Khattara and Water User Organizations in Morocco

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Introduction

In arid and semi-arid regions, located at the southern and eastern margins of the Atlas mountain range, in Morocco, people live within oases relying mainly on traditional water systems called *khattara* (qanat). The khattara system has been a common form of underground water utilization since its development several hundred years ago, especially in Tafilalet region where it extends to the southeastern part of Morocco (Oshima, 2001).

There are about 570 khattaras in this region; however, only around 250 are currently operational (ORMVA/TF, 1997). This reduction in numbers is caused mainly by drought and other multiple related factors. It has become difficult to maintain khattara because of the economic difficulties related to drought (Oshima, 2004). To improve the present situation, khattara water users started to establish associations, essentially non-governmental organizations (NGOs), for getting financial support for khattara rehabilitation work.

This chapter focuses on the role of these associations on khattara management. The data on traditional organization of khattara and associations were collected mostly through interviews conducted by the author.

A Brief Overview

The government of the Kingdom of Morocco advocates the importance of participation of inhabitants in developing national agriculture and rural development policy. In this policy, the importance of NGOs and local organizations is highlighted (Ministry of Agriculture, Rural Development and Sea Fisheries, 1999). It also refers to the necessity of reinforcing capability of these organizations to cooperate with other organizations including administrative organs (ibid.).

In line with this policy, the Regional Agency for Irrigation and Agricultural Development of Tafilalet (hereinafter referred to as "ORMVA/TF", in French, Office Régional de Mise en Valeur Agricole du Tafilalet), was created by the government in 1966 and has been promoting the establishment of Associations. The ORMVA/TF has been trying to support traditional khattara water users organizations to transform to Associations since 2000 to cope with the high demand for financial assistance for khattara rehabilitation in the region (Oshima, op.cit).

In general, khattara systems fall under the supervision of the traditional khattara organization composed of water users. The management of water from khattara for irrigation is regulated by the customary law of distribution, known as water rights. The water cycle of khattara varies from 8 to 25 days, and is utilized by approximately 100-200 people. Each water user's organization divides water users into irrigation groups of specific length of water rights, and selects representatives (called *mzrag*, pl. *mzārīg*) from each group. One leader (*sheīkh*) of the khattara is also selected among water users (Figure 1). Hence, typical traditional khattara organizations have a leader representing a few hundred water users.

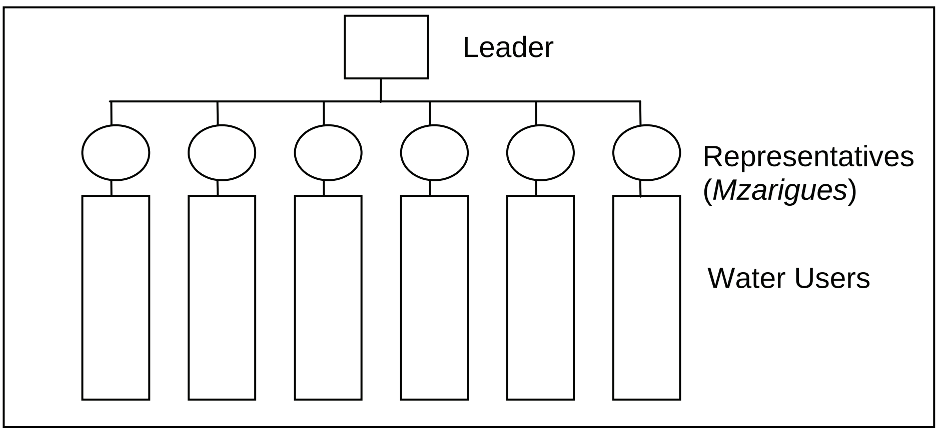

Figure 1. A schematic representation of the structure of a traditional khattara organization.

The traditional khattara organizations are managed by water users and carry out khattara maintenance and rehabilitation works by fairly distributing their workloads and financial burdens in proportion to the amount of water rights of each individual. The experience, knowledge and unity of water users accumulated through these activities provide a strong basis for continuation of maintenance and rehabilitation.

However, the traditional organizations do not have legal status or registration, and their operation does not fall under the local laws. Because of this reason, external organizations, including international development agencies and NGOs, are reluctant to extend their support to these traditional organizations. On the other hand, the Associations must be established in accordance with the Association Law enacted in 1958 and partially modified in 1973 and 2002

(Benyahya and Bouachik, 2003). Therefore, the establishment of associations which include khattara development in their activities has been gradually spreading among khattara villages.

Classification of Associations

Associations related to khattara management can be classified into two categories according to their field of interest: (a) associations whose activity specializes in khattara management; and (b) associations aiming at supporting all activities related to rural development, including khattara. The former is referred to as Khattara Associations, while the latter as Associations for Rural Development. Both types of associations are registered by the government through a prescribed procedure; there is no difference in the legal status between the two.

The three main objectives of Khattara Associations can be summarized as distinct stages:

1. To prepare khattara development projects, which require financial assistance from external organizations;
2. To demonstrate the importance of khattara systems in local development; and
3. To increase the income of people living in khattara villages.

So far, most of these associations have only focused on the first stage; they have not yet been able to expand the scope of their activity to the next stages.

Associations for Rural Development have been established by local people for sharing common interests, with similar three-stage actions. In Tafilalet region, 191 Associations were established. The primary of these associations focuses on rural development, social development, and cultural exchange in order to improve the standard of living of the population in rural areas (ORMVA/TF, 2003).

Case Study – The Jorf Area

The author selected the Jorf area (the region of Fezna-Jorf-A.S. Ghèris, at a distance of ca. 7 km from Erfoud in the north-west) in Tafilalet region, for carrying out the field survey in 2004 (Figure 2). In Jorf area, there are 59 khattaras, but only 19 (32%) are currently operational. The criteria for selecting this area as a case study were: 1) existance of numerous operational khattaras; 2) associations related to khattaras have already been established; and 3) the *status quo* and types of associations varies significantly in the area.

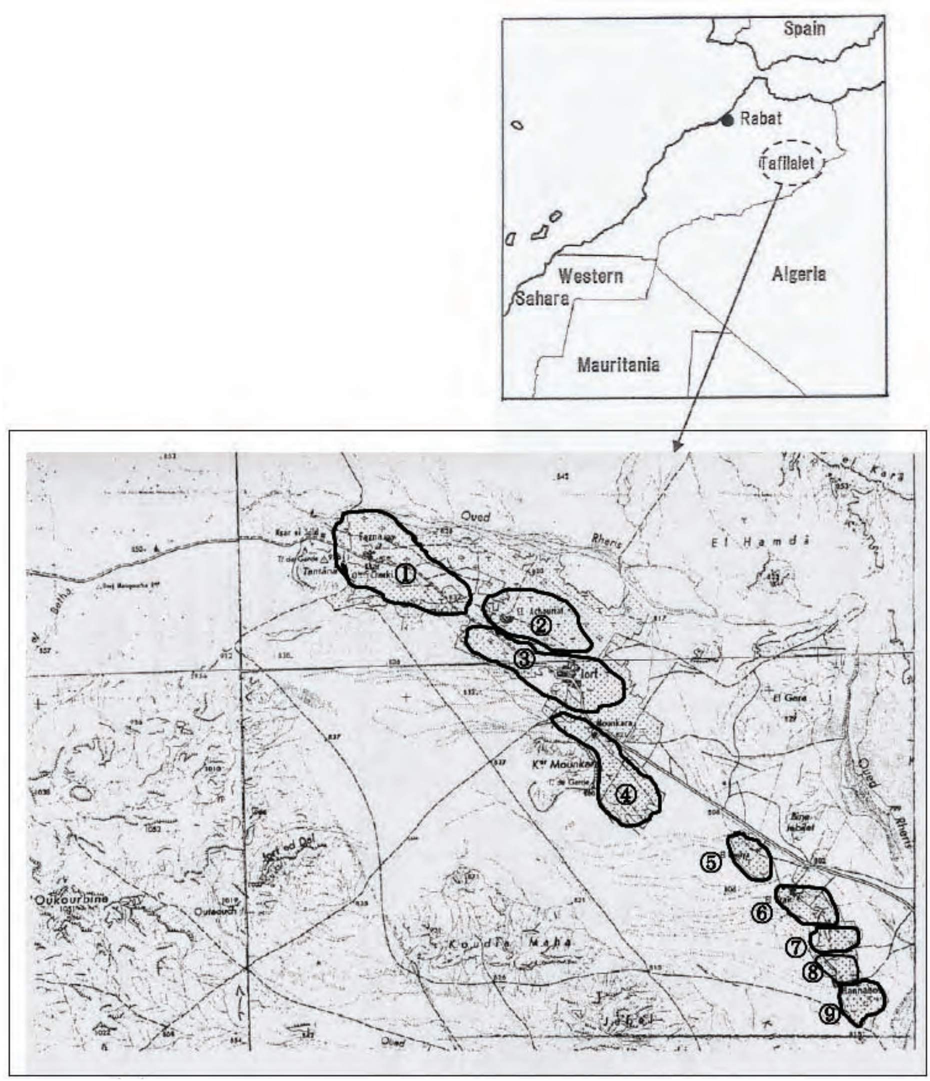

Figure 2. Map of Associations in the Jorf area.
Legend: ① Gfifat Khattaras Fezna; ② Achauria Khattaras; ③ Jnan Nbi Khattaras Jorf; ④ Mounkara Khattaras; ⑤ El Amal; ⑥ Al Kheir; ⑦ Lakhtitira Khattara Hannabou; ⑧ Ghriss Khattaras Hannabou; and ⑨ El Ouahda Khattara Qadimat Hannabou.

The ORMVA/TF has been trying to facilitate the provision of governmental support to khattara rehabilitation efforts, mainly by transforming traditional organizations into formal and legally registered associations. At first, they attempted to unite all the khattaras in this area into a single organization. But through discussion with the representatives of each traditional khattara organization, they agreed to create nine distinct Associations (please see Figure 2). This reflects the aspiration of the local people, who had strongly hoped to establish an association for each village, or even each khattara.

As a result of this effort, eight Associations were established in Jorf area during the year 2001, except for the El Amal Association which was already well-established a year earlier. Seven of these associations are classified as Khattara Associations, and two are Associations for Rural Development. The number of the khattaras that belongs to one Association varies from one to twenty four. We can also find associations whose active area covers more than one village (Table 1).

