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The United Nations World Water Assessment Programme

Insights

Seeing Traditional Technologies in a New Light

Using Traditional Approaches for Water Management in Drylands

Edited byHarriet Bigas, Zafar Adeel and Brigitte Schuster

United Nations University International Network on Water, Environment and Health (UNU-INWEH)

UNITED NATIONS UNIVERSITY
UNU-INWEH
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World Water Assessment Programme

The United Nations World Water Development Report 3
Water in a Changing World

Coordinated by the World Water Assessment Programme, the *United Nations World Water Development Report 3: Water in a Changing World* is a joint effort of the 26 United Nations agencies and entities that make up UN-Water, working in partnership with governments, international organizations, non-governmental organizations and other stakeholders.

The United Nations' flagship report on water, the WWDR offers a comprehensive review of the state of the world's freshwater resources and provides decision-makers with the tools to implement sustainable use of our water. The WWDR3 represents a mechanism for monitoring changes in the resource and its management and tracking progress towards achieving international development targets. Published every three years since 2003, it offers best practices as well as in-depth theoretical analyses to help stimulate ideas and actions for better stewardship in the water sector.

Water in a Changing World has benefitted from the involvement of a Technical Advisory Committee composed of members from academia, research institutions, non-governmental organizations, and public and professional organizations. To strengthen the scientific basis and potential for implementation of its recommendations, interdisciplinary expert groups were also created for a number of topics, including 'Indicators, Monitoring and Databases', 'Business, Trade, Finance and Involvement of the Private Sector', 'Policy Relevance', 'Scenarios', 'Climate Change and Water', 'Legal Issues' and 'Storage'. An accompanying case studies volume, Facing the Challenges, examines the state of water resources and national mechanisms for coping with change in 23 countries and numerous small island developing states.

This series of side publications also accompany the WWDR3, providing more focused, in-depth information and scientific background knowledge, and a closer look at some less conventional water sectors. These publications include:

Scientific Side Papers

This series provides scientific information on subjects covered in the WWDR and serves as bridge between the WWDR3's contents and scientific, peer-reviewed publications.

Sector and Topic-Specific 'Insight' Reports

The reports and documents in this series will provide more in-depth information on water-related sectors, issues and topics in a stand-alone manner. Examples of the subjects of this series include Integrated Water Resources Management, transboundary issues and technology, among others.

Dialogue Series

Sectors and topics to which water is cross-cutting or important will be covered in this series of side publications. Some examples of subjects discussed in this collection of reports include climate change, security, biodiversity, poverty alleviation and land use.

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Introduction

Zafar Adeel

Management of scarce water resources is a major challenge for people living in drylands (please see box for a definition of drylands). Over the centuries, dryland dwellers have overcome this challenge through traditional methods of water harvesting and management, which have ensured long-term sustainability of water resources through demand management and adequate resource replenishment. In general, these methodologies – despite being effective and cost-efficient – are either in decline or have been completely abandoned. Building up on previous work undertaken within the United Nations University (UNU) on dryland management, UNU launched an initiative in 2001 to specifically address the research needs and to evaluate the current status of traditional water technologies in drylands around the world. This summary provides the context for the case studies presented in this publication and describes how they have helped develop a better overall understanding of the traditional water management technologies, and in doing so, brought greater international attention to this field of science.

Water challenges in drylands management

drylands are unique in their dependency on relatively scarce available water – this scarcity exists on a gradient ranging from mild in dry sub-humid areas to extreme in hyper-arid areas (or deserts) and adversely impacts the land productivity. The limited availability of water results in quite profound impacts on how the human societies based in drylands relate to their environment and balance the tradeoffs in land and water use. These tradeoffs often create competition, and sometimes conflict, between different riparian users; for example, farmers and pastoralists often compete for water use. Over the millennia, dryland societies thriving in these settings have adopted sustainable and equitable approaches for managing their water as well as other natural resources. Today, water management in drylands is undergoing a serious paradigm shift in the face of new challenges and driving forces.

The most significant of these challenges is desertification (please see box for a definition of desertification), which hampers the achievement of sustainable development and natural resource management in drylands. Desertification is closely linked to management of water resources, agricultural and rangeland management approaches, climate change processes and changes to vegetation cover and biological diversity. The magnitude and impacts of desertification vary from place

Acknowledgements

This report synthesizes the findings already published in the book *What Makes Traditional Technologies Tick? A Review of Traditional Approaches for Water Management in Drylands* (Adeel et al., 2008).

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The information presented in this book has been made possible through the dedicated work of the researchers supported by the Blucker Fund. All of these researchers worked closely with the local communities in their respective research sites. We owe gratitude to the researchers for their extensive work and commitment, and to the communities for lending their support to the research work and for being part of the effort to revive and revitalize the use of these traditional technologies.

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to place and change over time. This variability is driven by the degree of aridity combined with the pressure people put on the ecosystem's resources, as shown in Figure 1. As water availability increases 200 m^3 per person per year in hyper-arid areas to ca. 3,000 m^3 in dry sub-humid areas, density of human population also increases from ca. 10 per km^2 to ca. 70 per km^2, respectively. A similar pattern for livestock density also exists, and is also related to the stress patterns in drylands. As a result, the maximum population stress is found in drylands that are relatively abundant in water, i.e. semi-arid regions.

There are consistent global manifestations of the impacts of desertification in terms of the well-being of people living in dryland developing countries. A global evaluation report on desertification developed by the Millennium Ecosystem Assessment (MA) has helped us better understand the nature and impacts of desertification (Adeel et al., 2005). The MA report has determined that growing desertification in drylands – which occupy over 41% of the world's land area and are home to over two billion people – threatens the homes and livelihoods of millions of poor.

These impacts of desertification on dryland populations are further exacerbated by political marginalization of the poor and the slow growth of health and education infrastructures. For example, the MA report shows that infant mortality in drylands in developing countries averages about 54 children per 1,000 live births, ten times higher than that in industrial (OECD[1]) countries, as shown in Figure 2. The hunger rates in children under the age of 5 in drylands demonstrate a clear linkage to food insecurity as well as to the level of aridity. As mentioned earlier, it can be argued that semi-arid areas are worse off in terms of human well-being as a result of a high degree of sensitivity and pressure, which also generate the highest degree of land degradation. The region-to-region variability is also significant, in which the Gross National Product (GNP) per capita in OECD dryland countries exceeds that of dryland countries in other regions almost by an order of magnitude. This is not surprising, considering that economic performance relates to many other governance and macro- and micro-economic factors. Thus, the economic status of dryland societies is not entirely linked to the low availability of basic ecosystem services such as water and biological productivity.

