What Makes Traditional Technologies Tick?
A Review of Traditional Approaches for Water Management in Drylands

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Edited by

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Preface

This unique book contains work by a group of dedicated young scholars who have been supported by a generous donation from the Blucker Fund. I would like to take this opportunity to express our sincere thanks to Mrs. Julie Blucker and Mr. Makoto Hiratsuka, whose support and encouragement has enabled these young scholars to study traditional hydro-technology in drylands.

As a geographer by academic training, I am always interested in learning from local people living in drylands. Over the past 50 years I have visited many different dryland areas while continuing my own comparative studies of foggara oases. I have had many chances to observe advanced, alternative and traditional (indigenous) technologies used in drylands. In that sense, the people of drylands are my teachers, instructing me how inhabitants can adapt to harsh environments and to manage issues associated with water scarcity.

Reviewing this half a century of my professional life spent in conducting research in drylands, I realize that my commitments as a faculty member have always made it difficult for me to spend sufficient time in the field. It is, therefore, opportune that these Blucker Fund fellowships have given a number of young scholars the possibility to conduct his or her research in developing countries, working closely with local communities. These scholars have become well acquainted with local manners, customs and languages in the field.

Water is a key challenge in drylands. From the prehistoric age up to the present, people have invented various technologies to catch and use water, either as rainwater, surface water, ground water or even as moisture from condensation. In ancient times, impressive hydraulic structures such as the Marib dam in Yemen and the Sennacherib Aqueduct in Mesopotamia were constructed to provide water for people in water-scarce areas. In the Syrian desert, the Harbaqa dam provided flood water irrigation during Roman times. These large dam systems eventually fell out of use many years ago, leaving only historical accounts and archaeological ruins.

On the other hand, we also have good examples of the continuous adaptation of traditional technology in drylands. An example is the Qanat system, variations of which are known as Foggara, Karez, Khattara or Aflaj. The Qanat system was probably invented around 3,000 years ago in Northern Persia or the Caucasas, and was used in Iran, Afghanistan, Arab countries, North Africa and China. In those countries, there is some renewed interest in this old system of underground channels, due to its energy efficiency (relying on the use of gravity) and prevention of over-extraction of groundwater (based on a system that cannot mechanically pump water from a sunken groundwater table).

Despite their sustainability and adaptation to dryland conditions, the need for continuous hard labor to maintain such traditional systems does not attract young researchers. Many traditional water management systems have fallen into disrepair. In order to address this dilemma, the introduction of new technology has been studied, and revived systems are now operating well in some countries.

Information about these innovations is not well disseminated amongst researchers, decision makers and local leaders. However, during the past several years, signs of improvement are visible in a number of countries. In 2000, the Iranian government organized an International Conference on Qanat in collaboration with the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations University (UNU) and other selected international and national institutions. Based on the Yazd Declaration of this conference, an International Qanat Research Center was established in Iran in 2004. Already, the center has published an excellent summary of 18 elderly Muqqanis' (traditional qanat technicians) oral descriptions of their experiences. In Xinjiang, China, the Xinjiang Karez Research Society published a complete inventory of Karez in Xinjiang. This is a good example for other countries because they include not only scientific and technical data, but also historical information. In Algeria, the Office National des Resources Hydrauliques published a complete, GIS-based inventory of all foggara of the Wilaya d'Adrar.

The above mentioned approach to reinstate and update traditional hydro-technology began at the beginning of the 21st century. The future generations should follow the direction of this revived international attention to traditional technology. It is interesting to note that the United Nations Convention to Combat Desertification (UNCCD) is also interested in the role of traditional technology in combating desertification. In parallel to these trends, a Traditional Knowledge World Bank was established through support from UNESCO and the Toscana Government of Italy to provide existing data on the Internet.

We are now living on our planet together and facing global environmental problems such as climatic change, desertification and serious energy shortages. Our ability to ensure quality of life for us and for future generations depends how we use precious water resources. I believe that traditional hydro-technology is an excellent topic to be seriously pursued by future young researchers and decision makers. To ensure our future, we need a harmonious network to think and work together on this topic across the national boundaries.

Prof. Iwao Kobori
Senior Advisor
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March 2008

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The information presented in this book has been made possible through dedicated work of the researchers supported by the Blucker Fund. Each of these researchers worked closely with communities in their respective research sites. We owe gratitude to these 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.

Promoting Traditional Water Management in Drylands: Adapting Traditional Knowledge to Meet Today's Challenges

Zafar Adeel

Introduction

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 chapter provides the context for the studies presented in this book and describes how it has 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.

> ***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 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 evapotranspiration (Adeel et al., 2005).*

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. Limited by the availability of water, there are 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 also 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 under 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 the 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 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 ca. 10 per km^2 to ca. 70 per km^2, respectively. A similar pattern for livestock density also exists, and is related also 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.

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 the reduction 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.*

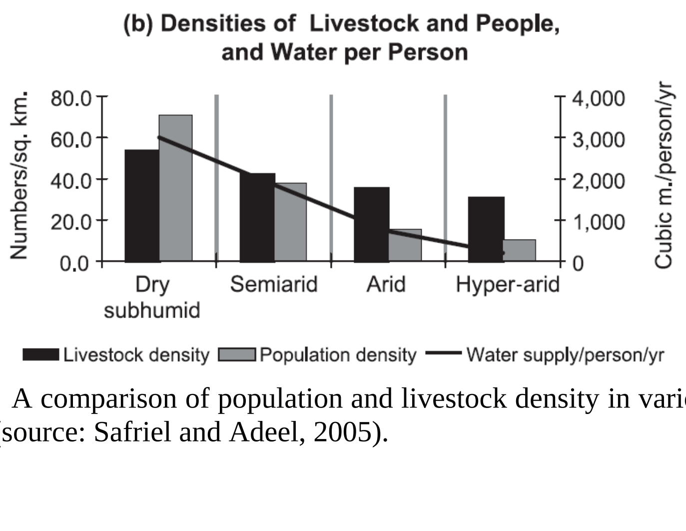

Figure 1. A comparison of population and livestock density in various dryland subtypes (source: Safriel and Adeel, 2005).