Table 1. Office members of the associations in Jorf area.

Association Name	Number of Office Members	Number of Khattara†	Status in the Traditional Khattara Organization		
			Sheikh	Mzrag	Water User
Gfifat Fezna	9	10(10)	1	-	8
Achauria	7	5(5)	2	1	4
Jnan Nbi	21	24(21)	10	10	1
Mounkara	13	4(0)	4	7	2
El Amal	13	4(2)	2	4	7
Al Kheir	9	2(0)	2	6	1
Lakhtitira	9	1(0)	1	4	4
Ghris Hannabou	9	8(2)	5	2	2
Al Ouahda	9	1(0)	1	4	4
Total	99	59(40)	28	38	33

†The number in parenthesis indicates the number of khattara without water at present.

Also a union, comprising presidents of all the nine associations in this area, was also established in order to develop common strategies to cope with the threats to khattaras in the area. One of the greatest threats is the expansion in the use of motor-pumps for irrigation in upstream or catchment areas, leading to the decline of groundwater tables. The union also facilitates exchange of information and knowledge acrss the khattaras.

The Status Quo of Associations

In Fezna, both associations of Gfifat and Achauria are not active. This is a result of depletion of the respective khattaras. All khattaras in this district have already dried up since the 1970s because of the lowering of the groundwater level due to widespread use of motor-pumps in the upstream area. Those responsible for establishing khattara associations in the Fezna district have faced general indifference from the users, who formerly relied on khattaras. Despite these hurdles, the associations were established at the insistence of ORMVA/TF. There is a local belief that the water availability in these khattaras may be restored in the future and the association might be useful.

In the two districts of Jorf and A.S. Ghèris, five Khattara Associations and two Associations for Rural Development were established. Some of the associations have already been successful in securing economic assistance from external organizations. It is interesting to note that receiving external aid seems to be a matter of chance rather than a reflection of the level of effort or activity by a particular association. When economic assistance is granted by an external organization, they often choose a khattara using their own criteria, thus bypassing the preferences of the respective association. This complicates the role of associations and local users tend to favor creation of associations for individual khattaras. The associations in these districts are striving to change this pattern.

For associations spanning more than one village, consensus building and cooperation work is quite challenging because each village has its own interests and priorities. People of each village or each khattara openly expressed their strong intention for establishing their own organization. This obviously points to a misunderstanding about the concept and role of these associations.

When compared to the Khattara Associations, the Associations for Rural Development are very active. They have greater experience in project implementation in partnership with external organizations. Their engagement is in the day-to-day activities of people.

In the case of the union, the members have been dissatisfied with the leadership and have expressed reservations about the utility of the union. While the union is dormant, members of the union are considering a change in the presidency as a way of reactiviating it.

Relations Between Associations and Traditional Khattara Organizations

In general, a traditional khattara organization comprises water users and manages all issues concerning khattara. Therefore, there is a tendency of people who have a high status in the traditional khattara organizations to also become office members of the respective associations (please see Table 1). In some cases (e.g., Lakhtitira Association and Al Ouahda Khattara Qadima association), all office members are representatives belonging to a traditional khattara organization. This type of association can be considered as a "reinforced" traditional organization by achieving a legal status.

When an association works on more than one khattara in a village (e.g., Mounkara Association, El Amal Association, Al Kheir Association and Ghris Hannabou Association), each khattara selects their own representative from either a traditional khattara organization or water users. This leads to a multiplicity of institutional arrangements.

Al Kheir Association is considered to be an active association. Its establishment was at the initiative of ORMVA/TF, but was not established as a khattara association like the others. Instead, they developed an Association for Rural Development, and selected as office members people who already had a high status in a traditional khattara organization. This is a type of association where the traditional khattara organization has obtained legal status as an Association for Rural Development through the registration process.

Challenges for Associations' Activities

Factors that determine the activeness of an association can be summarized as follows:

- Availablity of sufficient water volume in khattaras;
- Behavior of the inhabitants and water users;
- The size of the activity area within one village; and
- Existence of strong leadership.

It is needless to say that the existence of water flow in khattaras is the most important factor that determines the activeness of an association. Conversely, khattaras that have dried up do not become a choice for aid programs; and it is natural that such associations have no motivation for being active.

Typically, associations that are limited to a single village are more active. This is mostly driven by the sense of commonality of purpose and interest. Such motivation is lacking in associations that span more than one village. The commonality of cause was demonstrated in the El Amal Association in El Bouiya. In 1999 two khattaras, which had been the main source for irrigation in El Bouiya, were damaged by flood. The young people in this association made coordinated efforts to repair them, and through this work developed a spirit of collaboration and cooperation.

The existence of strong leadership is also an important factor that impacts the level of activity of an association. There are number of examples where the lack of such leadership has led to the corresponding associations becoming dormant or dysfunctional.

In many cases, activities of the associations are limited to seeking economic assistance from external organizations, even if they have other stated objectives in the declaration of their establishment. It is also documented that witnessing other associations receiving economic aid from external organizations was a primary moviation to establish their own association.

Because there are very few funding opportunities for khattara rehabilitation, there is a strong competition among the associations to get financial aid, and each inhabitant insists that their khattara (or khattaras) are badly in need of help.

This competition became more intense after some associations were successful in receiving economic assistance.

Conclusions

On the whole, many of the problems facing use and management of khattaras can be broadly classified as either caused by natural factors or by social practices and norms. There are many problems that are caused by societal behaviors, like pollution to irrigated lands by utilization of washing detergents and shortage of manpower due to exodus from rural areas. Comparatively, one may argue that these problems are much more serious when compared against those caused by natural factors.

A large part of these problems is driven by a change in lifestyle and way of thinking. Therefore, it may be necessary to take comprehensive measures to solve the problem. While technical assistance is important for khattara rehabilitation, simultaneous reinforcement of organization of water users is also very important for sustainable development of khattaras and regions. This reinforcement can be possibly achieved by the efforts of associations and assistance from external organizations. These associations, which represent a new concept of khattara management, can be considered to be evolving. One hopes that they will play an important role in khattara development in the future.

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Traditional and Contemporary Water Harvesting Techniques in the Arid Regions of Tunisia

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Introduction

The Middle East and North Africa (MENA) region is by far the driest and most water scarce region in the world. Rapid population growth, increase of household income, and expansion of irrigation have exacerbated the situation. There is evidence that limited water availability is slowing down the economic and social development of MENA countries (Renard et al., 1996; Oweis et al., 2001).

The MENA region encompasses mainly poor, developing countries. They often do not possess the technical know-how, financial capacity or the institutional structures to adopt modern water management technologies. However, over centuries societies in this region have accumulated valuable knowledge and developed practices to cope with water shortages (Oweis et al., 2001; Ben Mechlia & Ouessar, 2004).

The southeastern region of Tunisia is extremely water scarce, with annual rainfall ranging from 150 to 230 mm. Areas, where traditional water harvesting techniques are applied, are limited (Bonvallot, 1979; El Amami, 1984). However, since the independence of Tunisia there has been a gradual expansion of cultivated fields, mainly olive trees. This development was supported by the construction of *tabias* and water spreading structures in the foothills and surrounding plains, exploited normally as rangelands. In parallel, the Soil and Water Conservation Service of the Ministry of Agriculture has further introduced modern technologies (gabion units, groundwater recharge wells, etc.) especially during the last two decades, which witnessed the implementation of the national soil and water conservation strategy and the water resources mobilization strategy (Ministère de l'Agriculture a & b., 1990).

The enrichment of the existing traditional techniques has raised the question of the nature of the linkages between the traditional and the newly introduced water harvesting technologies. Are they complementary or conflicting? What are the perceptions of the local communities of these changes in the landscape useage? What impacts (positive and negative) have they induced? What future prospects could be considered?

General Characteristics of the Watershed of Wadi Oum Zessar

The watershed of *Wadi* Oum Zessar is situated in the southeastern region of Tunisia, in the province of Médenine. It stretches from the south-west of the Matmata Mountains near the village of Béni Khdache across the Jeffara plain and into the Gulf of Gabès, terminating in the saline depression (*sebkha*) of Oum Zessar (Figure 1). The general characteristics of the study area are provided in Table 1.

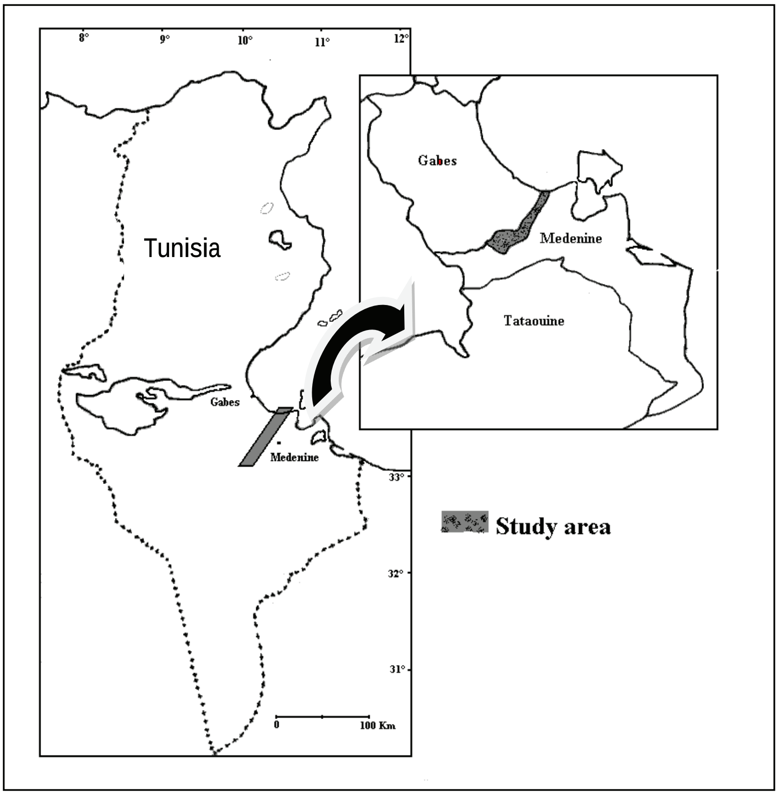

Figure 1. A map of Tunisia showing the location of the study site.