Evaluation of future development scenarios by the MA shows that if these present trends in land and water use continue unchecked, the global extent of desertified areas will likely increase. It is projected that population growth and increases in food demand will drive an expansion of cultivated land, often at the expense of woodlands and rangelands (Adeel et al., 2005). The MA report also highlights the global and transboundary nature of the desertification challenge. The adverse impacts of desertification on the global environment – such as increasing dust storms, floods and global warming – are well known and documented. There are also alarming impacts of desertification on societies and economies, as shown in Figure 2. These impacts are directly related to human migration and economic refugees.

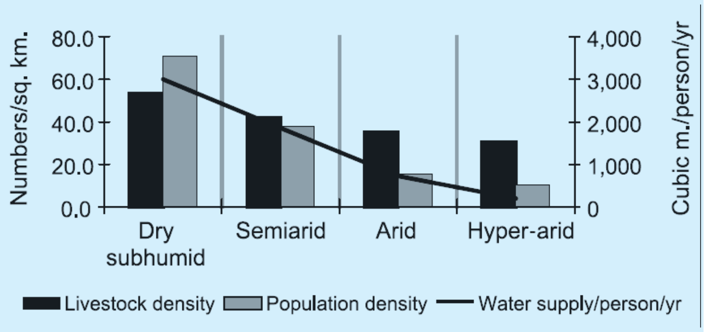
On a more positive note, numerous adaptive and corrective approaches for natural resource management are available to match the degree of aridity and other local constraints. These approaches – with underlying integration of land and water management – can help protect and restore the capacity of the dryland ecosystems to provide key benefits and services. In this respect, communities – and their knowledge of the ecosystems around them – can play a central role in the adoption and success of effective land and water management policies. Needless to say, they need support in the form of institutional and technological capacity, access to markets, and financial capital. On the whole, prevention through community-based efforts is a much more effective way to cope with the dryland challenges because any subsequent attempts to rehabilitate desertified areas are costly and tend to deliver limited results.

Efforts to meet the drylands challenges will typically yield multiple local and global benefits, and help mitigate other major environmental issues like

Drylands

Drylands include all terrestrial regions where the production of crops, forage, wood and other ecosystem services are limited by water. Formally, the definition encompasses all lands where the climate is classified as dry sub-humid, semi-arid, arid or hyper-arid. This classification is based on the values of the Aridity Index, which is defined as the long-term mean of the ratio of an area's mean annual precipitation to its mean annual potential evapo-transpiration (Adeel et al., 2005).

Figure 1 **A comparison of population and livestock density in various dryland subtypes.**



Source: Safriel and Adeel, 2005.

1 The Organisation for Economic Co-operation and Development (OECD) currently consists of a group of 30 member countries that have ratified the Convention of the OECD (further information on the OECD is available at http://www.oecd.org).

Desertification

Desertification is defined as the land degradation in drylands resulting from various factors, including climatic variations and human activities. Land degradation is, in turn, defined as a reduction in or loss of the biological or economic productivity of drylands. The Millennium Ecosystem Assessment (Adeel et al., 2005) has argued that measurement of persistent reduction in the capacity of ecosystems to supply services provides a robust and operational way to quantify land degradation and desertification.

human-induced global climate change and loss of biological diversity. Such efforts are also critical and essential for successfully meeting the Millennium Development Goals – particularly those related to poverty reduction. The possibility of long-term success is much greater when these sustainable land and water management approaches are linked to providing dryland people with viable livelihoods and utilizing their social capital in the form of traditional knowledge.

Significance of traditional approaches in drylands management

human societies in drylands have learned to cope with water scarcity, and often developed these management approaches in close overlap with social and cultural evolution. As a consequence, traditional knowledge (please see box for detailed description of traditional knowledge) has two salient features: it leads to practices that are (a) socially acceptable, and (b) linked to sustainable utilization and management of natural resources. The latter point is particularly crucial for drylands, where sustainability of water resources – in the face of inherent scarcity, wide-ranging fluctuations on a seasonal and annual basis, and potential conflicts and competition among users – is a matter of life and death.

Traditional methods of water harvesting and management overcome this challenge by following sustainable management of water resources.

A good example of such traditional water management approaches is to be found in oases, where traditional practices demonstrate the appropriate usage of the physical and geomorphological factors of these areas (Safriel and Adeel, 2005). In general, oases encompass a water distribution and management system, planting structure that helps regulate a micro-climate, cultivation of plants that are tolerant of aridity and salinity, waste recycling systems, and sand dune stabilization techniques.

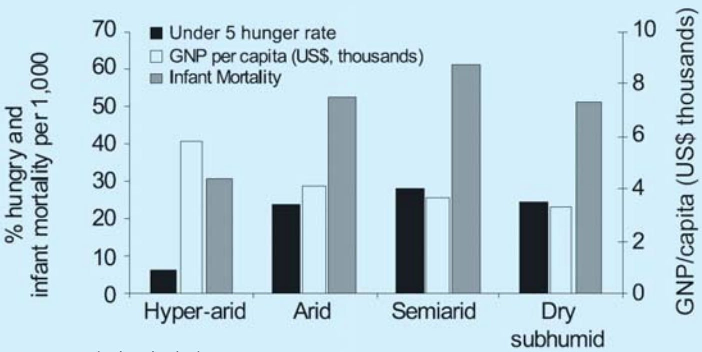
Another striking example of a traditional water management system is the *qanat* (also called *kanat* or *karez* in Asia, *foggara* or *khattara* in Northern Africa, and *falaj* in the Arab world). It is an underground 'engineered' water management system that has been employed as variants of the same technology for centuries in a number of countries in Northern Africa and Western Asia, as well as other Asian countries including Afghanistan, China, Islamic Republic of Iran, and Pakistan. The *qanat* management system, as shown in Figure 3, operates on the basis of utilizing a man-made gradient to draw water from aquifers. Water withdrawal in such traditional systems: (a) is achieved under gravity and without application of an external power source; (b) minimizes evaporation losses because water storage and transport is mostly underground; and (c) can only withdraw water which is available in the aquifer through natural recharge, avoiding any over-exploitation of groundwater resources. This traditional technology is a particularly effective system considering the water scarcity, weather conditions and low-level technology generally available in this region. In communities working together to maintain these systems, long-term benefits can be enjoyed by all without a major capital investment and with nominal operation and maintenance cost.

Another part of traditional water technologies are the locally adapted architectural innovations also used to facilitate water conservation by condensing atmospheric water, including stone heaps, dry walls, little cavities, and depressions in the soil, which allow plants to overcome periods of high drought (Laureano, 2003; Safriel and Adeel, 2005).