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 percent 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 five in drylands demonstrate a clear linkage to food insecurity as well as the level of aridity. As mentioned earlier, it can be argued that semiarid 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.

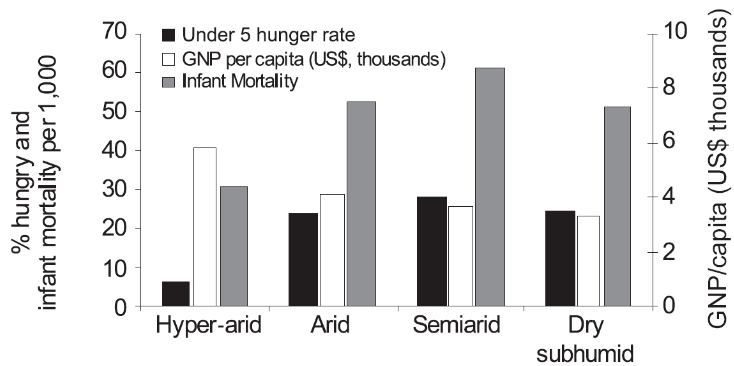

Figure 2. Human well-being statistics for drylands (source: Safriel and Adeel, 2005).

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 also projected that population growth

[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).

and increase 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 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/water management approaches are linked to providing dryland people 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 learnt 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 fluctuation on a seasonal and annual basis and potential conflicts and competition amongst 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.

As a good example of such traditional management approaches, oases demonstrate the appropriate usage of the physical and geomorphological factors around oases (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.

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 adpated 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 species and animal breeds (United Nations Convention on Biological Diversity – UNCBD).*

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 roooted 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 a 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 manay ways, therefore, traditional knowledge is actually contemporary knowledge. Traditional knowledge is embedded in traditional knowledge systems, which each community has developed and mantained in its local context (World Intellectual Property Organization – WIPO).

Another striking example of a traditional water management system is "qanat" (also called Kanat or Karez in Asia, Foggara or Khettara 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, Iran, Pakistan and China. The 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 is (a) 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 costs.

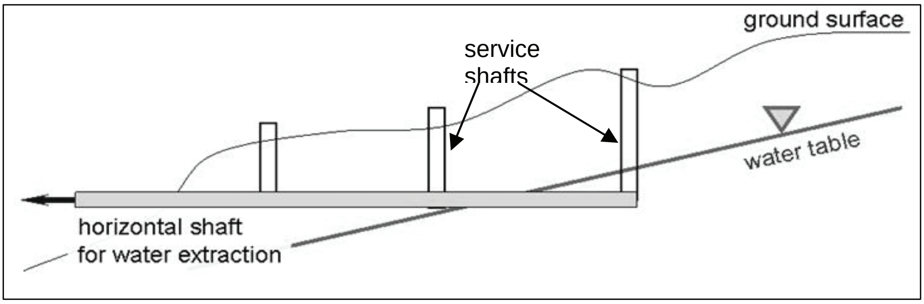

Figure 3. A schematic representation of a qanat water delivery system.

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 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 labor-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 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 favorably 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, very limited research effort has been undertaken 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 labor-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 the 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 rigor to problem-solving.

The objectives of this initiative were four-fold.

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 subprojects explored the comparative evaluation of these systems in different geographic and environmental settings.

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 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).

There are also some indications that the subprojects 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, they 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 Atacama desert, which have already and will continue to experience a decrease in precipitation as a result of global climate change. 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 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 lack of research and lack of financial resources, respectively.

It is hoped that the work presented in this publication will contribute up 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 rigor, 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.

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Assessment of Three Collective Renovations of Traditional Qanat Systems in Syria

Joshka Wessels

Introduction

In the summer of 2000, a small group of Syrian villagers renovated and cleaned their own common water source with international help. The water source is an ancient Byzantine water tunnel system called qanat. This was a pilot renovation, and two subsequent renovations took place in the south and south-western parts of Syria during 2001 and 2004, respectively. This work raised some interesting questions: In this time of ecological farming and increasing environmental awareness, is it possible to re-use an ancient water supply system? And what policy criteria could be used to assess feasibility? We used a unique approach in feeding back field data to the local communities, with edited video footage of qanat renovations and interviews of qanat users.

Study Area

Syria is located at the eastern part of the Mediterranean Sea between Lebanon and Turkey. The country's climate comprises dry hot summers with mild winters and rainy spells in autumn and winter. The population is ca. 19 million people with a growth rate of 2.3 % (2006 estimate). The main language is Arabic and the population consists of various ethnic groups of which Arabs form the majority (90.3%). The main religion is Sunni Islam (74%), 10% is Christian and the rest are other Muslim sects.

Water is the main limiting factor for agriculture in Syria. Through ingenious water extraction techniques, ancient peoples like Persians and Romans coped with the dry climate. One of the techniques is called qanat, a subterranean tunnel that taps the groundwater and leads it artificially to a human settlement and agricultural lands using gravity flow conditions (Lightfoot, 1996; Beaumont *et al.*,1989). This chapter presents practical efforts on how collective community action renovated qanats. We look at four case study sites in Syria; Shallalah Saghirah in the north-west, Arak in the centre, Qara and Dmeir both located in the southwest.

Shallalah Saghirah is a small village located 70 km from the northern city of Aleppo towards the Syrian desert. It consists of some 25 households. The village did not have electricity at the time the fieldwork was conducted, educational levels are low, the schoolteacher from Aleppo rarely visits the school building to teach the children, and there is public transport available only on request (Wessels, 2003 a & b).

Qara lies at the foot on the eastern side of the Anti-Lebanon Mountains near the border between Syria and Lebanon. The site contains 10 qanats of which five are still running. The qanats are regularly maintained and upgraded by the Directorate of Irrigation of the Awaj/Barada basin. The qanats are situated outside the urban settlement on a straight line running from North to South and show little decrease in flow.

Dmeir is a medium-sized town situated in the dry area on the borderline between the suburbs of Damascus and the Syrian steppe. The site has three running qanats. They have a traditionally developed rights and regulation system. The flow of the qanats seemed to be consistent and one of the qanats even increased after a small earthquake in 1992.