The climate in the watershed of *Wadi* Oum Zessar is predominantly of the Mediterranean type and is characterized by the continental, arid climate of the Matmata Mountains as well as the maritime, arid influence of the Mediterranean Sea. The temperatures in the study area range from as low as -3°C during the winter months (December to February) to 48°C during the hottest period of the year (June to August). The watershed is situated in an arid ecosystem with low annual rainfalls (between 150 and 240 mm) and high variability (both in time and space) (Derouiche, 1997). The 'wet' season stretches out over the months of November to February, and the remaining period is dry. The summer months are almost rainless. Highly intense showers (more than 50 mm/h) could occur at any moment during the period September to March (Fersi, 1976).

Table 1. General characteristics of the study site.

Area (km^2)	367
Annual rainfall (mm)	180
Mean annual temperature (°C)	20
Altitude (m)	0-690
Population (inhabitants)	24,188

The agricultural systems are marked by their diversity from the upstream to downstream areas of the watershed of *Wadi* Oum Zessar and are essentially characterized by:

- A non-regular agricultural production that varies from year to year depending on the rainfall regime;
- The development of arboriculture and the extension of newly cultivated fields at the expense of rangelands;
- The predominance of olive trees and the development of episodic cereals;
- The gradual intensification of the livestock husbandry systems; and
- The development of irrigated agriculture, exploiting surface and groundwater resources (Sghaier et al., 2002; Labras, 1996; Rahmoune, 1997).

The farming systems mainly encountered in the study are described in detail below (Sghaier et al., 2002).

The "Jessour" System

This system is mainly found in the upstream areas of the watershed in the mountainous zone of Beni Khédeche. This is an ancient system consisting of a series of stone and earth walls, called *tabias*, built across the stream beds of narrow valley watersheds. The *tabias* collect and retain soil washed down hillsides by torrential rains (200 mm tend to fall all at once), forming terraces in a stair-step fashion down the natural slope. The rainfall also collects on these steps and permits cultivation of olives and barley, the traditional crops, and sometimes apples, apricots, chickpeas, faba beans, lentils, watermelons and vegetables.

In the Matmata mountains, where there is higher rainfall, the *Jessour* system has allowed for the cultivation of figs, grapes and apples. This mountain area is marked by fruit arboriculture, most notably the olive. Annual crops such as cereals, vegetables and some annual crops (beans, small peas, etc.) are also occasionally cultivated. The cropping areas are extremely small and rarely exceeded 0.25 ha. Tree densities are relatively high and can exceed 60 trees/ha. On average, farmers own six parcels. Recent research (Labras, 1996; Sghaier and Chahbani, 1997) has revealed that the average annual agricultural income by farmer is estimated to be TND 1,195 (approximately USD 1,000) with almost 70% generated by vegetable production. The gross margin per hectare is relatively low, around TND 110 (approximately USD 90) (Labras, 1996). The yearly non-agricultural income is estimated at TND 200 (approximately USD 170).

System of Irrigated Perimeters

Two subsystems can be distinguished: private irrigated perimeters and public irrigated perimeters.

Private irrigated perimeters: This subsystem is based on surface wells. It can be found both in the upstream and downstream areas of the studied watershed. Cash crops, vegetables and fruit trees are produced, some of which in greenhouses. The cropping area varies between 0.2 and 10 ha (Rahmoune, 1997).

Public irrigated perimeters: This subsystem is situated in the downstream zone of the study area and is fed by tube wells that are typically drilled with government support. The water management is ensured by a collective interest association known as Association d’Intérêt Collectif (AIC).

The System of Olive Trees

This system is marked by the dry arboriculture dominated by olive trees. It is mainly encountered in the plain and in the piedmonts. The area varies from 5 to more than 45 ha. Other tree species are also cultivated, such as almond and apple, among others.

The Mixed Agropastoral System

This system combines rain-fed, marginal agriculture with a livestock husbandry component. It emerged because former pastoralists gradually transformed their land use systems by introducing an agricultural component, which became increasingly important at the expense of livestock husbandry. This system is mainly found in the downstream area of the studied watershed on fragmented areas, ranging from 25 to 85 ha. The livestock typically consists of 20 to 150 goats and sheep, and up to 100 dromedaries grazing in the saline rangelands of the *sebkhas* (saline depressions). The marginal agriculture occupies only small areas and the majority of the income is derived from non-agricultural livelihoods.

Water Harvesting: Description and Inventory

A wide variety of traditional and contemporary water harvesting technologies, such as terraces, *jessour, tabias,* cisterns, gabion check dams and recharge wells are used in the study area. Water harvesting in the studied watershed has a long history (Carton, 1988) as evidenced, for example, by the remnants of a small retention dam that dates back to the Roman era (Figure 2). The various water harvesting techniques found in the study area are described in detail below.

Terraces

Like in other regions of Tunisia and the world, terraces are constructed on steep slopes using small retaining walls made of rocks to slow down the flow of water and to control erosion (Oweis et al., 2001). It seems that this technique is the oldest adopted water harvesting technique in the watershed. However, most of the terraces are abandoned and only remnants are still found in the upper area of *Wadi* Nagab. They have recently been readopted for small-scale afforestation works or olive tree plantations in the mountain ranges (Figure 3).

Figure 2. Storage dam dating back to the Roman era near the village of Koutine.

Figure 3. New terraces on the jebel of Tajra.

Jessour

This is another ancient water harvesting system particularly widespread in the region of the Matmata mountains (Ben Ouezdou et al., 1999). Jessour are built in the inter-mountain run-off courses and consist of a series of stone and earth walls, called tabias *(*or *sed, katra)*, that are erected across the stream beds of narrow valley watersheds (Figure 4). The tabias collect and retain run-off water and silt washed down hillsides by rainfall, forming terraces in a stair-step fashion down the natural slope. The terraces are used for cultivation of fruit trees (olive, fig, almond, date palm, etc.), legumes (pea, chickpea, lentil, broad bean, etc.) and cereals (barley, wheat).

Tabias

Tabias are usually constructed on foothills, in particular in areas with rather deep soils and gentle slopes. A *tabia* is formed by an earth bund, reinforced from below by a stone wall, on the sides by a stone-lined spillway typically erected along contour lines, and at the ends by lateral bunds (Figure 5). Water is stored until it reaches a height of 20 to 30 cm and is then diverted, either through a spillway or at the upper ends of the lateral bunds. The *tabia* gains its water directly from its water storage basin (*impluvium*) or through diversion of *Wadi* run-off (Alaya et al., 1993). In general, annuals and fruit trees are cultivated on it.

Figure 4. A typical traditional *Jessour* of the region.

Figure 5. Newly installed *tabia* on the piedmonts area.

Cisterns

Cisterns, locally known as *fesquia* or *majel,* are built to collect and store rainfall. The water is used for different purposes including domestic consumption, irrigation and for livestock. In the study area, a cistern is simply a cement coated sub-surface hole (Figure 6). Cisterns with varying capacity (5 to 50 m^3) are found in the entire watershed of *Wadi* Oum Zessar.

Figure 6. Cisterns for drinking water and animal watering.

Gabion check dam units

These structures are made of blocks of galvanized nets (gabion) filled with rocks. They are built in the *wadi* beds (Figure 7). In general, they have the form of a rectangular spillway. They are used for the purpose of slowing down the run-off flow so as to increase the infiltration rate to the underground water tables and also in order to divert a portion of the run-off to neighbouring cultivated fields (*tabias*). These units are encountered as small check dams on the main intermittent water courses.

Recharge wells

When the permeability of the underlying bedrock is judged to be too low, casting tubes may be drilled into the wadi beds to enhance the infiltration of run-off water to the ground aquifer. In the watershed, these recharge wells were installed behind gabion units (Figure 8).

Figure 7. Gabion unit on *Wadi* Naguab.

Figure 8. Recharge well installed behind a gabion unit on *Wadi* Koutine.

Water Harvesting Realizations

Massive water harvesting projects were initiated in the province of Médenine, and particularly in the watershed of *Wadi* Oum Zessar, in the 1980s. The focus was on micro-watershed treatment and maintenance of existing structures in an area of approximately 36,000 ha (7,200 ha in the study area) and 39,000 ha (11,000 ha in the study area). Moreover, 270 recharge and spreading units (240 units in *Wadi* Oum Zessar) have been installed. Investments of TND 9.71 million (USD 8 million) were made for the province, TND 2 million (USD 1.6 million) in the study area (CRDA, 1998). At that time, the *Wadi* Oum Zessar represented a main focus for the implementation of the various practices undertaken. In fact, more than 70% of the water harvesting units have been installed in this watershed.

During the 1990-2000 decade, the regional services of soil and water conservation executed two main national programs, namely the Soil and Water Conservation Strategy and the Water Resources Development Strategy. The work undertaken mainly consisted of the construction of *jessour*, *tabias* and terracing (Figure 9). By the end of 2000, recharge and spreading units were built and recharge wells installed.

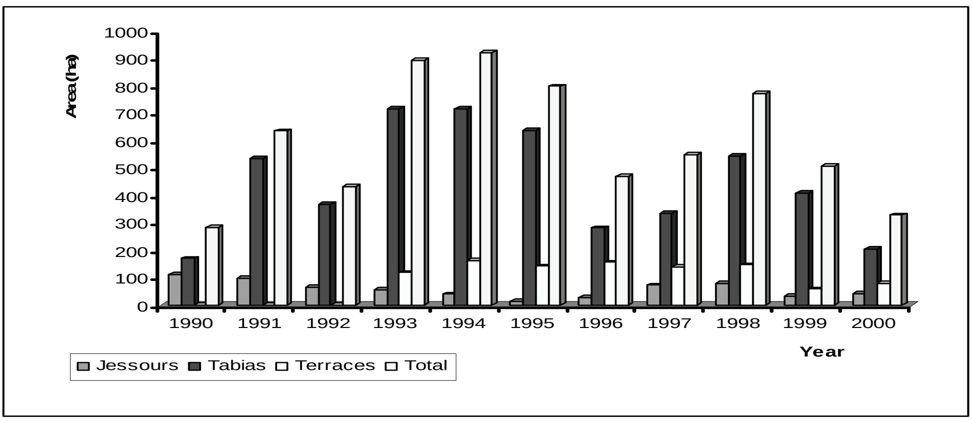

Figure 9. Work undertaken for the period 1990-2000.