As most of the drylands around the globe are situated in developing countries, application and development of traditional knowledge and technologies for water management should ideally be encouraged. However, present trends indicate that use of these traditional water management technologies is falling by the wayside. There are four major reasons for this pattern.

First, changes in the socio-economic situation in these countries have typically meant that there are fewer skilled experts available to undertake development and management of these systems. As urban populations grow and rural-to-urban exodus continues, the manpower available for maintaining these primarily rural applications becomes limited. The social, cultural and economic implications of

Figure 2 **Human well-being statistics for drylands.**



Source: Safriel and Adeel, 2005.

this change in water management approach are poorly understood. Conversely, economic incentives – particularly to young entrepreneurs – to utilize these approaches are few.

Second, 'newer' water supply solutions like electric-powered tube wells or irrigation systems based on water delivery through canal and channels may hold greater appeal for the general public for various reasons. While being less labour-intensive, the real cost of these alternative approaches is not obvious to the end-user. This is mainly because developing-country governments typically provide heavy subsidies for capital investment into these systems and for power supply for their operation. Furthermore, the concept of 'real-cost pricing' is politicized in the context of the water-as-a-human-right debate, thus precluding a more unbiased and rational cost-benefit analysis of traditional versus 'new' technologies. The new approaches do not compare favourably against more traditional ones when all the costs are fully accounted for. Finally, the information dissemination by governments to the general public encourages the perception of these systems as archaic and outdated.

Third, only very limited research work has been carried out to improve these traditional technologies to better cope with the stresses imposed as a result of population growth, desertification, and other external social and economic driving forces. Consequently, there are technical problems in adopting new materials such as concrete pipes for use in *qanats* and less labour-intensive maintenance technologies. There are also unresolved economic cost-benefit analyses in determining the best ways to meet water demands.

Fourth, at the international level – particularly with development and aid partners – investment into research, evaluation, maintenance and deployment of traditional technologies is virtually non-existent. The rhetorical emphasis on traditional knowledge and technologies has not led to a major investment of resources. One notable exception to this is the initiative 'World Traditional Knowledge Bank', which has systematically focused on compiling data and information, and is supported by the European Commission.

Given the potential for sustainable management of water resources through the development and application of traditional water management technologies, one can argue that there should be a strategic and proactive investment in these technologies. Such a proactive approach is endorsed also in the MA report, which shows that coping with desertification and its related economic conditions will likely fare better when proactive management approaches are used.

Contributions by the United Nations University

The United Nations University has aimed to help developing countries resolve pressing global problems through capacity building and policy-relevant research. In this context, the challenges faced as a result of desertification and water scarcity in drylands have featured centrally in its activities. Building up on previous work undertaken within UNU on dryland management, UNU launched an initiative in 2001 to specifically address the research needs and to evaluate the current status of traditional technologies. This initiative was funded through the generous financial support of a philanthropist, Ms. Julie Blucker. It provided limited research grants to young researchers who were working with local communities to better understand their problems and help bring scientific rigour to problem-solving.

The objectives of this initiative were fourfold.

First, the initiative aimed to better understand and demonstrate the importance of traditional water management systems through focused research and field activities. In order to do so, a number of sub-projects explored the comparative evaluation of these systems in different geographic and environmental settings.

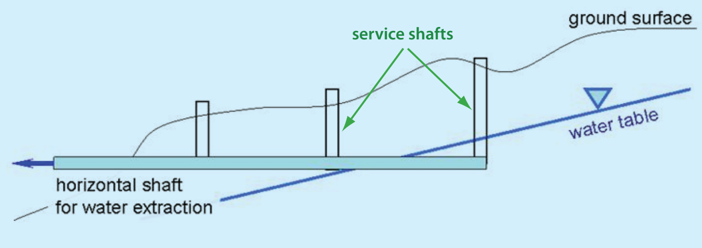
Traditional Knowledge

Traditional Knowledge refers to the knowledge, innovations and practices of indigenous and local communities around the world. Developed from experience gained over the centuries and adapted to the local culture and environment, traditional knowledge is transmitted orally from generation to generation. It tends to be collectively owned and takes the form of stories, songs, folklore, proverbs, cultural values, beliefs, rituals, community laws, local language, and agricultural practices, including the development of plant varieties and animal breeds (United Nations Convention on Biological Diversity).

Traditional knowledge is information, skills, practices and products – often associated with indigenous peoples – which is acquired, practiced, enriched and passed on through generations. It is typically deeply rooted in a specific political, cultural, religious and environmental context, and is a key part of the community's interaction with the natural environment (IISD, 2003).

Traditional knowledge itself has a number of different subsets, some of them designated by expressions such as 'indigenous knowledge', 'folklore', 'traditional medicinal knowledge' and others. Contrary to common perception, traditional knowledge is not necessarily ancient. It is evolving all the time, a process of periodic, even daily creation as individuals and communities take up the challenges presented by their social and physical environment. In many ways, therefore, traditional knowledge is actually contemporary knowledge. Traditional knowledge is embedded in traditional knowledge systems, which each community has developed and maintained in its local context (World Intellectual Property Organization).

Figure 3 **A schematic representation of a *qanat* water delivery system.**



Source: Safriel and Adeel, 2005.

Second, the initiative aimed to understand in a scientific manner the relationship between local communities and the management of traditional water systems. This evaluation was done with the view that traditional knowledge and technologies are not static but evolve in contemporary societies. The research projects focused on means and ways for improving traditional water management systems according to evolving socio-economic patterns.

Third, the initiative indirectly helped build the capacity of local researchers to undertake community-oriented field research, particularly highlighting South-South collaboration.

Fourth, there was an emphasis on raising public awareness on key issues pertaining to utilization of traditional water management technologies. This awareness-raising was extended to the international community through publications and international workshops.

Typically, each researcher demonstrated that their work was a part of an ongoing active research activity and involved *in situ* field work and was developed with due consideration given to community involvement. This sub-project deployment was done selectively, and based on dozens of applications that were received as a result of public advertisement about the project.

The project led to the deployment of sub-projects in key areas that are hubs of traditional water management technologies, such as rural Syria, mountain-terraced Yemen, North Africa, Omani desert and Pakistani hilly drylands. Many of the researchers engaged in the initiative undertook the research work as part of their graduate studies. This engagement, therefore, enabled them to further the research capacity in the respective local settings, and to personally achieve higher academic qualifications. As the initiative was designed to link directly with the local communities, in many cases it provided the additional incentive for the researcher to develop stronger ties with the respective communities. This has clearly been the case in Tunisia, where the researcher (Dr Mohammed Ouessar) is now running a strong non-governmental organization (NGO) to help explore new livelihoods (Ouessar et al., 2003). Similarly, in Oman, the researcher (Prof. Abdullah Al-Ghafri) has accepted a faculty position after the conclusion of his graduate programme (Al-Ghafri et al., 2003).