Arak is a village located in the centre of Syria. Arak lies some 20 km east of the famous town of Palmyra in the middle of the Syrian steppe. It is very dry and the site knows three qanats of which two are still running. The community does not regularly maintain the qanats.

The Abandonment of Qanats

Generally, a qanat system consists of an underground part and a part above ground surface. The underground part is divided into the “water production section” and the “water transport section”. In the “water production section”, the water is collected, either from a natural source or through infiltration of groundwater. This section is underneath the groundwater level of the surrounding area. The “water transport section” transports the water to the surface. This section is usually lined with plastering on the sides to prevent leakage of water. The gradient of the tunnel is very precise and should not exceed 5% in order not to let the flow erode the rock or sand in which the tunnel is dug (Goblot, 1979). On the other hand, the gradient should not be too low because then the water cannot be transported to the surface (ibid.).

By nature, a qanat is a truly sustainable technique of extracting groundwater. It only relies on gravity and it cannot exhaust or over-exploit an aquifer. The technique is thought to originate from Old Persia (present day Iran) around 3,000 years ago (Beaumont et al., 1989; Goblot, 1979). In the Arab world, the ancient tunnels systems can be found in an area spanning from Iraq to Morocco and from Syria to Oman. They have different names, for example “Foggara” in

Algeria and Morocco or “Falaj” in Oman. Qanats are not dug anymore because of the dangers that accompany the digging; a lot of traditional qanat diggers are reported to have died during construction. There are only approximately 40 traditional qanat diggers (muqannis) left in Iran, for example.

Qanat systems are increasingly drying up and being abandoned throughout the Middle East and North African region. Modern development, population growth and changing socio-economics force users to change their lifestyle to one based on agricultural self-sufficiency as well as on other non-agricultural income sources (Wessels, 2003; Lightfoot, 1996; Beaumont et al. 1989). With these societal transformations, users lose interest and look for modern techniques of water supply. Diesel operated or electric-powered motor pumps frequently replace qanats. Consequently, the falling groundwater tables affect qanats, until they finally dry up. But the problem is not only technical; the younger generation pulls towards the cities and finds jobs other than farming. This group of youngsters literally abandons qanats. With the abandonment of qanats the indigenous knowledge and collective action critical for qanat upkeep also disappear.

Qanats in Syria

In 2000-2001, an ICARDA team conducted a reconnaissance survey in Syria guided by a map prepared by researchers from Oklahoma State University (USA) in 1994. We documented geographical, socio-economic, and hydrological characteristics and interviewed local experts and officials from various institutions. We found a total of 42 sites containing 91 qanats, of which 30 were still in active use. Others were dry or drizzling and almost abandoned. We assume that more qanats existed in the past but these were difficult to re-locate and beyond repair.

In Syria, the concentration of running qanats is around Damascus, Homs and in the steppe areas. The qanats used to provide the main water supply for drinking water and agriculture. Through circumstantial evidence we found that Syrian qanats were already in use during the Roman times. The digging technique and type of the qanats varies considerably throughout the country. In general, there are two types of qanats:

1. *Infiltration qanats*: In areas where the surface is flat, for example in the steppe (badia), the qanats can be long (more than 3 km) and dug into limestone rock or sandy soil. These qanats are based on groundwater infiltration from an alluvial fan or floodplain sometimes supported by natural sources in karstic holes. The walls of these tunnels are usually plastered with extra casing made of brick walls. This type of qanats is vulnerable to climatic factors, needs intensive maintenance and often collapses during floods and is consequently abandoned.

2. *Spring qanats*: Another type of qanat is located in the hills and mountains. This type is dug in hard rock or limestone and is in general short (not exceeding 3 km of length). This type bases its water supply on natural sources and infiltration of groundwater from the hills or mountains. Most of them have casings of airshafts or some plastering of the walls. Lastly, there are unique qanats that are located on the fringe of the steppe, tapping from natural springs that might even be sulphuric. Spring qanats are less subject to floods and collapsing, however, regular maintenance is a condition for keeping them running.

The water of Syrian qanats is used mainly for irrigated agriculture. The division of the water is based on its own local system of rights and regulations. Each user household has an irrigation share measured in time, the so-called “dor” (turn). This turn can last as little as 14 minutes or as much as one or two days, depending on how much land and water rights the particular household owns. The regulation system is based on a fixed amount of rotation in days in which all households with user rights have their turn. This rotation is called “addan”. Ideally, all land in the irrigated garden (bustan) should be irrigated within this “addan” but usually only some parts are irrigated either in summer or winter depending on the crops. The differences in “addan” for each qanat depend on many factors. Mainly it depends on the number of first users, the discharge of the qanat water, type of soil, type of main crops, and the total land surface. In some cases this might mean that the fixed “addan” has been there since the qanat has been dug, maybe even since Roman times.

Irrigation shares can be traded and are usually attached to land. In the past, a father would try to gain as much land and water shares as possible to divide a fair amount of each among his eldest sons. In this way, the land and water share would stay within the same family for decades or even centuries. Keeping the shares within the family is still very important. For example, if a farmer in Arak decides to leave his farm and start a business in Palmyra or Damascus, he could sell his land with attached water shares to his cousin. However, many farmers arrange for a caretaker for their shares when they leave their farm. In this way, they can always come back to their original land.

In each community, there are families with the biggest irrigation share who are represented in a committee that governs the qanat use and division of the water shares. There is usually also a so-called “natour”, a guard that makes sure that the shareholders get their rightful amount of water. The water shareholders pay a yearly amount to the committee from which the salary of the “natour” is paid and which forms a budget for maintenance and repair. When a committee or natour is not established, it is difficult for the community to maintain the upkeep of their qanat on a regular basis. In some of these cases, governmental assistance is given.

Already in early 1990s scientists came to the conclusion that qanats are being abandoned as water tables fall and qanat galleries go dry (Lightfoot, 1996). A valuable cultural heritage is vanishing. But the traditional technology can be combined with modern technology. In Qara, we have seen that combining ancient qanats and modern drip irrigation systems for fruit trees might prolong the life of some qanats and encourage younger generations to commit to their upkeep. Some farmers have their own reservoir, which is filled with water during their traditional turn. Attached to the reservoir is a modern drip irrigation system that waters extensive amounts of fruit trees. Another option to think of is to encourage eco-tourism based around qanats to provide alternative income for the farmers. As we have observed in countries like Oman, renovation of neglected qanats is possible.