Perception of Water Harvesting Techniques

The local community's perception toward each water harvesting technique (traditional and modern) regarding its impacts on land production and productivity, and appreciation of the newly introduced techniques compared to the traditional ones, was studied. For this agro-socio-economic survey, the study area was divided into upstream and downstream areas. The results of the investigation are summarized in Table 2.

Farmers largely acknowledged the positive impacts of water harvesting technologies on groundwater recharge, siltation control and crop diversification. However, they remained skeptical on the role of these constructions with regards to yield improvement and run-off control. On the other hand, livestock herders were negatively affected by this intervention because the run-off water is almost entirely retained in the watershed. This resulted in reduced quality and quantity of the halophyte vegetation of the *sebkha* used as the main winter grazing area for camels.

Table 2. Farmers' appreciation of the water technologies impacts in the study area. The farmers were asked whether the works have resulted in a) yield increase, b) water erosion control, c) groundwater recharge, d) run-off reduction, e) flooding control, f) cropping diversification and g) biodiversity improvement. The farmers were divided in different groups as listed below. (Please note the symbols: ↑ - increase; ↓ - decrease)

Group	**Impacts of water harvesting (WH) technologies[a]**					
	Yield ↑	Erosion ↓	Recharge ↑	Run-off ↓	Flooding ↓	Diversification ↑
Beneficiaries of WH works	56%	100%	100%	33%	100%	100%
Irrigators with tubewells	87%	100%	100%	38%	75%	88%
Irrigators on surface wells	100%	100%	100%	50%	75%	100%
Herders	80% (rangelands)	60%	0% (species disappearance)	75%	100%	-
Fishermen	50% (of clovis)	100%	100%	75%	100%	-

[a]: *Expressed as a percentage of inquired farmers in favor of the statement.*

With regards to the preference of the different water harvesting technologies (*jessour*, *tabias* with natural impluvium, *tabias* on spreading units and gabions), the farmers reacted differently depending on their location in the watershed. In fact, in the upstream area, since the farmers are used to the *jessour*, the first preference (67%) is given to this technique, followed by the *tabias* and then the gabion. In the piedmont zones, however, the priority is given to *tabias* with natural impluvium (NA), *tabias* on spreading unit (SP), followed by *jessour*. In the downstream area, both *tabias* are ranked first (50%) followed by gabion and then *jessour*.

It is clear that the perception of the population of the used techniques depends largely on the tradition of the group and its location in the watershed.

Conclusions

In the arid regions of Tunisia, considerable investments are being made in maintaining the traditional water harvesting techniques and introducing new ones to capture the scarce amount of rainwater (100 to 230 mm annually) for agricultural, domestic and environmental purposes.

A large variety of traditional (*jessour*, cisterns, etc.) and contemporary (gabion, *tabias*, recharge wells, etc.) water harvesting techniques are encountered in the area. They have been playing various roles with regards to the exploitation of rainfall and run-off waters (soil water, vegetation, flooding, aquifer recharge, etc.).

The local population is, in most cases, aware of the environmental impacts of the introduction of new water harvesting techniques. Their perception depends largely on the agricultural activities they are involved in (i.e. rain-fed farming, irrigation, or livestock production, etc.) and the location of his fields/pastures in the watershed (upstream, piedmont, downstream, coast).

However, the wide range of possible (positive and negative) impacts that can occur as a result of the installation of the water harvesting structures is not fully understood (Ouessar et al., 2004). Furthermore, the interactions between upstream and downstream areas have to be studied in more detail as a basis to ensure equitable sharing of natural resources between different users.

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Karez in the Turpan Region of China

Qingwei Sun, Tao Wang, Iwao Kobori, and Luohui Liang

Turpan – An Oasis Supported by Karez

The Turpan oasis is located in the Turpan Depression, the second lowest point on the earth's surface after the Dead Sea. Turpan has a continental and hyper-arid climate with an average annual precipitation far less than the potential evaporation. In ancient times, the area was called 'Land of Fire', because average summer temperatures are higher than 38ºC.

The oasis at Turpan, located in the desert expanse of northwestern China's Xinjiang province, owes its surprisingly lush green environment to the karez underground system of water supply. For centuries the oasis has been the home to the Uighur, a distinct Turki-Mongol ethnic group.

Turpan has an interesting history. More than 2,000 years ago, the oasis was a strategic stop on the Silk Road – the major overland trade route linking China with India, Persia, and Rome (see Figure 1).

The area is well-known for its extensive water harvesting and channeling system, called *karez*, which orginantes from the Han Dynasty (200 BC). This irrigation system, which is sometimes referred to as the "Underground Great Wall", has provided the basis for agricultural activities in the very arid environment. Nowadays, there are still large stretches of fertile land irrigated by karezes that were mostly built during the last two centuries. Grape cultivation is the main land use in the oasis today. Many farms have drying towers for the production of raisins.

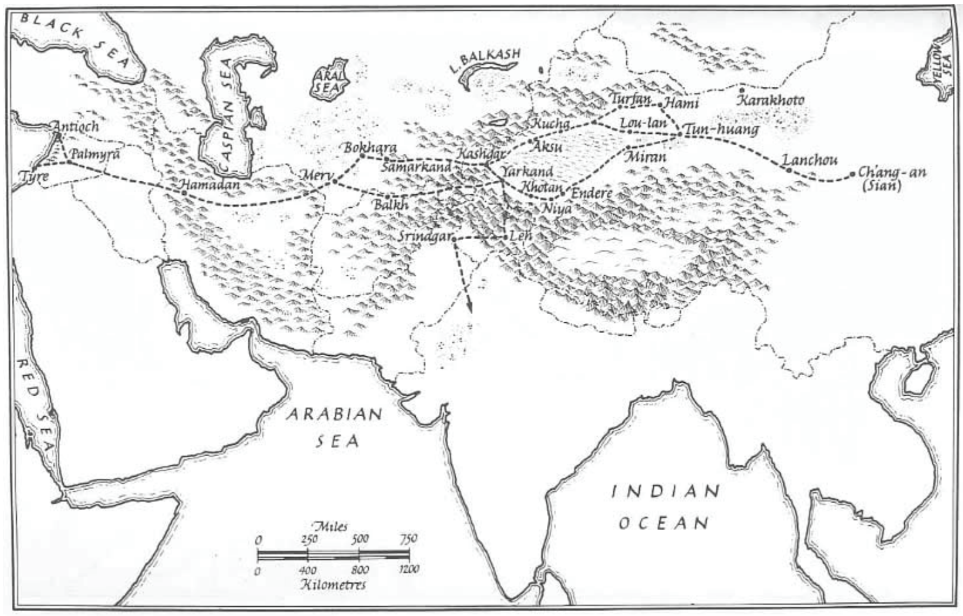

Figure 1. Main routes of the old Silk Road.

The Emergence of Karez in Turpan

The climate in Turpan is very hot and extremely dry. The Turpan Basin is one of the regions in China with the lowest precipitation (9 – 25 mm), far below the potential evaporation (about 3,000 mm). It is not unusual that there is no rain for a period of seven to ten months.

However, there are plenty of groundwater resources in the arid Turpan Basin which are recharged by melt water from the glaciers and snowfields of the nearby Tian Shan mountain range. The mountains are located north-west of Turpan and are over 5,000 m high. In the higher altitudes the annual precipitation is abundant, ranging from 800 to 900 mm. The karez system was designed to harvest, store and channel the valuable melting and flood water and provide irrigation water during the main growing season.

As there is a natural slope from the foothills at 900 m towards the deepest part of the Turpan basin at –161 m elevation, the topography of the area is favourable for this sophistacted irrigation system.

Thus, the combination of a desert climate, abundance of groundwater and suitable topographic conditions presented ideal conditions for the development of the karez system in the Turpan Depression. Some of the history of karez has been well documented in publications like: *the Proceedings of International Conference on Karez Irrigation* (1993); *Karez in Xinjinang* (2006); and *Turpan Chronicles* (1990).

Origins of Karez in Turpan

The origin of the karez system in Turpan is not entirely clarified. There are different hypotheses regarding when and by whom the system was introduced to the area.

Many Chinese historians report that the karez system was first documented near Xi'An, the capital of the Han Empire, during the Han Dynasty about 2,200 years ago. Accordingly, the karez technology was introduced to Turpan, when the area was occupied by the Han Empire. This theory is supported by the fact that the design of the karez system as well as the terminology for various parts of the karez are very similar in both regions.

On the contrary, the American scientist Huntington, who visited China at the beginning of the 20th century, documented that karez was introduced from the Persian Empire along the Silk Road at a later date, during the 18th century. This hypothesis was subsequently widely disseminated by authors in Europe and North America.

Nowadays, it is more and more widely acknowledged that the karez system has been developed in parallel in different places such as in Turpan, in the ancient Persian Empire, and during the Han Empire. It seems to be likely that local people simply designed similar irrigation systems in similar environments.

The Typical Structure of Karez in Turpan

Karez systems are very delicate irrigation systems made up of vertical shafts, underground canals, above-ground canals and small reservoirs. Melting snow from the nearby mountains is their main water source. Water is collected by vertical wells and conducted by underground channels to the oasis, where the water is collected for irrigation. A karez transports water mainly underground in order to reduce water loss from evaporation and to avoid pollution. A karez does not require any pumps, it runs from high to low ground owing to gravity alone.

Underground channels collect water from aquifers in pre-mountainous alluvial fans and conduct it to outlets in lower-elevation farmlands and settlements (Figure 2). While the length of these channels varies greatly from 3 km up to 50 km, they are typically about half a meter wide and up to 2 m high.

Every 30 to 50 m, there are vertical shafts that are needed for ventilation and maintenance of the karez. The vertical shafts are about 90 m deep at the higher parts of the karez, with their depth gradually decreasing towards the lower parts. A storage pond located at the end of the horizontal channel stores excessive water during the snow melting season. These reservoirs provide a stable water supply for irrigation and domestic use over the year. From there, irrigation channels divert the water to the fields.