Desertification in Chott El-Djerid, Tunisia. © UNESCO Felipe Alcoceba

There are also some indications that the sub-projects and their respective lead researchers have helped develop a better overall understanding of the traditional water management technologies, and in doing so, brought greater international attention to this field of science. Subsequently, the researchers emerged as leaders in traditional technologies, and helped set up professional networks and continued research beyond the scope of the project.

Outlook: the future of water management in drylands

the projections of water availability and quality of freshwater worldwide, and particularly in drylands, do not present a positive picture. In many cases, the dryland areas are anticipated to get drier (Ezcurra, 2006); these include areas in Western Asia, sub-Saharan Africa and the Atacama Desert that have already experienced a decrease in precipitation as a result of global climate change, and will continue to do so. Those climatic impacts, when overlaid with increasing population-related stresses and other anthropogenic impacts on water quality, mean a likely drastic decrease in water availability in the next few decades.

The global water challenge has far more severe ramifications for drylands than for any other ecosystem (Adeel et al., 2005). In drylands, the rural dwellers are particularly vulnerable. At the same time, there is greater room for innovation in water resource management and provision in rural settings. A combination of traditional technologies with non-renewable energy sources can bring new alternatives for livelihoods. Implementing such innovations poses challenges in terms of enhancing the capacity to understand and implement; both are often hampered by a lack of research and financial resources, respectively.

It is hoped that the work presented in this publication will contribute to the innovative solutions and enhancements to traditional technologies. As stated earlier, traditional knowledge is not static and stuck in history; rather it is dynamic and continuously evolving. It can certainly benefit from scientific rigour, combined with a South-South exchange of information and ideas. The circle can be completed by linking it to the local communities and integrating it with alternatives for sustainable livelihoods.

Case Study I: assessment of three collective renovations of traditional *qanat* systems in the Syrian Arab Republic

Joshka Wessels

In the summer of 2000, a small group of Syrian villagers, with international help, renovated and cleaned an ancient Byzantine water tunnel system called a *qanat*. This work raised some interesting questions: In this time of ecological farming and increasing environmental awareness, is it possible to reuse an ancient water supply system? And what policy criteria could be used to assess feasibility? This case study explores the feasibility of reusing this ancient water supply system to support sustainable development in the Syrian Arab Republic (Syria).

Overview of the study area

syria is located at the eastern part of the Mediterranean Sea, between Lebanon and Turkey. The country's climate is characterized by dry, hot summers, mild winters and rainy spells in autumn and winter. Water is the main limiting factor for agriculture in Syria.

The case study focused on four different study sites, including: one located in the Syrian desert; one at the foot on the eastern side of the Anti-Lebanon Mountains, near the border between Syria and Lebanon; one on the borderline between the suburbs of Damascus and the Syrian steppe; and one in the centre of Syria, in the middle of the Syrian steppe.

Traditional irrigation system: *qanats*

through ingenious water extraction techniques, ancient peoples such as the Persians and Romans coped with a dry climate. One of these techniques is the *qanat* system, a subterranean tunnel that taps the groundwater and leads it artificially to human settlements and agricultural lands using gravity flow conditions (Lightfoot, 1996; Beaumont et al., 1989). By nature, a *qanat* is a truly sustainable technique of extracting groundwater, as it relies on gravity alone and cannot exhaust or over-exploit an aquifer.

In the early 1990s, scientists came to the conclusion that *qanat* systems are increasingly drying up and being abandoned throughout the Middle East and North African region (Lightfoot, 1996). Recent societal transformations, such as modern development, population growth and changing socio-economics, have resulted in a loss of interest in traditional water techniques, and a shift in interest to new, modern techniques of water supply such as diesel-operated or electric-powered motor pumps. Furthermore, users are being forced to change their lifestyle from farming to one based on agricultural self-sufficiency or other non-agricultural income sources. As *qanats* are increasingly being abandoned, the indigenous knowledge and collective action critical for their upkeep also disappear.

Status quo of *qanats* in Syria

in 2000–2001, a team from the International Center for Agricultural Research in the Dry Areas (ICARDA) conducted a reconnaissance survey in Syria. Geographical, socio-economic, and hydrological characteristics were documented and local experts and officials from various institutions were interviewed. Altogether, the case study documented 42 *qanat* sites in Syria, including 91 *qanats*, of which 30 were still in active use. In Syria, the *qanats* are used to provide the main water supply for drinking water and agriculture. In general, they can be classified into two types: infiltration and spring *qanats*.

The water supplied by Syrian *qanats* is used mainly for irrigated agriculture. The division of the water is based on local systems of rights and regulations. Each user household has an irrigation share which is accorded based on the magnitude of land and water rights it owns. The regulation system is based on a fixed rotation in days in which all households with user rights have their turn, called *addan*. The differences in *addan* for each *qanat* depend mainly on the number of first users, the discharge of the *qanat* water, type of soil, type of main crops, and the total land surface.

Renovating *qanats*: challenges and opportunities

renovating *qanats* is not only technically difficult, but it also means challenging the modern lifestyles and mindsets of (young) people by introducing them to a type of 'green living'. There is a general consensus that, due to the increased population, socio-economic changes and modernization, the profit from *qanats* is no longer sufficient for user households to maintain their lifestyle. Therefore, *qanat* renovation has to provide the basis for a worthwhile profit, such as income generated through the irrigation of cash crops or through ecotourism and cultural heritage sites.

Another important aspect for successful *qanat* renovation is strong local leadership (Wessels, 2003*a*, *b*). As observed during the renovation in one pilot site, the old social hierarchical system had collapsed. This was further exacerbated by population growth, internal competition, erosion of leadership and outmigration. The introduction of participatory approaches during the pilot renovation paradoxically caused users' increased suspicion and contempt towards each other. The lack of local leadership to manage the conflicts between these users was identified as one of the key problems.

It could be demonstrated that renovation efforts were successful when strong and respected

Ketarras near Erfoud, Morocco. Photo: Bernard Gagnon

leadership as well as a long tradition of rules, regulations and agreements between users existed. It became clear that when users of the *qanat* system organize themselves to devise and enforce their own rules, they tend to manage local resources more sustainably than when rules are externally imposed upon them (Ostrom, 2000; Baland and Platteau, 1999; Wade, 1988).

Conclusions

Desertification and drought are the main, interlinked climatic challenges in the Middle East, and dwindling water resources will continue to put pressure on society and water users. These developments call for sustainable techniques of using water, which should be based upon a combination of modern technology and traditional techniques. In an ideal future, a new sustainable way of living will halt the pressure that human population puts on natural resources. The reuse of *qanats* for sustainable water management could contribute to such a lifestyle. Middle Eastern countries that have *qanats* should carefully consider whether government subsidies should be directed towards renovation of these systems.

