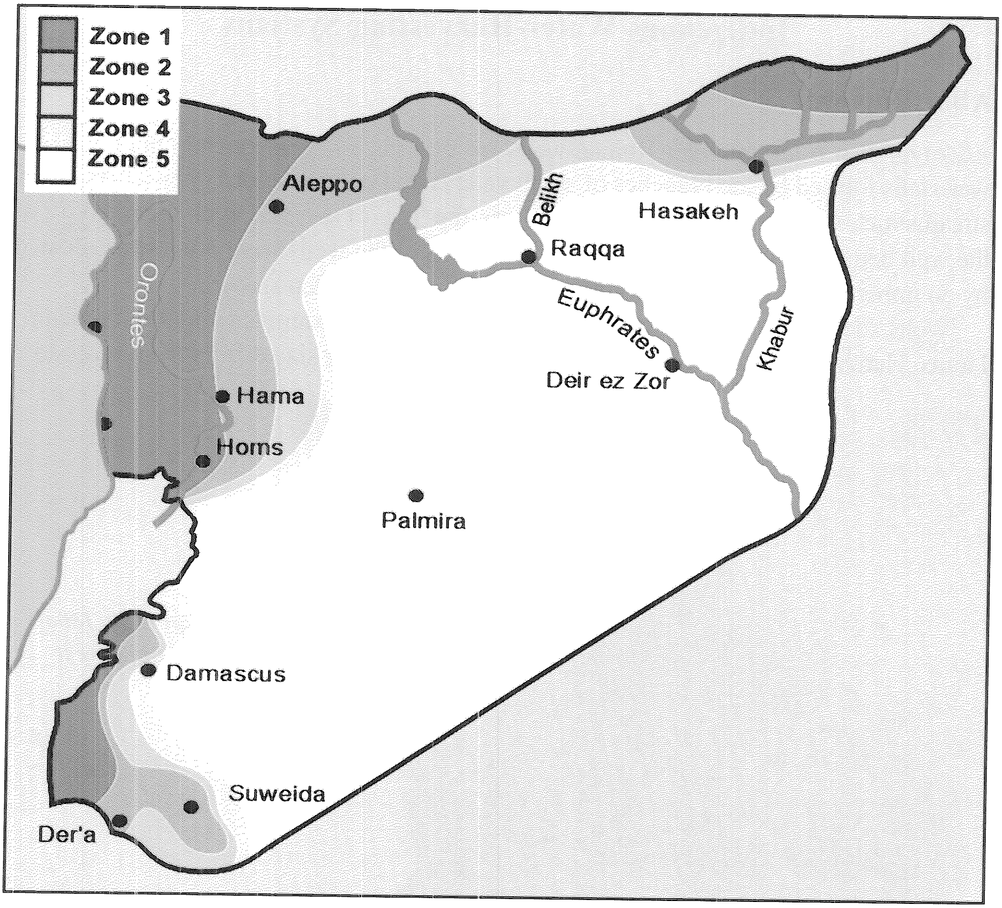


Fig. 5.2. Distribution of the agricultural stabilization zones in Syria.

Table 5.3. Rainfall-based stabilization zones in Syria.

Stability zone	Mean annual rainfall mm	Minimum annual rainfall mm	Probability of exceeding minimum rainfall %
I	more than 350	300	67
II	250-300	250	67
III	250	250	50
IV	200-250	200	50
V	less than 200	-	-