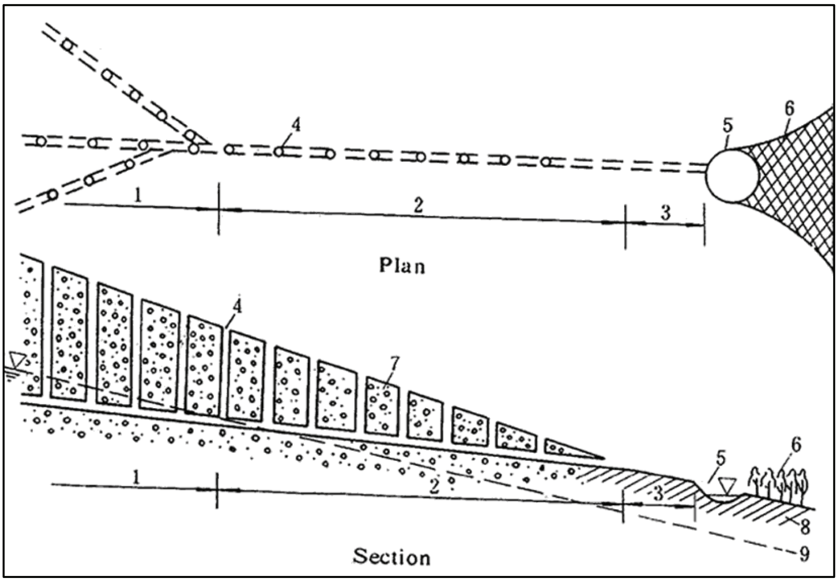

Figure 2. Schematic side and top views of a karez showing *(1)* a water harvesting underground tunnel, (2) a water-conducting underground channel, (3) an open channel, (4) vertical wells, (5) a small storage pond, (6) the irrigated area, (7) sand and gravel, (8) layers of soil, and (9) the groundwater surface.

Figure 3. A bird's eye view of the karez system in the Turpan Oasis (photo courtesy of Geroge Steinmetz).

The Construction and Management of Karez

Karez are constructed manually, and the construction can take up to eight years. The techniques and tools have remained almost unchanged over 2,000 years (please see Figures 4 and 5). The process begins with the digging of vertical shafts, which are then linked by an underground channel. Finally, the storage ponds are built and connected to irrigation channels.

Figure 4. Digging a vertical shaft (photo courtesy of Geroge Steinmetz).

It requires a lot of time and effort to maintain the karez system (see Figure 6). Traditionally, the underground channels were covered by trees, straw and soil to prevent flooding, contamination from sand, and freezing. This kind of cover is cheap, but has its drawbacks – it collapses frequently, blocking the channel. A better, but certainly more expensive solution is to use a cement cover. Often, when channels collapse, new sections are built to by-pass blocked passages.

Figure 5. Construction of a karez in Turpan, Xinjiang, China.

Figure 6. Cleaning an underground channel (photo courtesy of Geroge Steinmetz).

The Value and Status Quo of Karez Systems

In the Turpan Depression, the karez irrigation system has maintained a big oasis with tens of thousands of hectares of farmland, maintaining the livelihoods of thousands of people. Without the karez system, the landscape would be desert. In 2003, there were still about 400 karezes in operation, providing a total annual water supply of 230 million m^3 for the irrigation of about 8,800 ha farmland and domestic use for 60,000 residents.

Karez is a unique engineering relic, which has preserved ancient indigenous knowledge of hydrology and engineering. Nowadays, the karez systems in Turpan attract thousands of Chinese and international tourists. A karez museum has been established to display and explain the karez system.

Despite its long history which is believed to have started some 2,000 years ago, the peak period of karezes in the Turpan Basin was from the mid-19th century to the mid-20th century. In the 1950s, there were about 1,300 karezes with a total length of 4,000 km providing approximately 700 million m^3 of water and irrigating 24,000 ha of farmland. However, despite its high value for the region, on average 20 karezes have been abandoned every year since the mid-1960s. Today, the majority of karezes have fallen into dis-use and have dried up. Only about 400 are still operational, the supplied water volume decreased to 170 million m^3 (Figure 7).

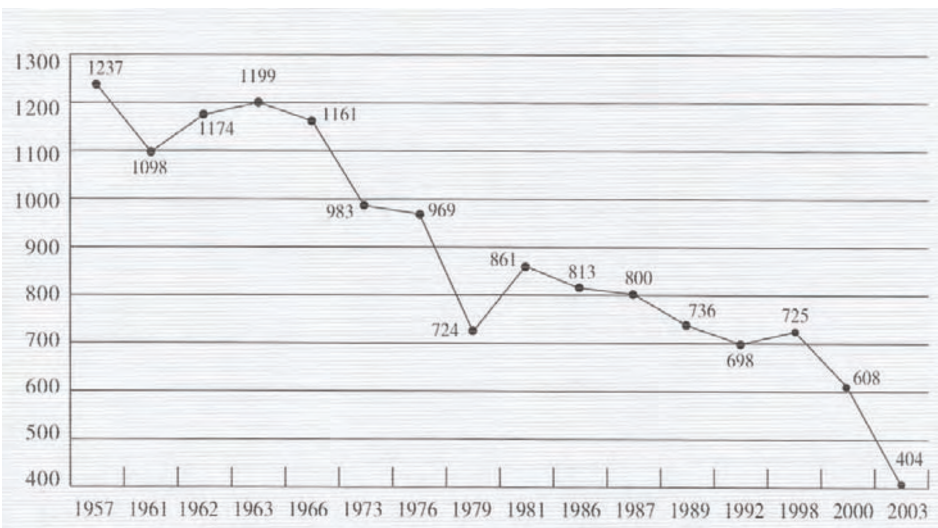

Figure 7. The decline of karez.

There are a number of reasons for the decline of the karez system in the Turpan oasis. First, rapid population growth and expansion of farmland since the 1950s has greatly increased the water demand in Turpan. At the same time, oil mining has become the major industry and has additionally augmented water consumption. In order to meet the increased water demand, reservoirs were constructed upstream, cutting off the karezes from their water source. At the same time, the increasingly wide-spread use of electrically-powered pumps has resulted in a decline of groundwater levels below the level of karez channels.

Conclusions

Karez is a unique and fascinating irrigation system with a long history in the Turpan oasis. It provided water for domestic consumption and agriculture and maintained a unique ecosystem in the desert. However, nowadays the karezes are increasingly abandoned and are not being maintained. This is partly due to the fact that the value of karez is not well understood. It is concluded that the government and local communities should join efforts to preserve and restore this ancient irrigation system.

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Zarh-Karez: A Traditional Water Management System Striving Against Drought, Increasing Population, and Technological Change

Faisal Farooq Khan

Introduction

This chapter discusses the root causes that have resulted in the desiccation of 40 out of 50 karezes in the Loralai District of Balochistan Province in Pakistan. Zarh-Karez, as one of the fifty karezes in this district, is analysed in more detail to explain the political, economic and social challenges that most of the karezes are facing. In addition, the chapter sheds light on the major factors that have enabled karezes to maintain their resilience throughout a severe drought from 1996 to 2003.

Extreme population growth is the major challenge that the Loralai District faces. In order to address the rising demand for food, the Government of Pakistan introduced electric-powered tube wells to boost agricultural production. This has resulted in a dramatic declince of groundwater tables. In some areas, the groundwater tables dropped from 100 m to more than 300 m, negatively affecting the traditional water management system.

Background Information About the Study Area

Population and society

The overall population of the Zarh village and Loralai district has doubled in twenty years and the population of Loralai is expected to increase beyond the one million mark by 2015. Population growth in Loralai is attributed to three major factors. First, the lifestyle of the local population has rapidly improved due to remittances made by overseas Pakistanis. Second, agriculture has expanded significantly through the sale of fruit produced by thousands of orchards in the district. Third, inside Afghan refugee camps, trade flourishes and contributes to significant increases in household incomes.

Gender roles and literacy

The involvement of women in natural resource management is mainly limited to tending livestock, grinding wheat and managing drinking water supplies, as a Pashtun woman's mobility is largely restricted to her family's compound. Children and village males gather fuel wood for cooking. Literacy rates in the village are low: 36.21% for males and 1.3% for females.

Droughts

Droughts are the major natural phenomenon in the area that affect lives and agriculture. It has been observed that the duration and severity of droughts is increasing, whereas the intervals between them seem to remain unchanged. The latest drought was the most severe and the longest, lasting for seven years from 1996 to 2003. 20 years earlier, there was also a drought period for four years from 1972 to 1976, preceded by a two-year dry spell from 1950 to 1952.

Irrigation and agriculture

Around the village of Zarh, villagers have access to about 900 acres of cultivable land and another 900 acres of rangelands. About half of the cultivated land is irrigated by the Zarh-Karez, while tube and open wells irrigate the remaining land and also ensure drinking water supply to all households. *Sailaba*, another indigenous irrigation practice that diverts torrents from hills to depressions, has practically fallen into dis-use in recent years.

Prior to the advent of tube wells in the region in the 1960s, livestock grazing and rangeland management was the main livelihood activity. After a century of pastoral lifestyle, in early 1970, the Government of Pakistan fostered rural electrification and provided electricity to hundreds of thousands of villages in various parts of the country. By 1972, the policymakers and planners chose electricity-powered tube wells as a single remedy to address the major challenges in the province, including water shortages, food insecurity and unemployment. This investment boosted fruit production and exports in the province, but resulted in a decline of groundwater levels.

Government policies affecting land use

In the last thirty years, the domestic, market catered to agricultural policies that promoted cultivation of water-intensive, exotic species of fruits and vegetables. At the same time, policies supported the installation of thousands of electricity-powered tube wells and windmills in areas still without electricity. This practice became detrimental for groundwater resources, particularly during the drought from 1996 to 2003. In some parts of the province, water tables dropped from 25 m to below 300 m. Nevertheless, no intiatives of drought mitigation were implemented.

At the same time, agricultural policies precluded cultivation and seed improvement of drought-resistant indigenous species like almonds, pistachios, pomegranates, dates and olives, even though markets for such produce exist overseas. Livestock and rangeland management, an old tradition of the tribesmen in the district, was entirely ignored by the government policies.

The government's much appreciated 'open passport' policy to export unskilled and semi-skilled manpower to the Gulf region contributed to an increase of buying power, resulting in consumption patterns that have added pressure on the already over-stressed natural resources.