The following are the main points to consider for renovation:

- willingness of the community to invest in future cleaning and renovation;
- existing technical knowledge of local people;
- social cohesion of the users' community;
- presence of a conflict management system;
- avoidance of excessive pumping around the *qanat* source; and
- a guarantee of safety for *qanat* cleaners.

Renovations can be successful when conducted in a carefully introduced participatory approach including the users of the *qanat* system, and where the ultimate responsibility and monitoring of the renovation remains with the farmers' cooperative.

Case Study II: Traditional Water Harvesting on the Mountain Terraces of Yemen

Najib M.A. Al-Ghulaibi

This case study was part of an initiative to maximize water delivery to farmed terraces in the northern mountains of Yemen, and to improve storage conditions for provision of water for human use during the dry seasons of the year. The proposed interventions were envisaged as a way of improving the economic value of the farmed terraces and sustaining cultivation. The overall goal was to halt terrace degradation and stop their abandonment as part of a move to limit migration from rural areas to the cities. The objectives of the study included development of ways to optimize use of seasonal precipitation and to increase the spring base-flow for irrigating the farmed terraces during the dry seasons.

Overview of the study area

the al-Qimmah watershed is located in the northern highlands of Yemen and is characterized by steep, terraced mountain slopes, a rocky escarpment and green valleys. Precipitation mainly occurs in two monsoon-influenced rainy seasons.

During the spring rainy season, when the rain falls with great intensity though at infrequent intervals, there is high surface run-off of the water into the beds of the wadi flood courses. This run-off may be collected in storage facilities. During the dry season, the persistent sunshine causes high evaporation of water stored in uncovered reservoirs.

Mountain terraces and traditional rainwater harvesting in Yemen

The early settlers of the Yemeni mountainsides were forced to use every possible patch of soil for cultivation due to diminished spring and summer rains when the climate became dryer. Terracing the steep mountain slopes provided a solution for slowing soil erosion due to retention of the run-off water on the terraces.

Where the rains were not sufficient to grow a crop to maturity, the farmers began simple, but very effective methods of harvesting rainwater from adjacent rocky slopes serving as catchment areas. These types of simple devices are still in use today, and terraces function as both soil and water conservation structures on sloping land.

Until 50 years ago, people in the mountainous areas of Yemen were highly dependent upon rain-fed agriculture on the picturesque terraces that give Yemen its distinctive landscape character. Traditionally, water harvesting was an appropriate and well-adapted solution for sustainable and secure food production. But newer approaches are now needed to satisfy the growing demand for water.

a) Governance system of water rights

The traditional governance system of water rights in the study area varies from district to district. In general, there is an agreement between the farmers in each district, which is monitored by an elected local farmer who has expert knowledge of the land and is familiar with the landowners.

Run-off water harvesting rights can be divided into two main components:

1. In the case of a farmer owning the run-off catchment area for his terraces, he may choose either to utilize the run-off on his land or to divert it to the terraces below. The farmer below does not have any prior legal right to the run-off water, and the farmer farther up may prevent him from receiving it.
2. In the case where more than one farmer shares ownership of the catchment, this area is divided between the individual farmers based on the size of the land owned. Each farmer's section of land has its own apportioned catchment, and no one is entitled to divert run-off water from one section to the other without permission.

When sufficient run-off occurs, farmers irrigate their terraces and direct the extra water from the upper terraces to the lower ones, until the water eventually reaches the wadi bed. The main channels are repaired and maintained through cooperation between all of the farmers. There is no standard legal provision that allows for run-off to be diverted across land owned by another farmer, unless there is a signed agreement in place.

b) Reservoirs for run-off water storage

Storage reservoirs or cisterns to collect run-off water are common in villages high up in the mountains. However, due to their limited storage capacity and high water demand in the area, the reservoirs can cover the water needs for only five months of the year. The shortfall of water for domestic use and drinking purposes is just below 25,000 m^3 per year, in addition to the need for water for supplementary irrigation. An additional 50 reservoirs are required to cover the shortfall of water for domestic use alone, at a total cost of US$550,000.

Challenges facing the Yemeni mountain terraces

For the agricultural cycle, the climatic conditions pose two challenges: the length of the dry season and the great annual variability in the precipitation pattern, which results in major changes of the agricultural production from one year to the next. Natural dry spells regularly lead to significant decreases in yield. During the dry season, provision of supplementary irrigation is required to sustain plant growth. This can be done through water stored in reservoirs during the previous rainy season, traditionally harvested water or water re-directed to the fields from springs.

Additionally, there is the problem of domestic water shortfalls, which forces women and children to carry water from distant wadis or springs, as well as the associated financial implications for communities where villages are abandoned by farmers seeking work opportunities and better living conditions in the cities.

The problems described above are intensified by the following conditions, affecting Yemen in general, and having particularly damaging effects on the traditional system of terraced agriculture and rainwater harvesting:

- The patterns of rainfall have changed; this has had deleterious consequences for rain-fed crop production.
- The population has increased rapidly, and the need of food and water increased accordingly. Population growth at 3% per year means that the population doubles over a 25-year period.
- Groundwater levels have dropped because of over-consumption of water. This has enormous implications for the sustainability of agriculture.
- Abandonment of terraces due to urban migration, and the collapse of terraces due to road construction, are causing uncontrolled run-off that is damaging the downstream terraces (Vogel, 1987, p. 21).

Conclusions

A drier climate combined with population growth and a changing global economy has produced enormous pressures on the sustainability of terrace agriculture in the Yemeni highlands. Human ingenuity devised ways to sustain settlement in these marginally arid regions through construction of terraces and diverse water harvesting structures, which, over time, have proven to be effective.

However, neglect of these water harvesting systems threatens to destroy the entire ecosystem. Water scarcity, low income from terraces, and labour-intensive agricultural activities have all contributed to an increasing tendency to abandon the traditional way of life. The only way to halt the trend is to increase the income for the farmers and lessen the burden of work. The solution is to maximize the use of immediate run-off and to collect and store more of it before it is lost to the wadi flood courses. This case study serves as an example of how traditional mountain terrace agriculture can be preserved throughout Yemen through traditional water harvesting techniques.

Case Study III: Khattara and water user organizations in Morocco

Keiko Oshima

In arid and semi-arid regions in Morocco, people live within oases relying mainly on traditional water systems called *khattara* (the corresponding term to *qanats* in Syria). The *khattara* system has been a common form of underground water utilization since its development several hundred years ago. This case study focuses on the role of user associations for khattara management in the south-eastern Tafilalet region of Morocco.