Renovation Efforts with Qanat Communities

Four qanat sites were investigated between 1999 and 2003; at three sites (Shallalah Saghirah, Dmeir and Qara) major renovation activities took place between 2000 and 2004. We will briefly describe the process and results of these renovation efforts.

A pilot renovation was done in 2000 in Shallalah Saghirah; our team initiated a qanat cleaning based on the priorities and traditional knowledge of the community during focus group meetings with the village elders, the so-called "haqoun". The qanat is the only source of water in the village and dates back to the late Byzantine period, supported by the find of an oil lamp from this period. After some differences between the haqoun were settled, some young men became interested in renovation of the qanat. The haqoun made an informal written agreement among themselves to regulate the use, maintenance and renovation of the qanat. They selected a young village supervisor and made a list of all the workers that would be available for the cleaning work. With this agreement and a technical workplan and budget, the committee and the researchers initiated a search for funds necessary for cleaning and renovation. From June until September 2000 the renovation took place in Shallalah Saghirah with funds from the German and Dutch Embassies in Damascus. The workers were qanat users and all blood-related. A representative of the Aleppo Museum attended the worksite on a daily basis. The village supervisor was instrumental for motivating his fellow workers when disputes happened between them. However, an unsolved revenge case threatened the cohesion between the workers. One day, tensions rose high and resulted in a clash in the evening hours. The local police arrested six community members and jailed them until they calmed down. The workers group split up into two factions again and our research team halted the work for 22 days until the cousins resolved their problems. Eventually, a traditional Bedouin shaykh from the outside mediated and the conflict was solved by the usual payments to each other. The work could continue but the spirit was lost. The final day was on 16 September 2000 and was concluded with the killing of three sheep. The technical result of the renovation was positive and the team measured a 30% increase in water flow in the winter directly after the cleaning. Perhaps more important, despite the social difficulties, 16 young villagers have learned how to maintain their community's qanat.

A second renovation took place in Dmeir in 2001. The users community was well organised into a traditional system of "water committees" and "water guards" supervised by the farmers' cooperative. They were also willing to pay part of the renovation costs themselves from their credit system. Also involved were the General Directorate of Antiquities and the Regional Directorate of Irrigation of the Awaj/Barada Basin, active in qanat renovation in the Damascus Province. In this way, both the formal and the informal institutions were participating. The research team called for a meeting to discuss the renovation process. The attendants were the qanat committee members, notable persons from the community, and representatives from both the General Directorate of Antiquities and the Regional Directorate of Irrigation of the Awaj/Barada Basin. Based on priority activities, the costs and the participation of each party, a written contract was prepared to define each party's duties. A contract was developed and signed by each party. The period of the renovation was from November 2001 until February 2002. The actual renovation work was carried out by a group of contracted labourers, supervised by the head of the qanat committee. The damaged and eroded parts of the constructed walls were restored: almost 150 m^2 of the qanat walls was rebuilt. The qanat wall is 270 m long, and was built with stones 20-30 cm wide. The whole Qanat wall and a part of the ceiling were plastered, and damaged parts restored. Protective wall and covers were built for the cleaned airshafts and the qanat path was cleaned. The outlet was protected.

A third renovation effort was carried out in Qara between 2003 and 2004. One of the qanats in Qara, Ain el Taibeh, has provided the monastery of Deir Mar Yaqoub with water since its establishment during the Byzantine era. But the qanat ceased to flow in January 2002. The monastic community had requested our research team to compile scientific advice for them based on the survey work done in 2001 and 2002. This advice was duly developed in September 2002 concluding with social, institutional and technical recommendations for the qanats. The government support was reasonable: farmers were required to be involved at an equal level in the renovation efforts. The presence of the renovated monastery, its frescoes and the importance of the site for international heritage justified the assistance to maintain and conserve this valuable system as a human ecosystem. Having secured the outside funding from the Swiss, German and Dutch Embassies, the monastic community began preparing the renovation efforts at the beginning of September 2003. The work was carried out by the qanat experts and continued for ten days. The group of qanat experts consisted of 5 specialist workers from Ma'aloula and 3 builders from Nebk. All workers had experience with qanat renovation. The group from Nebk was specialised in the traditional building of tunnels using slabs of stones whilst the group from Ma'aloula cleaned the tunnel and reinforced the airshafts. A daily supervisor was appointed from the Ma'aloula group. A representative from the Irrigation Directorate of Awaj/Barada Basin regularly visited the site to inspect the work. The mother of the Monastery of Deir Mar Yaqub took care of the overall project coordination. On 11 April 2004, the renovation work was finished and the monastic community measured an increase of water supply.

Voices of Qanat Users

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”. A collection of video interviews forms the basis of an analysis of perspectives of qanat users. These interviews shed some light on why renovation efforts were and were not successful. The most important question during the interviews was why people are abandoning qanats and not keeping up the maintenance like before. Some quotes of qanat users:

“The young people want more income and they do not get it from the land we have now. It is more profitable to go and earn your money with something other than farming the bustan.”

“Those who are not interested in agriculture, they do not care and they went to get jobs in the government and are the ones who abandon the qanats. In the last 50 years because the income from other sources is better, they left for the other jobs.”

“I have already 100 descendants joined in the “house of Abu Zaal”. I can call myself a great-grandfather and they all want bread,” he says “and because of the economical reasons, the young people abandon the qanat.”

“Dmeir used to be a small village built around the temple with a wall and 7 doors that would close at night. In 1937 two major floods destroyed a lot of houses and people were forced to move or fall back on government support until 1945. They built houses outside of the city walls. There were also Dmeiris who lived abroad in the States and Europe and they donated money to build houses further. Then the city developed, we received domestic water supply, electricity, roads and telephone. Also the way people made a living changed. The French came and established an army base which gave a lot of jobs for us. People opened shops because this place is good for a stop-over between Damascus and Palmyra. So people moved away from agriculture and also demanded more money and could spend more money because of their salaries. Because of the little ownership, they keep it just for exercise or hobby farming, they rent it out or sell their rights when they need money.”