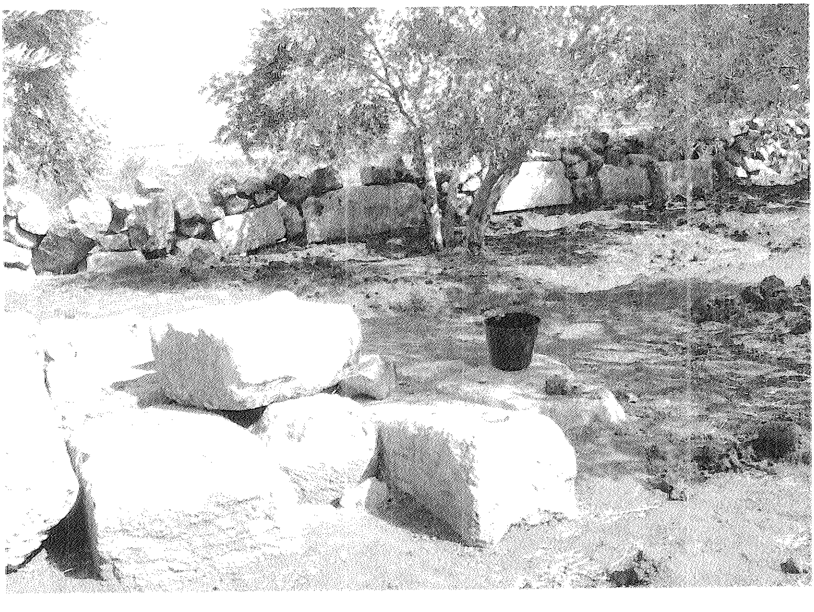
Indigenous Water-Harvesting Systems

Abar Romani

Abār (singular *b'ir*) *Romani* ('Roman wells' or 'cisterns') were frequently built at waterfalls formed by the branches of small valleys and on mountain slopes where small streams met. A narrow intake was dug to form the 'top' of the well, with the majority of the well being dug underground. The interior walls of the wells were often strengthened by an impermeable layer of hydraulic cement, which was often smooth.

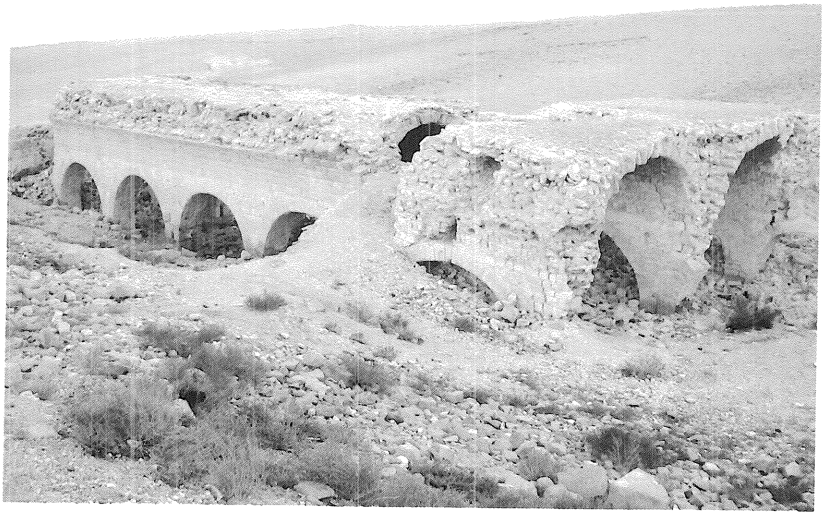
Wells such as these are located throughout Syria, and examples may be found at Homs, Hama, Deir Ez-Zor, and Aleppo for instance. Their size differs from place to

A Roman well, Jabal Barisha, northwest Syria.



A Roman well, Jabal Barisha, northwest Syria.

place, and is often related to the nature of the area's rock formations. These wells are often in a poor state of repair, due to accumulation of deposits resulting from erosion. The State has plans to reconstruct and rehabilitate these wells, through the Comprehensive Development Program for the Syrian steppe. The wells (which harvest and store surface runoff in order to benefit both people and animals) are considered to be one of the Syrian steppe's main water resources. Table 5.4 shows the distribution of Roman wells in the Syrian provinces. Fig. 5.3 shows the locations of different indigenous water-harvesting systems in Syria.



A Roman water structure, Homs Steppe, Syria.

Table 5.4. Distribution of Roman cisterns in Syrian provinces.

Province	No. of wells	Storage capacity m^3
Homs	800	60-70
Hama	50	60-70
Aleppo	250	60-125
Deir Ez-Zor	5	60-70
Al-Suweidah	10	60-70
Total	1115	

Birak and Khazzanāt

Birak and *khazzanāt* are large water storage structures which were widely used in southern Syria, particularly in Damascus, Bosra, and Suweidah. *Birak* (singular *birkah*) are water storage tanks or basins that receive water via large waterways. The walls of these basins are constructed of smooth stones. In the middle of the construction is an elevated outlet (above the level of the pool bed), which allows water to be withdrawn and transported to villages and farms. *Birak* are common in the Dara'a region (Bosra Al-Sham).