Overview of the study area

the Jorf area is located in the arid and semi-arid regions at the southern and eastern margins of the Atlas Mountain range of Morocco. Here, the khattara is the main water harvesting system used. There are about 570 khattaras in the Jorf area. However, only around 250 are currently operational (ORMVA/TF, 1997). Khattara water users began establishing associations to acquire financial support for khattara rehabilitation work.

Status of Khattara organizations

In general, the khattara system falls under the supervision of the traditional khattara organization, composed of water users. A typical traditional khattara organization has a leader representing a few hundred water users, which carry out khattara maintenance and rehabilitation works by fairly distributing their workloads and financial burdens proportionate to the water rights of each individual.

Since the traditional organizations are not registered as legal entities, their operation does not fall under the local laws; external organizations, such as international development agencies, are therefore reluctant to extend their support to these traditional organizations.

However, the establishment of associations including khattara development in their activities has gradually been spreading (Benyahya and Bouachik, 2003). The Regional Agency for Irrigation and Agricultural Development has supported a process for transforming traditional organizations into formal and legally registered ones. As a result, nine associations were established in the Jorf area during 2000 and 2001. Seven of these associations focus on khattara management, while two support a broader strategy for rural development.

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

Challenges of Khattara management for associations

associations in the Jorf area have faced significant challenges in khattara management, which have affected and determined the level of activity of these organizations. Some of the factors which determine the level of activity of an organization are:

- availability of sufficient water volume in khattaras;
- behaviour of the inhabitants and water users;
- the size of activity area within one village;
- the existence of strong leadership; and
- the ability of the organization to secure and establish funding.

The widespread use of motor pumps has led to a significant decline in groundwater table levels, which has resulted in many khattaras in the region drying up. However, there is a local belief that the water availability in these khattaras may be restored in the future and that the associations might be useful.

Those responsible for establishing khattara associations have faced general indifference from the users who formerly relied on khattaras. This is a result of the depletion of the respective khattaras. If the water availability in these khattaras improves in the future, it is expected that the attitudes of the users will also change.

The size of activity area led to some misunderstandings about the concept and role of these associations, and people of each village or each khattara openly expressed their strong intention to establish their own organization. Consensus building and cooperation work was identified as a challenge that needed to be addressed. Furthermore, strong leadership will help prevent associations from becoming dormant and dysfunctional.

It was observed that when associations receive economic assistance from external organizations, the perception of these associations by the local users changes so that they tend to favour these types of associations. The associations in these districts are endeavouring to change this pattern.

Additionally, associations are faced with the significant challenge of securing and establishing funding. In many cases, activities of the associations are limited to seeking economic assistance from external organizations, and this has been documented as a primary motivator for establishing one's own association. The limited funding opportunities for khattara rehabilitation increases the amount of competition between the associations for financial aid, which intensifies once some associations are successful in receiving economic assistance.

Conclusions

In general, many of the problems facing the use and management of khattaras can be broadly classified as either caused by natural factors or by social practices and norms. A large part of these problems is driven by the change in the lifestyle and way of thinking. While technical assistance is important for khattara rehabilitation, effective and strong associations of water users are also required for the sustainable development of khattaras. Assistance from external organizations can support this process.

Case Study IV: perception of traditional and contemporary water harvesting techniques in the arid regions of Tunisia

Mohamed Ouessar, Mongi Sghaier and Mondher Fetoui

In Tunisia, the enrichment of existing traditional water harvesting techniques has raised questions regarding the nature of the linkages between traditional and modern techniques: Are they complementary or conflicting? What impacts (positive and negative) have they induced? What future prospects could be considered? This case study examines the perceptions of the local communities with regards to traditional and contemporary water harvesting technologies.

Overview of the study area

the watershed of Wadi Oum Zessar is situated in the south-eastern region of Tunisia, in the province of Médenine. It is an area of 370 km^2, with an annual rainfall of 180 mm and a mean annual temperature of 20 °C. It has a population of 25,000 inhabitants.

The temperatures in the study range from as low as -3 °C during the winter months to 48 °C during the hottest period of the year. 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 agricultural systems in the watershed of Wadi Oum Zessar are marked by their diversity, from upstream to downstream, 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).

Areas where traditional water harvesting techniques are applied are limited (El Amami, 1984). Since the independence of Tunisia, there has been a gradual expansion of cultivated fields, mainly of olive trees. This development was supported by the construction of *tabias* and water spreading structures in the foothills and surrounding plains which were previously used as rangelands. At the same time, the Soil and Water Conservation Service of the Ministry of Agriculture introduced modern technologies (gabion units, groundwater recharge wells, etc).

Water harvesting: techniques, achievements and local perceptions

a) Technologies

A wide variety of traditional and contemporary water harvesting technologies are used in Wadi Oum Zessar, including:

- Terraces: This is the oldest adopted water harvesting technique in the watershed. 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).
- *Jessour*: These consist of a series of stone and earth walls, called *tabias*, erected across the stream beds of narrow valley watersheds. They collect and retain run-off water and silt washed down hillsides by rainfall, forming terraces in a stair-step fashion down the natural slope.
- *Tabias*: These are usually constructed on foothills, in particular in areas with rather deep soils and gentle slopes. 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.
- Cisterns: These are built to collect and store rainfall. The water is used for different purposes including domestic consumption, irrigation and for livestock.
- Gabion check dams: These structures 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.
- 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 create recharge wells to enhance the infiltration of run-off water to the ground aquifer.

b) Achievements

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. Moreover, a large number of recharge and spreading units were installed. In total, investments of US$8 million were made for the province and US$1.6 million in Wadi Oum Zessar (Commissariat Régional au Développement Agricole, 1998).

During the 1990s, the regional services of the Soil and Water Conservation Service executed two main national programmes, namely the Soil and Water Conservation Strategy and the Water Resources Development Strategy. The work undertaken mainly comprised the construction of *jessour*, *tabias* and terracing. By the end of 2000, recharge and spreading units were built and recharge wells installed.

The Flaming Mountains near Turfan, China. Photo: Wikimedia common.

c) Local perceptions

The perception of the local population towards the water harvesting techniques largely depends on the tradition of the group and its location in the watershed.

Farmers largely benefit from the positive impacts of water harvesting technologies such as through enhanced groundwater recharge, improved siltation control and crop diversification. However, they remain sceptical on their role with regards to yield improvement and run-off control. In the upstream area, where farmers traditionally used *jessour*, the preference is given to this technique, while in the piedmont zones and downstream area, *tabias* were the first choice. Gabions were more appreciated downstream.