There is general consensus that due to the increased population, socio-economic changes and modernisation, the profit from qanats is not sufficient anymore for user households to maintain their lifestyle. Therefore, qanat renovation should provide a worthwhile profit, which can be sought in the form of value-added crops and ecotourism/cultural heritage value.

Another important aspect for successful qanat renovation is strong local leadership (Wessels, 2003). In Arak, the willingness of qanat users to invest in renovation was very low due to internal disputes that were not resolved by the community leader. Therefore, renovation did not take place. Even with outside help and funding, a participatory renovation effort would probably have increased tensions between the villagers. This is exactly what we observed during the pilot renovation in Shallalah Saghirah; the old social hierarchical system had collapsed. This was further exacerbated by population growth, internal competition, erosion of leadership and out-migration. A user illustrated this by his remark “Our five forefathers were like one hand, their system took care of the qanat and prevented children and sheep damaging the trees in the garden and they grew all kinds of vegetables and even cotton....but those after them did not keep these rules, the system did not last!”. The introduction of participatory approaches during the pilot renovation paradoxically caused users’ increased suspicion and contempt towards each other. In hindsight, not all users respected the leadership of the democratically elected village supervisor and an old revenge flared up in the process. The main problem at the pilot site was the lack of local leadership to manage the conflicts between these users.

The renovation efforts in both Dmeir and Qara were successful and we found that an important reason for this success was the presence of strong and respected leadership and a long tradition of rules, regulations and agreement between users. There are some consistent findings that emerged from empirical research in collective action, one of them is that when the users of common-pool resources organize themselves to devise and enforce some of their own basic rules, they tend to manage local resources more sustainably than when rules are externally imposed on them (Ostrom, 2000; Balland and Platteau, 1999; Wade, 1998). As a result, both in Qara and Dmeir there was no open dispute about decisions and the users community invested a great deal in the costs of repair and maintenance. Any disputes were dealt with inside the traditional conflict management system guided by a shaykh or mukhtar (village leader). Furthermore, professional expert contractors rather than users themselves carried out the dangerous renovation work.

Policy Options

Desertification and drought are the main, inter-linked climatic challenges in the Middle East, and dwindling water resources will put continuing pressure on society and water users. These developments call for sustainable techniques of using water. Often the solution is sought in modern technology, such as desalinization of seawater, but traditional techniques of sustainable water use can be found on the ground. In an ideal future, a new sustainable way of living will halt the pressure that human population puts on natural resources. The re-use 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.

As we have observed, successful renovation of qanats in Syria is technically possible; however, a thorough social and hydrological assessment is required in advance. We developed some ideas that can be used to decide whether it is feasible to renovate.

The following are the main points to consider for renovation:

- willingness of 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 qanat source; and
- a guarantee of safety for qanat cleaners.

Participatory approaches are preferred and the ultimate responsibility and monitoring of the renovation should be with the farmers' cooperative. However, care should be taken with introducing the notion of "democracy" into this scenario. If familiarity with democratic principles is low at the community level, participatory approaches can potentially lead to conflict. The pilot renovation proved that the introduction of participatory approaches increased tensions between users, and the presence of a strong local leader would have been valuable. We hope with these efforts to preserve the traditional knowledge on qanats that still barely exists in Syria, and by starting with the community needs and priorities to revive sustainable qanat use for the future.

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Traditional Water Harvesting on the Mountain Terraces of Yemen

Najib M.A. Al-Ghulaibi

Introduction

This chapter presents a study that was sponsored by the United Nations University and carried out by the author over a two-year period from May 2003 to April 2005. It formed part of an initiative to maximize water delivery to farmed terraces in the northern mountains of Yemen, as well as 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. 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.

Mountain Terraces and Rainwater Harvesting in Yemen: A Historical Context

In prehistoric times, Arabia enjoyed more rainfall than today. The situation changed around 4000 BC when the so-called mid-Holocene moist phase came to an end and the climate started to become much dryer (McClure, 1988). The diminished spring and summer rains brought adequate precipitation to sustain modest covers of vegetation, but the crops no longer grew as abundantly as before. The early settlers of the Yemeni mountainsides were thus forced to use every possible patch of soil for cultivation. In addition, they faced a challenge when the slopes started to become denuded, and high rainfall events were accompanied by severe soil erosion. Terracing the steep mountain slopes was an answer, and through an enormous labour input the farmers created millions of terraced fields in the Yemeni highlands (Vogel, 1987).

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 employed today. Man-made diversions are created by heaping up gravel and stones. As soon as it rains, the run-off is funnelled by the artificial berms into broader channels which direct the water from the bare hillsides onto the terraced fields. The system is called sawaji irrigation, using the local Yemeni Arabic term (Vogel, 1987). A quantitative analysis of rainwater harvesting for terraced agriculture in today's Yemen is given by Eger (1984) for the Amran region in the central highlands of Yemen, and by Rappold et al. (2003) who provide data for the more southerly region of Taizz.

Terraces function as both soil and water conservation structures on sloping land. The process of soil erosion down-slope is greatly slowed due to retention of the run-off on the terraces. It has been documented archaeologically that terrace construction in Yemen dates back to at least the 3rd millennium BC (Wilkinson, 1999). Large parts of this terraced terrain have been cultivated continuously since that time.

Figure 1. Traditional water harvesting in the mountain terraces (Al-Qimmah watershed during rainfall. *Source:* Al-Ghulaibi, 2004)

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 brilliant solution for sustainable and secure food production. But newer approaches need to be found today to correct for the imbalances introduced through more recent developments.

Study Area and Natural Resources

The al-Qimmah watershed is located in the northern highlands of Yemen, in Hajjah Governorate (see map, Figure 2). The main road from Amran to Hajjah Governorate crosses the upper part of the watershed (see map, Figure 3). The study area covers approximately 700 ha, comprising the watersheds of Wadi Abr Jaher and Wadi Mqaled. Steep, terraced mountain slopes, a rocky escarpment and green valleys characterize the watershed. The elevation ranges between 1600 and 2700 m above sea level. Erosion of volcanic lavas and pyroclastics has furnished rich soils (Vogel, 1987).