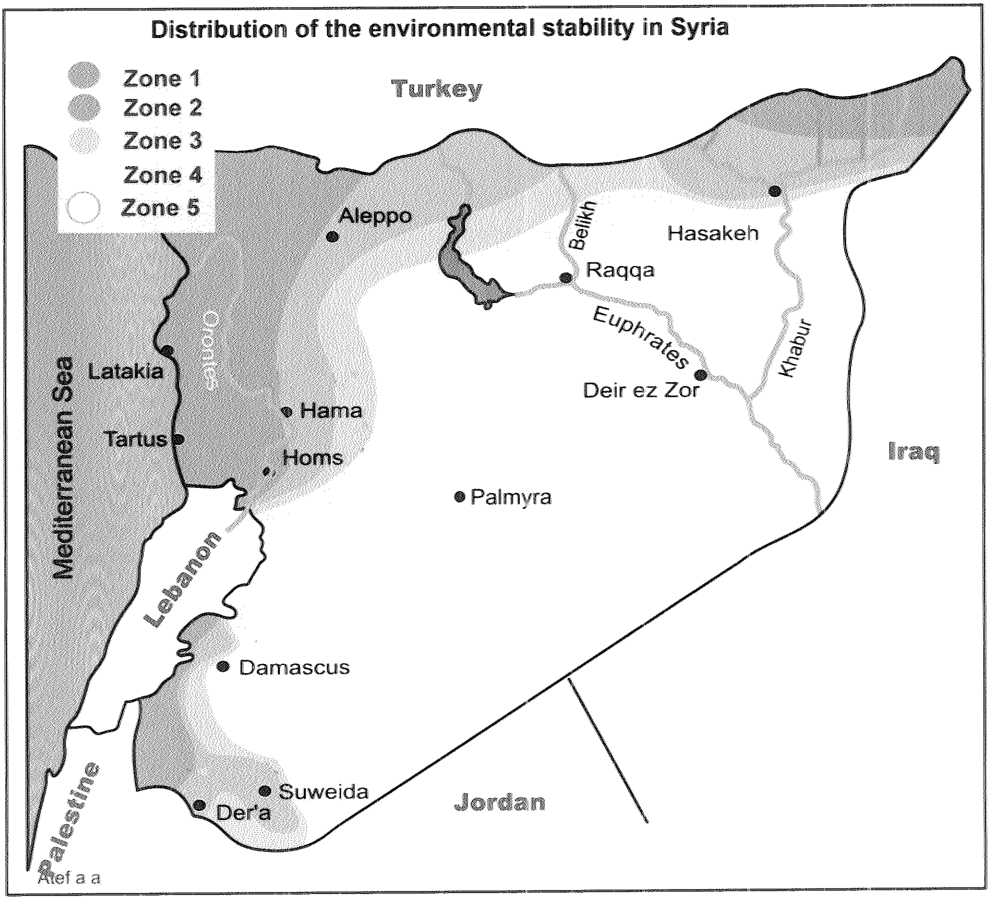
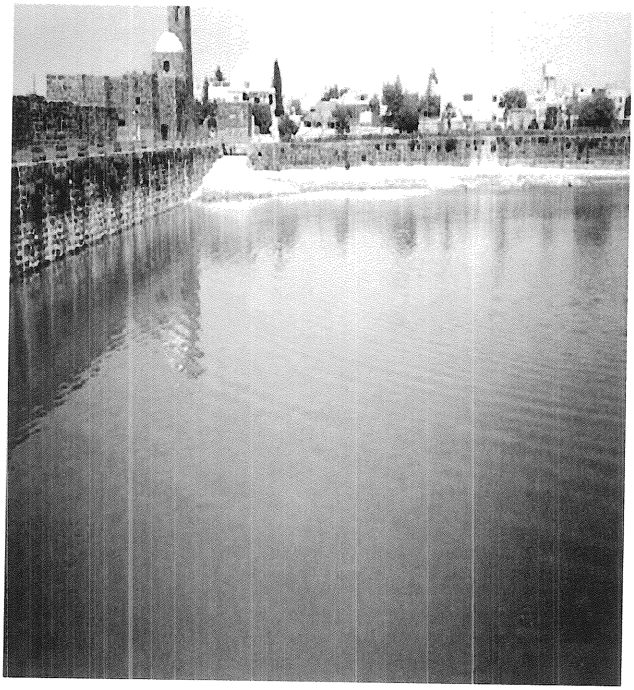


Fig. 5.3. Geographic distribution of different indigenous water-harvesting systems in Syria.