The Historic Development of Karezes

A typical karez consists of a mother well, an underground tunnel, a number of vertical shafts at a distance of 40 to 50 m from each other, and an outlet. An open on-farm water channel then connects the karez to the farmland. The length of a karez may vary from 300 m to 15 km. *Hazarawal* (Persian speaking residents of Central Afghanistan), famous for their specialist skills, typically construct karezes. Villagers are responsible for the maintenance and operations of the karez while the farm owners seasonally clean and desilt the karez channels.

The earliest historical evidence of the presence of a karez in Balochistan dates back to 2,700 years ago. By the time of independence of Pakistan in 1947 and before the 1950-52 drought, 22,000 karezes were operational in Balochistan. Fifty years later, 12,000 karezes were still functional, but today only less than 4,000 karezes have survived the latest drought from 1996 - 2003, which was also the longest and most severe drought in the history of Pakistan.

The provincial government of Balochistan, with the assistance of the Government of Pakistan, has recently completed the rehabilitation of 105 karezes in the province. The rehabilitation work was limited to the widening of mother wells, repairing the vertical shafts, desilting of channels, lining of on-farm distribution channels, and finding alternate sources of water for the dried karezes. Three delay action dams were built in the province to recharge karezes, but they all ran dry before the monsoon season approached.

The Department of Food and Agriculture is responsible for the karezes, because karezes are managed in conjunction with farmlands. Although the functionality of karezes is closely related with the condition of surrounding forests and rangelands in the catchment area, the Forest Department is kept aloof of karez rehabilitation attempts.

Karez Management Practices

Each clan of a tribe has its own karez. The user rights are determined by tribal affiliation and not by the duration of residence in a village. The operation and management of a karez is the responsibility of the water users. Normally, the head of a village, the *malik* (village head), is the person in charge of karez water distribution and management. Allocation of water quotas is generally based on centuries-old, verbal agreements amongst the first settlers. New quotas are only negotiated when new occupants settle down in an abandonned village. A classic example is the settlement of the nomadic Kakar tribe during late 1890s or early 1900s in Loralai to replace Hindu and Sikh families driven out by British rule.

Land is allocated among all men who have contributed to the construction of a karez. For example, if ten male persons have constructed a new karez or settled in an abandoned village with a karez that irrigates 100 acres of land, then ten acres of land will be allocated per male person. These men and their offspring will keep the land and water use rights associated with it as long as the clan lives in the village. Inheritance and number of offspring resulted in varying sizes of land owned and shares of karez water.

Simple measurement techniques are used to allocate water distribution quota. Interestingly, measurements of water distribution are time-based. According to a local malik, droughts are a regular phenomenon in the area and their ancestors were aware that quantification of water by volume would lead to conflict during the droughts. Allocation of water by time ensures some water for everyone.

The largest measurement unit of water is called *shabana roz* and corresponds to a day and night discharge of water from a karez channel into a landholding. A shabana roz varies from village to village depending on the size of the water gauge. There is no standard measurement of a shabana roz or standard relation with a particular size of farmland. However, there is a standard shabana roz at the village level and smaller units of water measurement are derived from that standard measure.

Figure 1. A water channel connecting a karez with the farm.

Clearly, a shabana roz discharge from the same karez equaling the same amount of water can serve very unequal sizes of land in two neighboring villages. For example, one shabana roz of water in the Zarh-Karez area is used for irrigating 270 acres of farmland, while just a few kilometers away one shabana roz is used for irrigating only 10 acres.

Table 1. Overview of how water is measured by time and size of farmland without any consideration to its volume.

Measurements	Duration	***Sargarah*** **Land size**	**Zakhpail Land size**
Shabana roz	24 hrs	350 acres	400 acres
Horr	12 hrs	175 acres	200 acres
Chareek	03 hrs	44 acres	50 acres
Chareekee	1.5 hrs	22 acres	25 acres
Gutt	45 mns	11 acres	12.5 acres

Furthermore, a landowner possessing land near the outlet or head of the distribution channel will get water first regardless of the size of his quota, whereas a landholder at the tail of the water distribution channel will receive his share in the end, even if he has the largest landholding in the village. The malik ensures that all landowners receive their allocated quota of irrigation water.

Land Classifications

In the district, land is categorised into four major categories: *mazrua* (cultivated), *ghair mumkin* (uncultivable wasteland), *banjar jadeed* (new cultivable wasteland), and *banjar qadeem* (old cultivable wasteland). Changes in the distribution and share of land use categories, though not officially recorded since 1966, have occured.

Figure 3. A glimpse of an orchard irrigated by a karez.

Mazrua or cultivated land in Zarh and other villages had on average expanded by less than 10% in the last thirty years. Old mazrua land is irrigated mostly by one karez, as the entire socio-economic and socio-political structure of a clan depends on the karez management practices and distribution of its water.

The main agricultural expansion has occurred in banjar jadeed and to some extent in banjar qadeem. Expansion of agriculture in the above two categories of land has not affected the existing karez water quotas and mazrua land ownership. Different traditional irrigation (*sailaba* and *khushkaba*) methods and electric powered tube wells are used to irrigate this land.

Distribution of ghair mumkin has not changed significantly. However, the droughts of 1950-1952, 1972-1976, and 1996-2003 have transformed some of the banjar qadeem land into ghair mumkin as part of the desertification process.

Since 1966, change in the land cover of mazrua and banjar jaded categories of land has mostly occurred due to human activities, whereas change in the land cover of banjar qadeem and ghair mumkin has occurred mostly due to climatic changes. Distribution of the first two categories of land was made according to the available manpower and with the clan's consent as decided upon in a jirgah.

Table 2. Land use trends practiced in seven villages (including Zarh, Chinjin, Shah, Surki Jungle, Chapli, Dargai Sargarah and Dargai Zakhpail) in the Loralai Province according to the four land classifications.

	Land Classifications			
	Mazrua	***Banjar Jadeed***	***Banjar Qadeem***	***Ghair Mumkin***
Irrigation	Mainly Karez Where possible, tube wells, hand pumps and open wells	Sailaba and/or Khushkaba Surplus water from a karez, if available	Khushkaba	None
Cropping	Orchards, grains, cotton, and vegetables	Vegetables and grains	Grains	None
Livestock	Stall feeding	Grazing	Grazing	Grazing
Housing	Mainly	Some	None	None
Ownership and access	By inheritance only. Not sellable outside the clan.	Shamilat Awara	Shamilat Awara	Shamilat None

Social Factors Contributing to the Survival of Karezes

Social cohesion and homogeneity of communities inhabiting the villages in the karez area were identified as the major factors ensuring sustainable management of a karez. As mentioned earlier, a karez is a communal holding that is used by everybody who belongs to the same clan of a tribe. This means that the operations and management of the karez are also the responsibility of all the villagers who irrigate their lands using karez water. When the karez needs to be repaired, all users must contribute according to their water share, either financially or in-kind.

To operate such a system of interdependency, strong social bonds and mutual trust are required. This is precisely what was witnessed in the case of successfully operated karezes such as Dargai karez and Chinjan karez. Inhabitants of the villages of both karez areas are from the same clans and have been living there since more than a century. On the contrary, Zarh-Karez, however, is under the jurisdiction and managed by different clans. This has resulted in social conflicts and parts of karez has dryed out, because only one of the clans still manages and maintains their share of the karez system.

Some villages rely entirely on their karez for irrigation, simply because karez water is most cost-effective. This was observed particulary in villages without large land holdings and where traditional farming practices still prevailed over progressive cultivation systems. Obviously, without alternative water supply systems, these villagers have strong incentives to maintain their karezes.

The government's interventions also contributed to the rehabilitation of karezes, because delay action dams were built to support recharging Zarh and Dargai karezes.

Factors Contributing to the Decline of Karezes

Several factors have severely affected the traditional water management system in the semi-arid region of Loralai.

First and foremost, many karezes dried up due to the drought experienced by Balochistan for eight long years. Thus, natural processes were one of the strong underlying causes for the decline of karezes. However, it needs to be noted that the government failed to make use of the excess water available during wetter periods. In addition, rural electrification and broad installation of electric tube wells as subsidized by the government resulted in a significant depletion of groundwater levels.

Agricultural development has also played a role. The agricultural sector started booming all over the country as a consequence of agricultural modernization; large orchards of exotic fruit trees were established everywhere in Balochistan. Agricultural subsidies fostered the cultivation of cash crops such as apples, grapes, and onions. However, these crops were not adapted to the arid climate in the Balochistan province and their cultivation proved to be very water-intense. Limited groundwater resources were over-exploited to satisfy the water needs of the new crops.

Furthermore, mass labour migration both in and out of Pakistan generally improved income levels. The resulting improvement of living standards contributed not only to a rapid population growth, but also led to changes in consumption patterns. Increasing demand for food and agricultural products was the outcome. This was an incentive for many farmers to increase the size of their farmlands. However, as their shares of the karez did not simultaneously increase, tube wells and other irrigation facilities were installed and increasingly substituted the traditional irrigation system.

Lastly, the influx of more than one million Afghan refugees additionally affected the karez water management and increased the pressure on the natural resource base. Pakistan communities were moved away from the Afghan border, making it difficult to maintain the management of the karez system. Zarh-Karez alone has become home to 22,000 Afghan refugees and internally displaced Pakistanis from the villages near the Afghan border.

Conclusions

In Balochistan, indigenous water management practices are regarded as the only way to re-establish integrated water resource management fundamental for the survival of people in this arid region of Pakistan. Thus, efforts should focus on rehabilitating karezes in an integrated approach and responding to the needs of local communities. Grassroots institutions will have to be revived for re-engaging people in karez management. Water-efficient and marketable indigenous species should be re-introduced in the karez areas and their cultivation should be fostered. Community-based disaster management plans for drought mitigation and flood control will need to be developed. Moreover, the unregulated use of tube wells and construction of ill-planned dams and reservoirs will have to be stopped immediately.

Traditional Water Distribution in Aflaj Irrigation Systems: Case Study of Oman

Abdullah S. Al-Ghafri

Introduction

The Sultanate of Oman is located in the southeast of the Arabian Peninsula (Figure 1). On a total area of approximately 310,000 km^2, Oman has a population of 2.2 million (Ministry of Information, 1997). Oman has a hot climate and is humid in the coastal areas, but is very dry in the interior. Average rainfall is 100 mm, except for in the south region which has a period of intense monsoon rainfall.