The annual rainfall is between 250 and 450 mm, with the precipitation occurring mainly in two monsoon-influenced rainy seasons: spring (March to May) with medium rainfall, and summer (July to September) which accounts for 50 to 60% of the annual precipitation. Overall, the rainy season of the year is short, falling within at most 4 to 6 months per year, and the dry season lasts for 6 to 8 months. During the spring rainy season, though the precipitation is often infrequent, the rain falls normally with great intensity which results in high surface run-off of the water into the bed of the wadi flood courses. This run-off may be collected in storage facilities. Yet, during the dry season when the clouds dissipate, the persistent sunshine causes high evaporation of water stored in uncovered reservoirs.

For Hajjah Governorate, the average PET (potential evapo-transpiration) is 2.7 to 3.3 mm per day during the dry, cold period and 4.5 to 4.8 mm per day during the months April to June. The average total amount of ET (evapo-transpiration) per year for Hajjah is about 1425 mm.

Problem Definition

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 another. Naturally, a shortage of precipitation leads to a significant decrease in yield. The extended periods without any precipitation at all have a serious deleterious effect on plant growth. This can result in severe physiological degradation of the plant, especially in the root zone. Low ground moisture retards root growth and causes leaves to fall prematurely.

When the rainfall starts again after a long period of drought, plant recovery is slow. Therefore the crops need to be carried through the long dry season by the provision of supplementary irrigation using water stored in reservoirs during the previous rainy season. Other possibilities are the application of traditional water harvesting techniques, or re-direction of water from springs to the fields. Supplementary irrigation during the dry season can increase the crop yield three times, as shown by field trials.

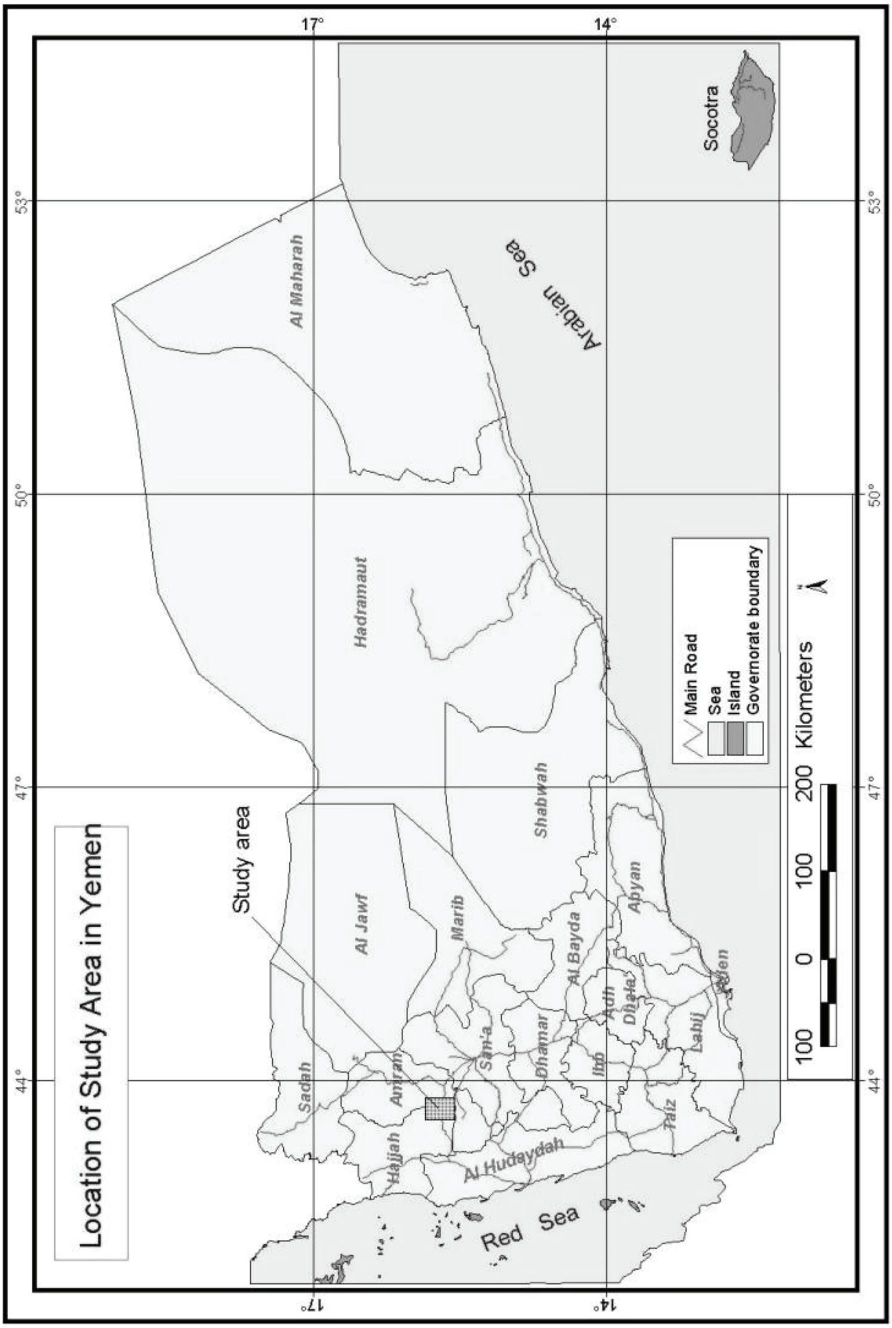

Figure 2. A map of Yemen showing the location of the study site.