Khazzanāt (singular *khazzān*), locally called *majahīr*, are open, stone-walled reservoirs. They receive water from nearby springs through channels dug under the surface of the ground. Built to provide water to both people and animals, these reservoirs are still in use today in Bosra Al-Sham and Suweidah.

Qanawat Romani

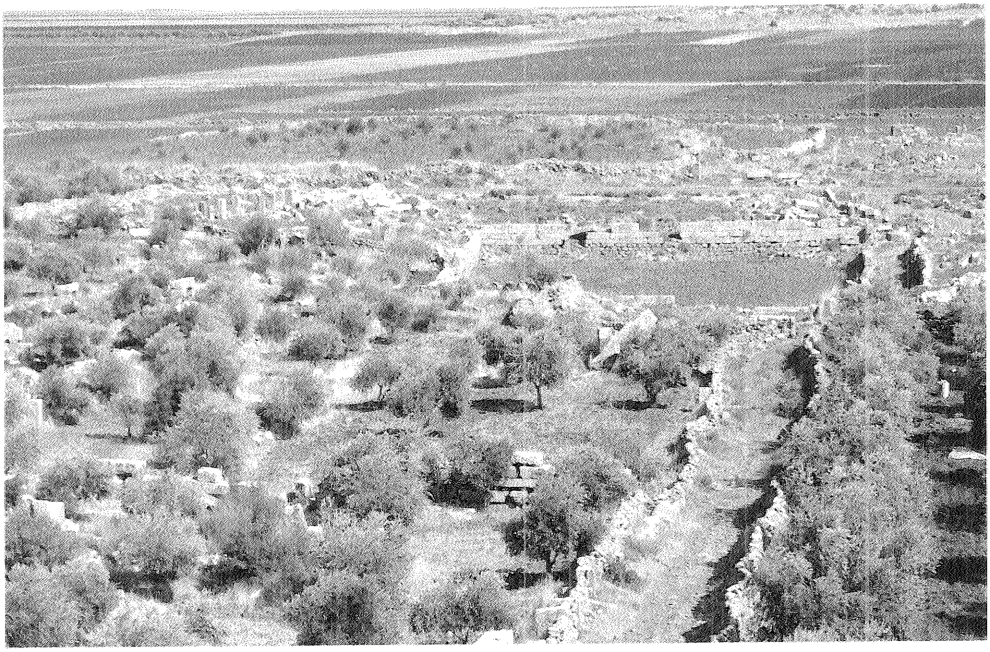
Qanawat (singular *qanat*) *Romani*, also known locally as *fujjarāt* or *aflāj*, are widely used in dry and semi-arid areas of WANA. These underground channels (or tunnels) were dug to collect and convey groundwater lying close to the surface. The channel is either partially or totally covered, and gravity causes water to flow to its outlet on the ground's surface at a lower elevation. Such underground channels have several vertical access shafts (or manholes) reasonably spaced along the *qanat* line, in order to facilitate construction and maintenance.