After oil, agriculture is the major economic sector for Oman, even though more than 80% of the land is desert. With 100,000 ha of cultivated land, the Sultanate is one of the major agricultural producers in the Arabian Peninsula, particularly regarding livestock production. However, only a very small percentage of land can be classified as agricultural land. Agriculture depends entirely on irrigation and more than one-third of the water used for irrigation is supplied by the traditional irrigation system called *aflaj*.

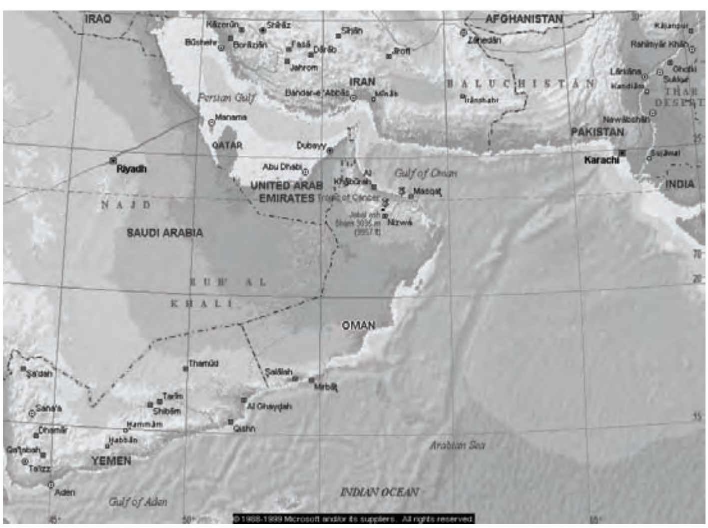

Figure 1. The location of the Sultanate of Oman.

Agriculture and Water Resources in Oman

In Oman, agricultural land is classified according to the following agro-climatic regions:

Musandam and Madha: Musandam is located in the extreme north of Oman, while Madha is a small, secluded island within the United Arab Emirates. Musandam is slightly wetter than most parts of Oman, with an average rainfall of 180 mm. The source of water is entirely from wells, but people additionally store rainwater in cisterns. Due to the limited groundwater resources, the agricultural area is threatened by salt-water intrusion. In Madha, the traditional irrigation system, *aflaj*, is the major water source.

The Btainah Coastal plain: This area has an average annual rainfall of 76-100 mm. It is the major agricultural region of Oman, responsible for 60% of the agricultural production in the Sultanate. Agriculture in this area is entirely dependent on irrigation.

The interior of Oman and Dahira plains: This region has an annual rainfall of less than 100 mm and is very hot. 50% of the land is irrigated by aflaj. Recently, a huge freshwater aquifer was discovered and the government has started developing its use.

*The mountain range of Jebel Akhdar:*This mountain range reaches a maximum altitude of 3,000 m and has an annual rainfall of 300 mm. The Jabal Akhdar plateau has a very unique climatic zone in Oman that enables cultivation of peaches, apples, pears, apricots, and almonds.

Sharqiyah plains: These plains are very dry and most of its agricultural land is irrigated by aflaj.

The Salalah plain: Located in the south of Oman, these plains receive an average annual rainfall of 70-360 mm. In this area, coconut cultivation dominates. The main water source for irrigation is tube and dug wells, while aflaj contribute to a lesser degree.

The Dhofdar Jebel: This region is located in the south of Oman. With its highest annual rainfalls in Oman (600-700 mm) due to the monsoon rains, these highlands provide good grazing land for cattle and goats.

The Najd: This a desert land in the southern part of Oman with poor soils and low water quality. However, it has a huge water aquifer, which is under development for agriculture.

Aflaj Irrigation Systems of Oman

Aflaj definition, distribution and history

The agriculture of Oman is almost fully dependent on irrigation (Abdel Rahman and Abdel Magid, 1993), because most crop-producing areas receive only between 100 to 200 mm of rainfall annually (Norman et al., 1998 a, b). The ancient aflaj irrigation system still plays a major role.

Falaj (singular of aflaj) is a canal system constructed above or underground to collect underground water, water from natural springs, or water from the baseflow of wadis. Aflaj provide water to farmers for domestic and/or agricultural use. The term falaj is derived from an ancient semitic root, which has the meaning to divide, reflecting that the water shares in aflaj are divided between the owners (Wilkinson, 1977).

Typically, a farming community owns all falaj water. Each farmer receives a share of the water depending on the size of his farmland(s) and his contribution to the construction of a falaj. Aflaj vary in size, ranging from smaller ones owned by a single family to larger ones that supply water to hundreds of owners. Although most aflaj in Oman are fully owned by farmers, there are some aflaj that are the government's property (Wahby and Al-Harthi, 1995) or are communally owned, serving, for example, mosques, or are contingency reserves (Al-Abri, 1980). Many villages and towns in Oman have more than one falaj system.

Aflaj technology was adopted in Oman 1,500 to 2,000 years ago (Sutton, 1984) and some of these systems date back to the times of the Persian occupation of Oman (Wilkinson, 1977). Comparable systems of irrigation have emerged and still exist in many places around the world: Afghanistan, China, Iraq, Iran, countries of the Arabian Gulf, Jordan, Syria, Cyprus, North Africa, Spain, Sahara, Japan, Yemen, and the Americas (Cressey, 1958; Sekai no Kangai, 1995). Some two dozen variants of names of these systems exist, including quanat; karez (southwest Asia); khettara (North Africa); and falaj (Arabia).

Types of aflaj

Aflaj in Oman are classified into three types according to their water source; *ghaily*, *daudi*, and *ainy* aflaj.

Ghaily aflaj represent 50% of the total aflaj in Oman. Their main source of water is the baseflow of wadis (Figure 2). Typically, the canal has a length of 200-2,000 m.

Daudi aflaj represent 25% of the aflaj in Oman. Their source of water is a mother well. Similar to the quanat of Iran, water in this aflaj type is conducted from deep water tables by an underground tunnel or channel system (Figure 3). Compared with other types, daudi aflaj have the most stable flow rate around the year. The channel of the falaj can be as long as tens of kilometers and, therefore, local people opened access shafts for air circulation and maintenance. Large aflaj can have more than one mother-well.

In the *ayni aflaj*, the source of water is a natural spring, called *ayn*. The ayni aflaj represent 25% of the aflaj in Oman. The length of the canal can be up to one kilometer.

Figure 2. A Ghaily *falaj* in the village of Nakhal (photo: November 2001).

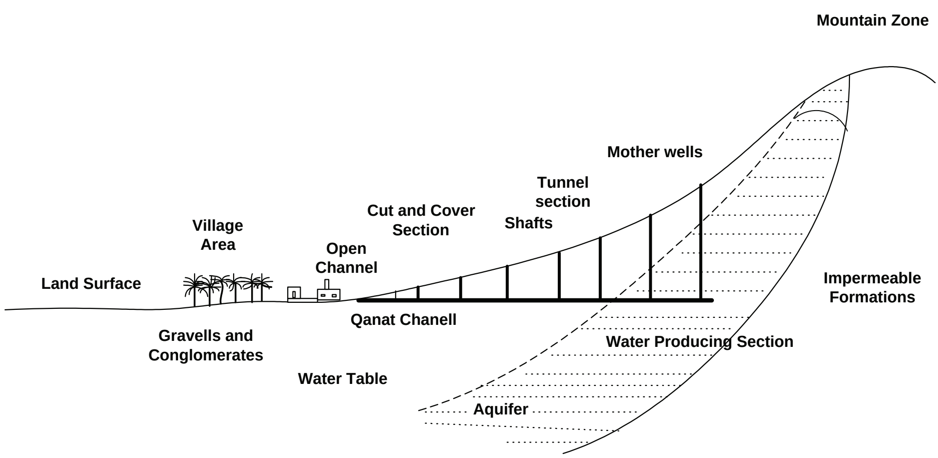

Figure 3. Cross section of a *daudi falaj* (*qanat*) in the piedmont zone (after Wilkinson, 1977).

Falaj water utilization

The aflaj systems are designed in such a way that domestic water demand is primarily served, followed by a supply of water for agricultural land. In most aflaj, the water is first directed to private households to meet drinking water demands. The water is then conducted through mosques, men's and women's public baths and finally to areas where water is needed to wash dishes and clothes. When domestic water demand is met, falaj water is used to irrigate the permanent cropland, mostly date palms, and, with the least priority, the seasonally cultivated land with wheat, tomato and onion (Al-Ghafri et. al., 1999, 2000a, 2000b). This arrangement helps farmers to control drought and guarantees basic crop production. Besides the agricultural and domestic use, aflaj systems are also sometimes used for industrial and other purposes, such as for water mills or to store water for travelers (Costa & Wilkinson, 1987).

Falaj administration

A typical large Omani falaj administration consists of a director (*wakil*); two assistants (*arifs*), one for underground-section services and the other for above ground-section services; an accountant (*qabidh*) or administrator (*aldaftar*); and a laborer (*bayadir*) (Al-Marshudi, 1995, Sutton, 1984). Depending on the size of the falaj system, aflaj can have all of the above administration, but at the very least they will have a wakil who is elected by the owners of the falaj and nominated by the head of the village (*sheikh*).

As the executing director, the wakil is in charge of the overall management of the falaj and is responsible for water distribution, leases, budget allocation, conflict resolution between farmers, emergencies etc. The arifs implement the wakil's directions, supervise the laborer and may determine the timing of the irrigation. Under the supervision of the director, the qabidh controlls the falaj income, updates the falaj accounts and prepares annual financial reports to the falaj owners. Some portion of the aflaj water can be leased short- or long-term. This is controlled by the auctioneer (*dallal*).

If a conflict occurs, either the wakil or the owners can complain to the sheikh. If the sheikh cannot solve the problem, they or the sheikh himself will take the matter further to the governor (*wali)* who is the government representative and in a position to refer the matter to the judge (*qadhi)* for reaching a final decision. Sometimes the wakil or the owners call for an audit committee to check the financial income and expenditure of the falaj. This committee usually consists of 3 to 4 trustees from the village (Al-Saleemi and Nabeel, 1997).