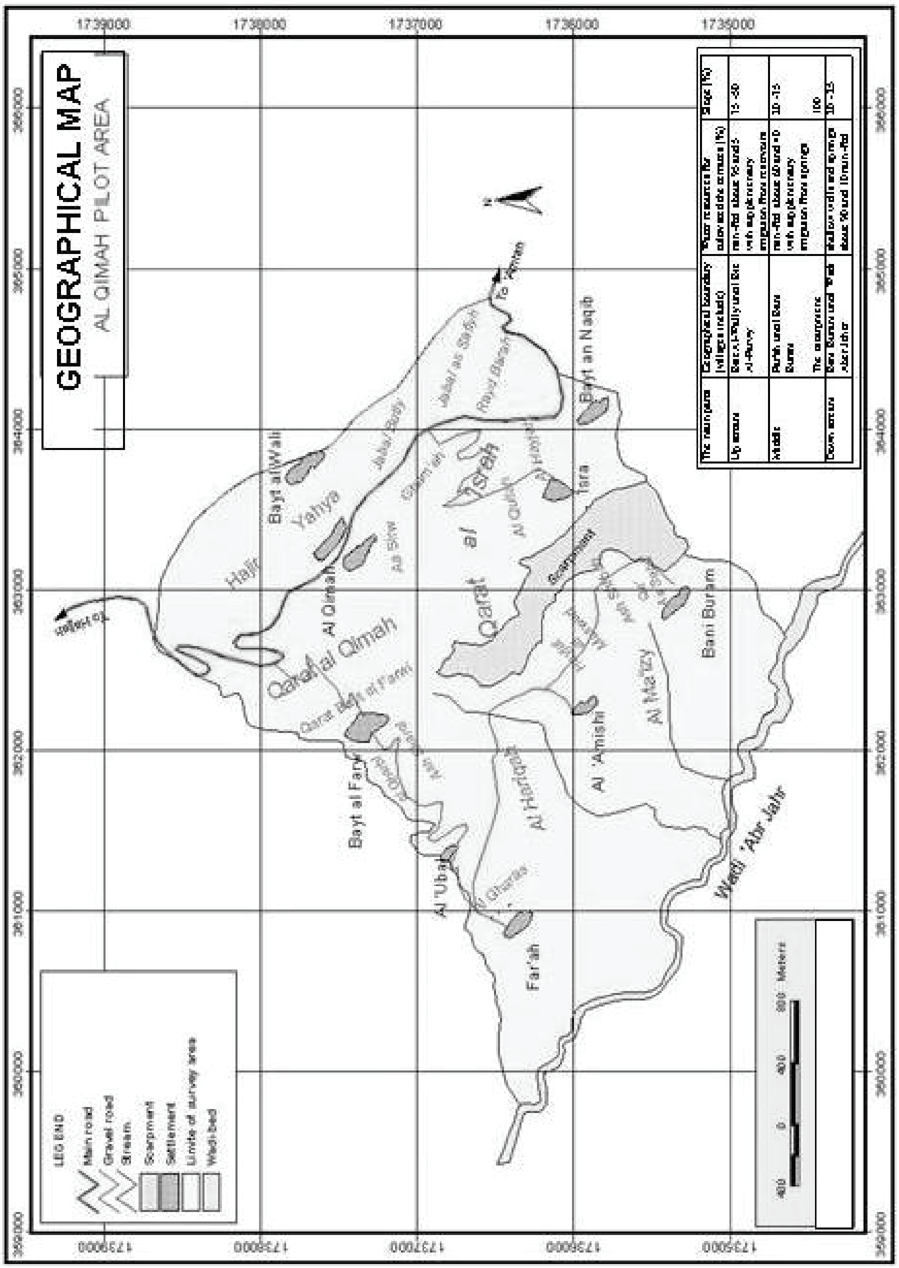

Figure 3. Geographical map of the study site.

In addition to the need for supplementing field irrigation, there is the problem of domestic water shortfalls during the dry season. Beginning in November, the water drawn from springs and stored in reservoirs starts to diminish. People are obliged to bring water from valley bottoms - using the base flow in the wadis - to the villages high up in the mountains, which can be done in this day and age through trucks. The cost of one litre of water delivered by this means is about 10 YR (Yemeni Rials) for a distance of approximately 1 km from the source of water to the village (100 YR = $US 0.55, according to the exchange rate for 2005).

The average consumption of drinking water is 3 to 4 litres per capita per day, equalling 100 litres per month per person. If the family consists of 10 persons, the monthly consumption will be 1,000 litres. Therefore the cost of water for this family would amount to 10,000 YR (= $55). Given an average monthly income of the farmer of 10,000 to 15,000 YR, there is clearly a financial problem here, which contributes to abandonment of the villages by farmers seeking work opportunities in cities. The alternative is to rely exclusively on women and children to fetch water from the base flow in the wadis or from springs, which may be considerable distances away, and to deliver the water to the villages on the high mountainsides. Women and children, together with draft animals, have to travel up to 2 to 3 kilometres on foot per day over arduous terrain for this purpose, carrying heavy weights. The expenditure of human energy and time is enormous.

The problems described above are intensified by the following considerations in the study area, which also affect Yemen in general, and have 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 20-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 (for details see Vogel, 1987).

Traditional Rainwater Harvesting on the Mountain Terraces: The Annual Cycle

From observations in the study area (both upstream and in the middle of the watershed), and from field interviews, we can trace the water harvesting practices over the course of an entire calendar year.

A. During the dry winter season (October to February) the farmers perform the following activities:

1. They repair the damaged terrace walls. Sometimes the farmers collaborate to rebuild collapsed walls, in which case the owner of the terrace normally provides the others with food during the course of the work. In instances where the farmer opts to pay for the labour, the cost for rebuilding a length of walling 10 m long and 2 m high amounts to about 9,000 YR (= $50). The work starts with the emplacement of the large stones first, and then the small rocks and soil packing are added.
2. Berms need to be erected around the edges of the terraces (about 0.5 m above the ground level of the terrace) to allow water to be trapped on the land. Each farmer does this on his own terraces.
3. The catchment area of each group of terraces (Yemeni dialect Arabic: *sebab*) needs to be cleared of loose stones in order to maximise run-off. These catchment areas have different parts, depending on the slope and surface configuration.
4. Maintenance work of the main delivery channel, which is normally 1 to 3 m wide and 1 to 1.5 m high, involves clearing it of rock and sediment accumulations, in order to facilitate delivery of run-off water to the terraces. The same applies to the branch channels and the main drainage channel (Yemeni dialect Arabic: *kuthwam*), some 0.5 m in width and 1 to 1.5 m high, which carries surplus water away from the terraces. It runs underground, with only the inlet and outlet visible. See Vogel (1987) for a similar description of an underground drainage system.
5. The terraces are ploughed, using draft animals. This is done three times. The first ploughing starts at the end of December, for the removal of grass and other weeds. The second ploughing happens after the first rain, to close the main soil pores and reduce evaporation. This is required to conserve as much moisture in the soil as possible. At the time of the second ploughing, the farmers also spread manure (from cows and sheep) onto the soil. The third ploughing, at the beginning of the spring season in March, is for sowing (Yemeni dialect Arabic: *sawab*), generally sorghum. In this last tillage, the farmers make furrows at right angles to the hillside gradient, in order to catch as much run-off as possible for the crop. The farmers plough and sow in one go, using a sowing funnel attached to the plough.