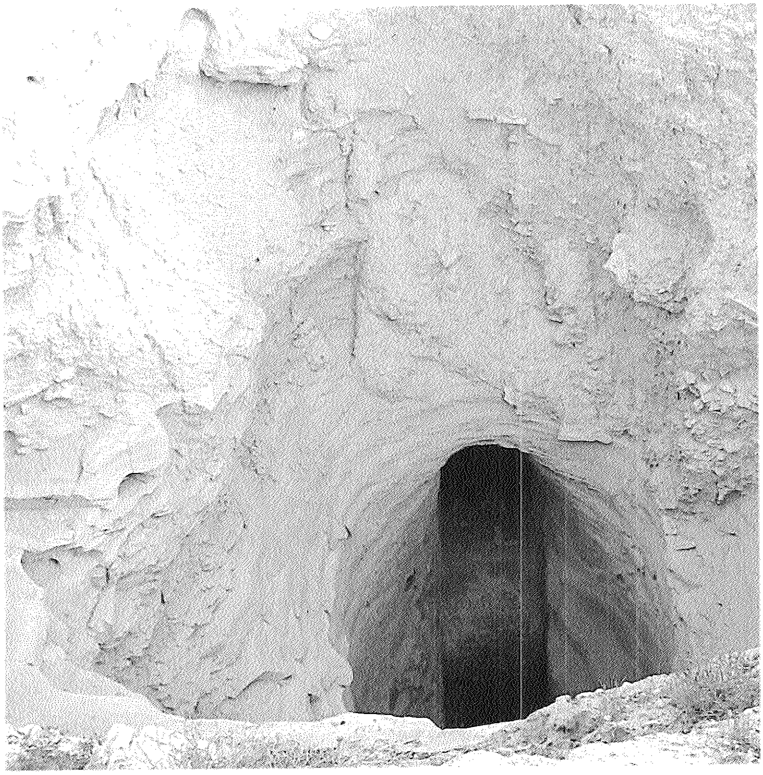
Birkah Al-Hajj, ***Bosra Al-Sham.***

Birkah, Andarin, ***Syrian Steppe.***

Qanawat can be found in different areas of Syria (e.g., Ghūtah, Nabk, Al-Qaryatīn, Palmyra, Taybah, Al-Kawm, Hama, and Aleppo). Most are, however, no longer effective, due to a drop in the water tables of the region as a whole and a lack of maintenance.



Khazzān, Jabal Barisha, ***northwest Syria.***



An underground channel (qanat), *Homs Steppe.*

A Roman open channel, Qalamun, Syria.

Roman Open Channels

Open channels were used to convey and distribute water to villages, towns, and farms in southern Syria (for example, Dara'a, Suweidah, and Hama). Water was transferred through them from the reservoirs described above (*ābār Romani, birak* and *khazzanāt*). They consist of 20 to 40-cm wide, carved stone channels that slightly overlap each other to prevent water leakage. Most of these channels are no longer of importance, due to vandalism by local communities and the damage caused by modern construction works, which eradicated most of them.

Nawā'īr

Many techniques were used to lift and convey water from rivers and wells. The most important technique used was the water wheel (driven either by waterpower or by animals), and locally known as *nawa'īr* (singular *na'ūrah*). The time at which they were first constructed is not known, but they are depicted in a mosaic from the fourth century AD which was found in Apamea.

A **na'ūrah** *on the River Orontes in Hama, Syria.*

Water wheels consist of a large-diameter head wheel which has buckets spaced along its circumference. Wheel diameters range from 5 to 21 m, while each wheel will have between 50 and 120 buckets. The wheel is usually rotated by the power of the river's flow, allowing the buckets to lift up the water and pour it into channels raised above ground level, thus providing water for drinking and farming.

Water wheel use spread along the River Orontes and gained fame, especially in the Hama area. Several decades ago, the total number was estimated to be approximately 80 wheels located between the Rastan dam and the Ghab. In 1985 approximately 5532 ha were irrigated using *nawa'īr*. Nowadays, the number of water wheels has decreased to about ten. Water wheels were also constructed and widely used in the Euphrates basin, particularly along the River Khabūr (a tributary of the Euphrates). Today, however, nothing remains of those wheels formerly located on the River Khabūr, as most of them were neglected.

Future Prospects and Potentials

The Syrian government is currently focusing on establishing several projects aimed at rehabilitating Syria's facilities for harvesting surface runoff water, either by maintaining the old systems or by implementing new projects. The *Integrated Development of Watersheds in the Syrian Steppe* project has the following aims:

- The development, through the integrated management of resources (water, soil, and vegetative cover), of a model for the permanent development, in dry areas, of watersheds accessible to all, with the intention of developing the steppe's resource use and guaranteeing sustainable animal production.
- The assessment of the impact of various soil and water conservation techniques, as well as of various erosion control and vegetative cover recovery techniques and practices for long-term watershed management.
- The utilization, locally, of rainwater—through the implementation of contour strips.
- The collection, through rainwater harvesting, of sufficient water for the watering of animals.
- The training of Bedouins in rangeland management.
- The provision of rangelands held 'in reserve'—in order to act as a standby during dry years.

The State's plan also includes a wide range of activities intended to improve water-use efficiency at the farm level under the umbrella of the On-Farm Water Husbandry in West Asia and North Africa (OFWH) Project.

Chapter Six

Indigenous Systems of Harvesting Rainwater and Runoff for Agriculture in Libya

Saad A. Algharian
Alfateh University, Tripoli, Libya

Introduction

Like several other countries in North Africa and the Middle East, over the last three decades Libya has been in the difficult position of needing to pursue socio-economic development in the face of severe water shortage. This has necessitated a continuous search for, and development of, potential water supplies (both from conventional and unconventional sources) and the directing of such potential supplies to aid in the realization of the country's development objectives. Such potential water resources include mass water transfer and redistribution of groundwater among the southern and northern water basins, wastewater treatment and reuse, and seawater desalination.