Falaj Water Distribution

In Oman, the method of allocating water shares among farmers is complex and differs from one place to another (Abdel Rahman and Omezzine, 1996). In most aflaj of Oman, water is distributed based on time, but water allocation based on volume also exists in a few cases. Four different water allocation methods are described below.

1. *Time intervals*: In some aflaj systems, the day is divided into estimated intervals, according to which farmers share the water. For example, the full day can be divided into seven intervals, using events such as dawn, sunrise, midday, afternoon prayer, sunset, evening prayer and midnight. However, this method is not very popular because the time units are too variable and unclear, often resulting in conflict between farmers (Al Abri, 1980).

2. *Tasa*: In the northern part of Oman a different, more sophisticated method of water distribution is used. The principle is very simple - one unit of water share (*tasa)* is determined by the time needed to fill a container with water (Figure 4). Each farmer will get a multiple or division of one tasa. The volume of the container varies according to the time unit.

3. *Liggil*: In some parts of Oman, usually in the mountains and particularly in small falaj systems, the falaj water is stored in a large water tank (*liggil*). Water is then distributed by volume according to the size of the farmland(s). Typically, in such falaj systems, the flow rate is very low and land shares are small (Figure 5) (Al-Ghafri et al., 1999, 2000b).

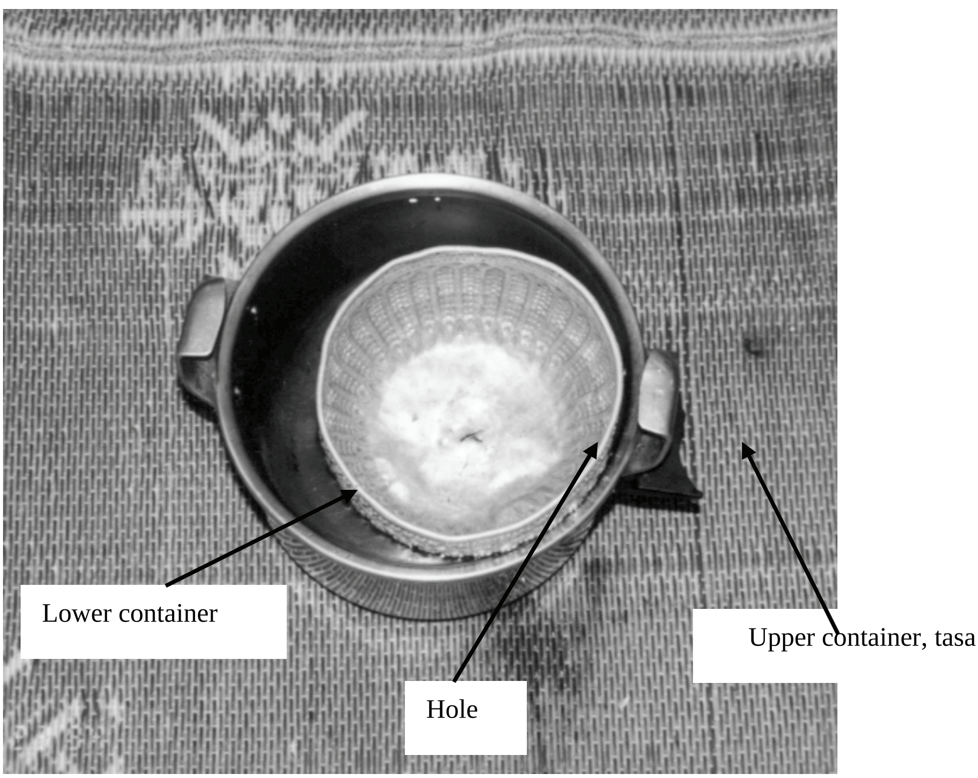

Figure 4. Tasa of *falaj Saiq* at Jabal al Akhdhar.

Figure 5. Liggil water tank for water distribution.

4. Athar: Athar is commonly used in all of northern and central Oman. It is one of the most complicated systems for allocating water among users. A farmers' committee is established to decide on the distribution of falaj water shares among falaj owners. The committee investigates in detail the flow rate, water flow fluctuations, soil type, number of owners and their proportional contribution in constructing the falaj, etc. Based on their findings, the length of the irrigation cycle (*dawran*) is determined. This can range from 4 to 21 days. Typically, the lower the flow rate, the shorter the dawran.

After the dawran is set, the water share for each farmer is determind using the time based unit of *athar*. Typically, each full day consists of 48 athars and two *baddas*, one for the day and one for the night. Each athar is further divided into 24 *qiyas*, which is practically the smallest unit of water share and approximately equal to the time required to irrigate one date palm tree with good falaj flow (Al-Ghafri et al., 1999). However, other units exist, representing different periods of time.

Once the water is divided between the shareholders, this distribution never changes and land and water shares are inherited among family members according to Islamic regulations. Each farmer will irrigate his farmland with the same number of athars at each dawran. Furthermore, the same sequence of exctracting water shares is maintained during the irrigation cycles (Norman et al., 1998b).

Water and land shares can be sold or leased. This is often done to finance falaj service and maintenance or for charity, e.g. to be used for mosques and Islamic schools.

Scheduling of Irrigation

As mentioned previously, for most aflaj in Oman, the day is divided into night-time badda and daytime badda; each badda typically equals 24 athars. The daytime badda begins at sunrise and ends at sunset, while the night-time badda lasts from sunset until sunrise. Farmers use a wide range of methods to determine the length of an athar representing the water share for a farmer. While farmers have started relying on watches nowadays, traditionally the timing of irrigation was determined by using sundials during the day and stars at night.

A typical traditional sundial used in northern Oman consists of a simple stick placed vertically on a flat rectangular area. 24 stones are carefully spaced to represent 24 daytime athars, with early and late daytime stones further apart from each other than stones representing midday athars. The stones are put in one line, in east-west direction. In order to adjust to the seasons, such a system typically has three lines, one for summer, one for fall and one for winter.

At night, farmers use stars to schedule irrigation and determine the length of an athar. Specific sets of stars are used for determining time, varying from one village to another. Farmers measure one athar by the time between the rise of (a) particular star(s) to the rise of the following star(s).

Nowadays, in many aflaj farmers use watches to determine the timing of water distribution. They count 30 minutes for each athar, so the full day is equal to 48 athars. Interestingly, when the modern watch was first introduced to Oman, a so-called sunset timing system emerged in which farmers adjusted the watch to 12:00 at sunset everyday. Since the late 1960s and early 1970s, farmers have gradually been replacing this system with the “normal” meridian time system.

Maintaing Equity in the Falaj Water Distribution System

In the traditional sundial and star method, because of the variation of the length of day and night throughout the year, farmers may have more or less water per athar. In northern Oman, where most of the aflaj exist, athar varied in length between 20 and 40 minutes. For example, during winter farmers irrigating at night will receive more water than farmers irrigating during the day, and vice versa for summer. The scheduling of irrigation using the stars to determine the timing can also be inaccurate.

In order to address these inequities, ancient farmers came up with various solutions. For example, they alternated the irrigation between day and night from one to the next dawran. Another method, which was mainly used in central Oman, was to simply design dawrans with an odd number of badas. This automatically results in alternation between day and night irrigation for the various farmers (Wilkinson, 1977).

In large aflaj systems, the stream of water of the main channel is divided into several sub-streams, depending on the size of the falaj and its flow rate (Figure 6). The amount of flow in each sub-canal is set to be equal. Farmers can irrigate from one stream or more than one stream at the same time. The farmer who irrigates using the main stream will receive the same amount of water as a farmer who irrigates from more than one sub-canal. Aflaj with a stable flow are usually divided permanently into major sub-streams. Each stream will be devoted to a specific land area. The dawran is not necessarily fixed for the entire falaj, but each major stream may have its own dawran.

During a drought a wide range of adaptation strategies exist and are applied, such as adjusting the dawran or reducing the number of sub-streams. For example, in Falaj al-Dariz the main stream is permanently divided into two streams, one with a dawran of 9 days, the other with a dawran of 10 days, reflecting the different soil types of the irrigated land. During times of drought, this falaj is united in one stream and the dawran is increased to 19 days. In Falaj Al-Ghayzayn, the falaj is also normally divided into two streams, both with a dawran of 7 days. During dry spells, farmers irrigate from one stream only. Thus, the dawran is doubled from 7 days to 14 days. In very low flow rates, the dawran is extended to 28 days (Birks and Letts, 1977). Wilkinson (1977) further reported that the dawran is altered seasonally in some aflaj to meet the changing requirements of summer and winter irrigation.

In Falaj Al-Farsakhi, farmers adopted a very simple method to ensure equitable distribution of water shares. The falaj water rights are divided into eight full days. Each day is further divided between groups of owners, from 4-8 owners in each group. While each group irrigates on the same day during each dawran, the order of irrigation is reversed for each dawran.

Furthermore, it is a common practice in small aflaj systems that farmers store some water in a big tank in order to maintain a stable flow rate throughout the year. The time for storing water is included in the time share of each farmer. It has been observed that water is only stored in this system when the water flow of the falaj becomes unmanageable. This method proved to reduce the time required for irrigation and increase its efficiency. If a farmer cannot finish all the stored water before the irrigation time of the next farmer starts, his remaining water will be allocated to the succeeding farmer.

Figure 6. Flow division in aflaj systems.

Conclusions

Agricultural production in Oman is almost fully dependent on irrigation, and more than one-third of the water used for irrigation is supplied by the aflaj. Aflaj are also very important systems that allow farmers to control and mitigate drought. Despite this, more than one-quarter of the aflaj have fallen into dis-use due to many social and technical problems.

At the same time, there is a trend that technical knowledge about the aflaj, including the traditional time measurement methodologies and aflaj construction and management, remains mostly with the older generation. Thus, the knowledge needed to manage and maintain the aflaj is slowly disappearing.

Another difficulty is that traditional ways of determining the timing for irrigation are complicated and differ from one aflaj to another. Particularly, the older generation resists the adoption of modern methods to measure time intervals.

The government in its efforts to rehabilitate the aflaj should thus not only focus on utilizing new materials and rebuilding structures, but should particulary aim to improve and modernize the management of the water-share system. One important aspect would be to standardize all existing traditional water-share units by converting them to one standard time unit. Another aspect is to ensure that the water rights in all aflaj of Oman are documented and regularly updated. This would require that each falaj keeps its own records about water right holders and their share and timing of water.

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