On the other hand, livestock herders are negatively affected by the water harvesting system because the run-off water is almost entirely retained in the watershed. This has resulted in a reduced quality and quantity of the halophyte vegetation of the *sebkhat* used as the main winter grazing area for camels.

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 for agricultural, domestic and environmental purposes.

The local population is, in most cases, aware of the impacts of the introduction of new water harvesting techniques on productivity. Their perception depends largely on the agricultural activities in which they are involved and the location of their fields/pastures in the watershed. However, the wide range of possible (positive and negative) impacts that can occur as a result of the installation of the water harvesting structures needs to be further explored (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.

Case Study V: Karez in the Turpan region of China

Qingwei Sun, Wang Tao, Iwao Kobori and Luohui Liang

The Turpan oasis, located in the desert expanse of north-western China's Xinjiang province, has a rich history dating back to over 2,000 years ago, when it was a strategic stop along the Silk Road. The area is well known for its extensive water harvesting and channelling system, called the *karez*, which originates from the Han Dynasty (200 BC). This case study looks at the role that the karez water systems continue to play in the Turpan region of China.

Overview of the study area

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 average summer temperatures reaching 38 °C. The Turpan Basin has a low annual precipitation (9–25 mm), well below the potential evaporation (about 3,000 mm). There are plenty of groundwater resources in the arid Turpan Basin, which are naturally recharged by melt water from the glaciers and snowfields of the nearby Tian Shan mountain range.

The oasis at Turpan owes its surprisingly lush green environment to the traditional underground system of water supply called karez. This irrigation system, which is sometimes referred to as the 'Underground Great Wall', has provided the basis for agricultural activities in this 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.

The emergence of Karez in Turpan

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. 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. Water is transported through gravity alone as the natural slope from the foothills at 900 m elevation towards the deepest part of the Turpan Basin at -161m is favourable for such a sophisticated irrigation system.

a) The typical structure of karez in Turpan

Karez systems are very delicate irrigation systems made up of vertical shafts, underground and above-ground canals and small reservoirs. Melting snow from the nearby mountains is their main water source. Water is collected from aquifers in pre-mountainous alluvial fans by vertical wells and conducted by underground channels to outlets in the lower-elevation oasis, where the water is used for domestic consumption or distributed to the farmlands in irrigation channels. A karez transports water mainly underground in order to reduce water loss from evaporation and to avoid pollution.

The length of the horizontal underground channels varies greatly, from 3 km up to 50 km, and they are typically 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. 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.

b) 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 for 2,000 years. 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.

A lot of time and effort is required to maintain the karez system. Traditionally, the underground channels were covered by trees, straw and soil to prevent flooding, contamination from sand, and freezing. Nowadays, a cement cover is often used, offering a more reliable, though more expensive, option.

The value and status quo of Karez systems

in the Turpan Depression, the karez irrigation system has maintained a large oasis with tens of thousands of hectares of farmland, maintaining the livelihoods of thousands of people. Without the karez system, the landscape would be a desert.

The karez system 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.

The peak period of karez use in the Turpan Basin was from the mid-nineteenth to the mid-twentieth century, when 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, the number of karezes has been declining since the mid-1960s. Today, the majority of karezes have fallen into disuse and have dried up. Only about 400 are still operational today, with the supplied water volume decreased to 170 million m^3 for the irrigation of about 8,800 ha farmland and domestic water use for 60,000 residents.

This is a result of the massive upstream construction of reservoirs in order to meet the exploding water demand for the expansion of the agricultural and oil mining industries and to meet the rapid population growth. These reservoirs have cut off the karezes from their water source. At the same time, the increasingly wide-spread use of electronically-powered pumps has resulted in a decline of groundwater levels below the level of karez channels.

Conclusions

The 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 the karez is not well understood. Thus, the government and local communities should join efforts to preserve and restore this ancient irrigation system.

Case Study VI: Zarh-Karez: a traditional water management system striving against modern challenges

faisal Farooq Khan

This case study examines the root causes that have resulted in the desiccation of 40 out of 50 karezes in the Loralai District of the Balochistan Province in Pakistan. It focuses on the Zarh-Karez, to explore the political, economic and social challenges that karezes are facing. In addition, it explores the major factors that have enabled karezes to maintain their resilience throughout a severe seven-year drought that occurred in the region.

Overview of the study area

Droughts are the major natural phenomenon in the Loralai region, affecting lives and agriculture. The duration and severity of droughts appears to be increasing, although the intervals between them have not changed. The latest drought was the most severe and the longest, lasting for seven years from 1996 to 2003.

During the early 1970s, the Government of Pakistan introduced electrically powered tube wells in order to address the major challenges in the province that resulted from extreme population growth, including water shortages, the rising demand for food, and unemployment. Cultivation of drought-resistant indigenous species, like almonds, pistachios, pomegranates, dates and olives, was neglected in favour of cultivation of water-intensive exotic species of fruits and vegetables which catered to the domestic market, gradually replacing traditional livestock production.

While these measures increased food security and served domestic markets, the development resulted in a dramatic decline of groundwater table levels. Some water tables dropped from 25 m to below 300 m. Unfortunately, no drought mitigation initiatives were put in place.

The Karez system and its management practices

in Balochistan, cultivated land is typically irrigated by a combination of traditional karezes and modern tube and open wells. Both systems also ensure drinking water supply to all households. Some villages still rely entirely on traditional karezes for irrigation simply because karez water is more cost effective. This can be observed particularly in villages without large land holdings and where traditional farming practices still prevail over more contemporary cultivation systems.

In the area, 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 with the farmland. The length of a karez may vary from 300 m to 15 km. Villagers are responsible for the maintenance and operations of the karez; the farm owners seasonally clean and desilt the karez channels.

Each clan of a tribe has its own karez. The user rights are determined by tribal affiliation and not by duration of residence in a village. The operation, management and maintenance of a karez are the responsibility of the water users. Normally, the head of a village, the *malik*, is the person in charge of karez water distribution and management. Allocation of water quotas is generally based on centuries-old, verbal agreements among the first settlers. New quotas are only negotiated when new occupants settle down in an abandoned village.

Land is allocated among all men who have contributed to constructing a karez, and is divided evenly among each contributor. The land and water use rights associated with it are passed down from generation to generation for as long as the clan remains in the village. Inheritance and number of offspring has resulted in a varying size of land owned and shares of karez water.

Simple measurement techniques are used to allocate water distribution quotas. Measurement of water distribution is based on time. This reflects the local perception that quantification of water by volume would lead to conflicts during the regularly occurring droughts. Allocation of water by time ensures some water to everyone. The *malik* ensures that all landowners receive their allocated quota of irrigation water.