However, due to a general mistrust of the reliability of these resources, coupled with the high cost of their development, it is increasingly felt that more attention should be given to the ancient, renewable and sustainable resource of rainwater. Following this course would require the effective improvement of water-harvesting technology, by means of a better understanding of the local hydrological cycle, which would allow it to be modified both to support rainfed agriculture and partially satisfy human and animal water requirements.

The importance of rainwater as a resource is reflected in the fact that the total precipitation above the 100 mm isohyet in northern Libya exceeds 30 billion m^3/yr. Of this, less than 3% is effectively used. The rest is wasted, through evaporation, deep seepage and runoff to salt sinks (Algharian 1987). Ironically, this valuable resource was more effectively used in ancient times, as revealed by historical and archaeological studies (Goodchild 1952).

Since the early 1970s, official agricultural and water resource institutions have made serious attempts to develop and integrate rainwater with other natural resource development programs concerned with soil and water conservation, forestry and range management, wildlife conservation and rural development. These programs have been partially realized through watershed terracing and forestation, the construction of storage and check dams, rangeland improvement and agricultural settlement projects based on rainfed farming and animal production.

More efforts are needed, however, if we are to realize the full potential of water-harvesting technology in Libya. This paper is a modest attempt to acquaint water-harvesting experts, decision-makers and interested readers with the indigenous water-harvesting systems used in Libya, as well as with the technical and socioeconomic issues relating to their past and present use. Their potential utility within the context of prevailing conditions is also assessed and improvements or modifications are suggested where appropriate.

Background

To facilitate the classification and discussion of indigenous water-harvesting systems in Libya, the country has been divided into four major geographical zones—easily distinguished by their prevailing hydroclimatic, agro-ecological and socioeconomic characteristics (see Fig. 6.1). These zones are described as follows:

- Zone I includes the Jefara Plain and the surrounding mountains and hills (known as Aljabal Algharbi). Average annual rainfall in this zone ranges from 350 mm, near to the Mediterranean coastline, to less than 100 mm on the southern slopes of the mountains, near the fringes of the plateau known as Alhamda Alhamra. Fig. 6.2 shows the average climatic elements near Tripoli, the largest city in this zone.
- Zone II includes the Eastern Mountains (known as Aljabal Alahdar), and the surrounding plains of Almarje and Benghazi. Average rainfall in this zone

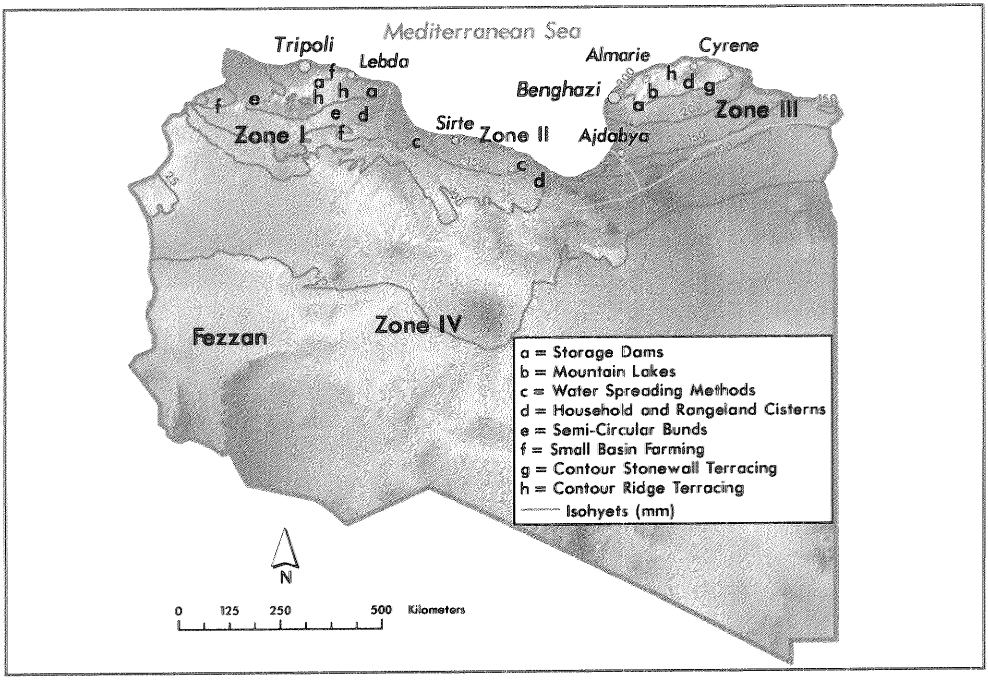


Fig. 6.1. The major agroecological and hydroclimatic zones of Libya, including the locations of indigenous water-harvesting systems.

ranges from more than 450 mm, in certain areas near the ancient city of Cyrene (modern Shahat), to less than 200 mm on the surrounding fringes of the zone. Fig. 6.3 shows a profile of the average annual climatic elements near Shahat.

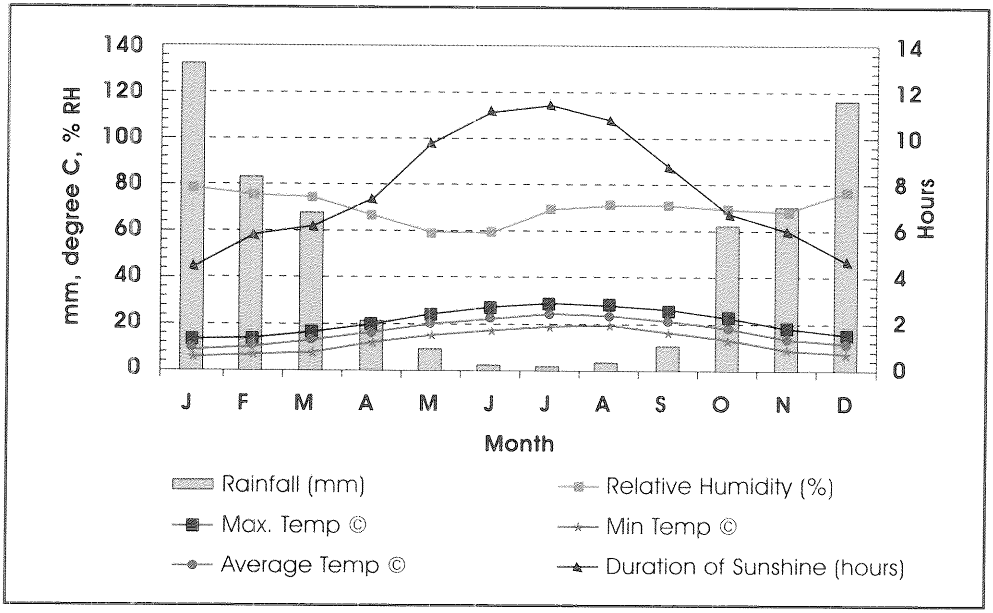


Fig. 6.2. Climate profile for the city of Tripoli in the coastal region of hydroclimatic zone I.