Ensuring the survival of Karezes

There are a number of elements which can help to ensure the survival of karezes. First, 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. Since a karez is a communal holding with many users, the responsibility for its operations, management and ongoing maintenance falls to these users, and each user must contribute accordingly.

Second, strong social bonds and mutual trust are required to operate such a system of interdependency. This was witnessed in the successfully operated karezes of this case study. On the contrary, it appears that karezes that are under the jurisdiction of, and managed by, different clans often are not well maintained and dry out due to social conflicts.

Third, government interventions also contributed to the rehabilitation of karezes, because delay action dams were built to support recharging karezes.

Challenges faced by the Karez system

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 seven 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 implement any drought mitigation measures. In addition, rural electrification and broad installation of electric tube wells subsidized by the government resulted in a significant depletion of groundwater levels.

Second, agricultural development has also played a role. The agricultural sector expanded in all parts of the country due to agricultural modernization. Agricultural subsidies fostered particularly the water-intensive cultivation of cash crops that are not adapted to the arid climate in the Balochistan province. Limited groundwater resources were over-exploited to satisfy the water needs of the new crops.

Third, shifts in population have also had an effect on the use of karezes. Mass labour migration both in and out of Pakistan generally improved income levels, resulting in a rapid population growth and improvement in the standards of living. This, however, contributed to a change in consumption patterns, including increased demand for food and agricultural products. This increase provided an incentive for many farmers to increase the size of their farmlands to meet the current demands. However, their corresponding karez shares did not simultaneously increase; tube wells and other irrigation facilities were installed, increasingly replacing the traditional karez irrigation system.

Lastly, the influx of more than one million Afghan refugees had an impact on the karez water management system and added pressure on the natural resource base. Local Pakistani communities were internally displaced, preventing them from continuing to maintain the karez system.

An oasis in Oman. Photo: Hendrik Dacquin

Conclusions

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

Case Study VII: traditional water distribution in *Aflaj* irrigation systems in Oman

abdullah S. Al-Ghafri

This case study looks at the traditional irrigation system called *aflaj* in the Sultanate of Oman. *Aflaj* are a widely used system in Oman, contributing significantly to the water supply for the extensive agricultural industry of Oman. This case study will examine how the *aflaj* system works, and how it is being used across Oman to manage the country's limited water resources sustainably.

Overview of the study area

the Sultanate of Oman is located in the south-eastern area of the Arabian Peninsula. Oman has a hot climate and is humid in the coastal areas, but very dry in the interior. Average annual rainfall is 100 mm, except for in the southern region, which experiences 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 a large proportion of cultivated land, the Sultanate is one of the major agricultural producers in the Arabian Peninsula, particularly in livestock production. Agriculture depends entirely on irrigation, and more than one-third of the water used for irrigation is supplied by *aflaj*, the traditional irrigation system.

Aflaj irrigation systems of Oman

A *Falaj* (singular of *aflaj*) is a canal system constructed above or below ground 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.

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 government property (Wahby and Al-Harthi, 1995) or are communally owned, serving, for example, mosques, or used as contingency reserves (Al-Abri, 1980). Many villages and towns in Oman have more than one falaj system.

Aflaj in Oman are classified into three types according to their water source:

- *Ghaily*: These represent 50% of the total *aflaj* in Oman. Their main source of water is the baseflow of wadis.
- *Daudi*: These represent 25% of the *aflaj* in Oman. Their source of water is a mother-well conducted from deep water tables by an underground tunnel or channel system. These have the most stable flow rate year-round.
- *Ainy*: These represent the remaining 25% of the *aflaj* in Oman. Their source of water is a natural spring called *ayn*.

The *aflaj* systems are designed in such a way that domestic water demands are first met, followed by water demand for irrigation purposes to agricultural land, first to permanent cropland and then to seasonally cultivated land (Al-Ghafri et al., 1999, 2000*a*, *b*). 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 travellers (Costa & Wilkinson, 1987).

a) 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. The methods to measure the time units differ significantly from one community to the next. Traditional sundial or star methods are still applied in many areas, while the use of modern watches is becoming more common in recent years.

The most commonly used method of water distribution is the *athar*, used in all of northern and central Oman. It is one of the most complicated systems to allocate water among users. A farmers' committee is established to decide on 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 the findings, the length of the irrigation cycle (*dawran*) is determined. After the *dawran* is set, the water share for each farmer is determined 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.

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.

Maintaining equity in the Falaj water distribution system

maintaining equitable shares of water throughout the year is the single most important principle underlying the traditional *aflaj* system in Oman. Different methods are used to adjust to the variation of the length of day and night throughout the year or to variations of water availability caused by drought.

Ancient farmers came up with various solutions to address these inequities (Wilkinson, 1977). For example, the length of the *dawran* is altered seasonally in some *aflaj* to meet the changing requirements of summer and winter irrigation. In addition, the rotation within the *dawran* or between *dawrans* may alter to ensure an equitable share of water for each user. In some cases, very sophisticated rotational systems have been adopted. To adapt to the reduced water availability during a drought, a wide range of strategies exist and are applied, such as adjusting the *dawran* and/or reducing the number of sub-streams of each falaj. Furthermore, it is common practice in small *aflaj* systems that farmers store part of the 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. This method proved to reduce the time required for irrigation and to increase efficiency.

Conclusions

Aflaj still play a very important role for the agricultural production of Oman, and they play a large role in the control and mitigation efforts against drought.

However, despite this, more than one-quarter of the *aflaj* have fallen into disuse due to many social and technical problems. At the same time, technical knowledge needed to manage and maintain the *aflaj* remains mostly with the older generation and is, therefore, slowly disappearing.

In addition to focusing on introducing new materials and rebuilding structures for the maintenance and rehabilitation of *aflaj*, as it is currently doing, the Government of Oman should particularly aim to improve and modernize the management of the water-share system. It can do so by standardizing all existing traditional water-share units by requiring them to be converted to one standard time unit, and by ensuring that the water rights in all *aflaj* of Oman are documented and updated regularly. This will require that each falaj organization keeps its own records about holders of water rights and their share and timing of water.

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During the consultation process for the third edition of the World Water Development Report, a general consensus emerged as to the need to make the forthcoming report more concise, while highlighting major future challenges associated with water availability in terms of quantity and quality.

This series of side publications has been developed to ensure that all issues and debates that might not benefit from sufficient coverage within the report would find space for publication.

The 17 side publications released on the occasion of the World Water Forum in Istanbul in March, 2009, in conjunction with *World Water Development Report 3: Water in a Changing World*, represent the first of what will become an ongoing series of scientific papers, insight reports and dialogue papers that will continue to provide more in-depth or focused information on water–related topics and issues.

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