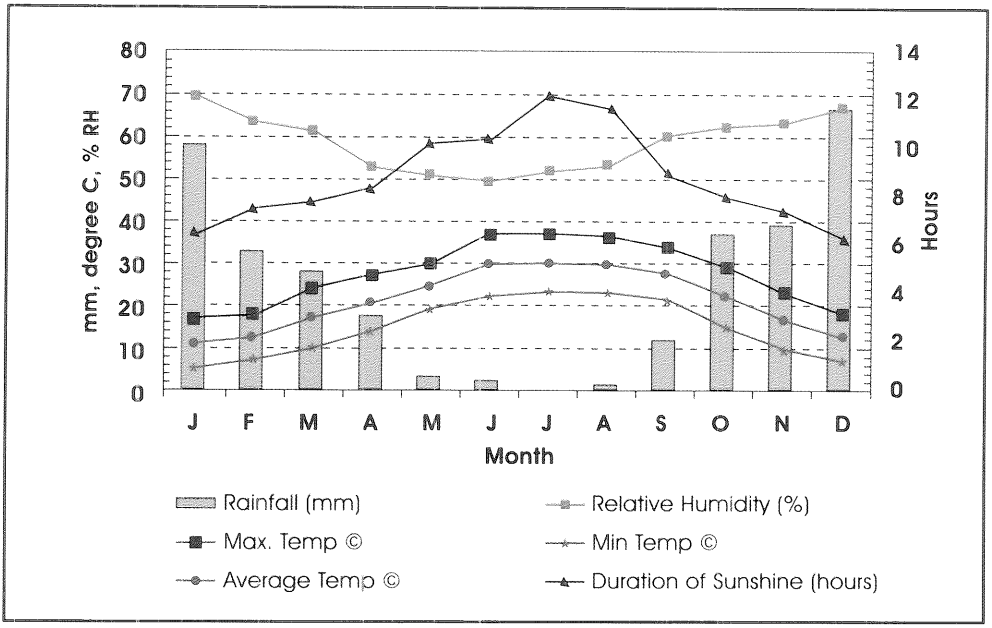


Fig. 6.3. Climate profile for the city of Shahat (ancient Cyrene), hydroclimatic zone II.

- Zone III includes the central coastal region surrounding the Gulf of Sirte (located between the cities of Misurata in the west and Ajdabya in the east). The zone extends 100 km to the south, with an average annual rainfall of between 100 and 200 mm. Several *wadis* and gullies dissect this zone and discharge their floodwaters, during the rainy season, either into the Mediterranean Sea or into inland depressions, floodplains or *sebkhas* (salt marshes).
- Zone IV includes the remaining southern parts of the country, where rainfall tapers from less than 100 mm per year down to zero in the desert proper. The past and present use of water-harvesting systems and their potential for future development, as well as most of the country's socioeconomic activities and population, are confined to the first three zones, where average annual rainfall exceeds 100 mm.

Indigenous Water-Harvesting Systems

Water-harvesting methods and techniques can be generally defined as hydraulic systems designed, implemented and operated to achieve the most efficient use of rainwater for productive purposes. A water-harvesting method or technique is a system because it integrates several site-specific components and characteristics, which vary from one location to another. Their appropriate selection and consideration determine the success or failure of the technique. These system components include climatic, edaphic and socioeconomic factors.

Apart from those modern water-harvesting techniques that have been recently introduced into the region, all the indigenous water-harvesting systems in Libya have evolved over the centuries according to the dictates of the above factors, as they were modified by the experience of local people in different locations. The similarity of these water-harvesting techniques throughout most countries in North Africa and the Near East is simply a reflection of their similar climates, edaphologies and socio-economies.

There are several ways of classifying water-harvesting systems according to the definition and terminology used by different authors and local users in any given country or region. Indigenous water-harvesting systems in Libya are classified in this paper into two basic categories, according to the nature of the water supply harvested, as follows.

1. Systems based on harvesting the floodwater of *wadis*, gullies and channel flows. Such floodwater is either collected and stored in surface reservoirs (with a view to later productive use) or directed into soil storage and used for floodwater farming (via spate irrigation and other water-spreading techniques). Three water-harvesting systems in Libya fall within this category:
    - storage dams
    - mountain lakes
    - water-spreading methods.

2. Systems based on harvesting rainwater of local origin, through runoff collection from rooftops and overland flow. The water collected in this way is either stored in tanks and cisterns, and later used to supply water to humans, animals and agricultural crops, or stored in the soil for crop production through the techniques associated with runoff farming. The indigenous water-harvesting systems that fall within this category include:
   - household and rangeland cisterns
   - semi-circular bunds
   - small basin farming
   - contour stonewall terracing
   - contour ridge terracing

Fig. 6.1 shows the zonal distribution of indigenous water-harvesting systems contained in the above categories. These systems will be described and discussed, in detail, below.

Storage Dams

Dams of varying shapes and designs were extensively used in the past, for both water collection and flood protection. The present remains of rock and mortar dams in several *wadis* and floodplains of the Western and Eastern Mountain zones provide a clear example of advanced runoff water management and conservation technologies having been used in the past. Some of these remains are still intact in Wadi Ka'am, Alazizia and Wadi Libda.

(a) *(b)*

The remains of the ancient Wadi Ka'am diversion dam: a) main diversion wall, b) intake gate of buried aqueduct.

It seems that the function of these dams was not confined to collection and storage of runoff water, which would have been exposed to heavy evaporative losses. The dams were also used to hold back the flow of torrential streams, minimizing soil erosion and spreading floodwaters so that they covered the largest possible cultivated areas downstream.

Some of these dams were designed and constructed to raise the level of collected water, in preparation for its diversion through specially designed aqueducts.