B. During the spring season (March to May), which is the first rainy season, the farmers perform the following activities:

1. They continue to repair and maintain the branch channels in order to maximize the run-off water directed to the terraces. As well, the so-called *mshanat*, Yemeni Arabic term for provisions made to catch small rocks and sediments before the run-off enters the terraces, are cleared.
2. If the run-off is low during the spring season, the farmers cultivate the fields with a slight slope running normally 0.5 to 1% back towards the mountainside. This reduces the loss of water that would otherwise flow over the terrace walls.
3. As soon as the rain starts, the farmer monitors his terraces. Some farmers will direct additional run-off water onto a terrace, while others may close their branch channel. This depends on the amount of the rainfall. In order to be able to drain surplus water from the upper terraces to the lower ones, in each terrace wall there is an outlet (0.3 m x 0.25 m) in the middle or at the end of the terrace wall (Yemeni dialect Arabic: *mansher*). This permanent stone emplacement allows excess water to pass onto the field below and plays a primary role in terms of soil erosion control.

C. During the summer season (July to September), which includes the main rainy season, farmers perform the following activities:

1. They monitor the terraces closely, because of the danger of flooding, following a heavy rainstorm. On these occasions the farmers may choose to breach the sides of the branch channels to prevent collapse of the saturated terrace walls.
2. Collaborative efforts are carried out to protect the crops on the terraces by diverting the main channel (Yemeni dialect Arabic: *sharm*) during time of excessive run-off.
3. One and a half months after sowing, the terraces are weeded to conserve soil moisture. In addition, the soil around the sorghum plants is hoed to reduce soil porosity and thereby deter evaporation.
4. After two months, the sorghum plants are stripped of about half of their leaves (Yemeni dialect Arabic: *kharf*), and the plants are thinned by hand to leave about 60,000 plants per hectare (see Berry, 1984, for details). These activities reduce plant transpiration and thereby help conserve soil moisture as much as possible, and at the same time they provide essential fresh fodder for animals.

Traditional Law of Water Rights

The traditional law 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; he has expert knowledge of the land and is familiar with the land-owners (Yemeni dialect Arabic: *al-muqaddim*).

From our interviews with the farmers, it became clear that the 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 lower down. The farmer lower down 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.

Reservoirs for Run-off Water Storage

Storage reservoirs or cisterns (Yemeni dialect Arabic: *majil*, pl. *mawajil*) are common in villages high up in the mountains to collect run-off water. The following is an inventory of these cisterns documented in the study area (see map, Figure 3).

1. Bayt al-Wali village

This village lies at an elevation of 2,688 m above sea level. There are three reservoirs which were built between 1966 and 1967 from fieldstones, and their floors and walls are coated with a lining of waterproof lime plaster. In 2002 the cisterns were renovated using stones and cement. The catchment area from which the run-off is funnelled into the reservoirs is in the Safeah mountains and measures about 3.4 hectares, with a gradient of about 10%. Before the run-off enters the respective reservoir, there is a basin to allow small rocks and sediment to settle. In case of a heavy rain, the cisterns may overflow.

The holding capacity and dimensions of these reservoirs are as follows:

a. 207 m^3 (4.4 m × 15.7 m × 3 m)
b. 304 m^3 (13 m × 13 m × 1.8 m)

c. 346 m^3 (12 m × 12 m × 2.4 m)

The total volume of these three reservoirs is 857 m^3. The water is used for domestic purposes, as is an older cistern built 70 years ago with a capacity of 98 m^3 (5.6 m × 4.6 m × 3.8 m).

2. Kuhlan-Afar village

The largest reservoir in the study area is of unspecified age and there is no living memory of its construction. It is almost circular, with plaster coating on its sides and bottom to prevent seepage. A circular depression in the middle serves as a sediment trap. Run-off water is led into this reservoir through channels built with fieldstones and plaster lining. Along the sides of these channels are perforations to encourage silt deposition. A second reservoir of smaller dimensions is found next to the large one. The total volume of both reservoirs is about 4,000 m^3, and the water stored in them is normally used for domestic purposes. When the first reservoir has filled up, water from it can be diverted to the second one, and in case of there still being excess water, this surplus can be directed to the terraces.

3. Al-Qimmah village

A new reservoir was built in March 2004 by farmers with funding from UNU and in cooperation with the farmers. It is located in Ubar Hamzah close to the main road coming from the west. The capacity of this reservoir is 63 m^3 (5 m × 5 m × 2.5 m), and the total cost for building it was 350,000 YR (about $2,000). The water is used for two purposes – namely as domestic water and as supplementary irrigation for the terraces during the dry period. The objective of the project was as an experiment to see how many square meters could be irrigated from this reservoir. It was found that about 200 m^2 (approximately two medium-sized terraces) can be irrigated from one filling. Under the assumption that the reservoir is filled twice a year, the water would also be sufficient to irrigate a greenhouse area of 500 m^2, from sowing to harvest. Farmers could, for instance, grow cash-crops such as cucumbers and tomatoes under such controlled conditions which would mean an increase in efficiency of water use and at the same time an income increase.

4. Bait al-Farawy village

There is one large reservoir (Yemeni dialect Arabic: sud, which also has the meaning of “dam”), which was constructed of fieldstones and cement in 2002. The holding capacity of this reservoir is 1196 m^3 (51 m × 5.1 m × 4.6 m). The water is used for domestic purposes and for providing water to animals. Before the water enters the main reservoir, there are two small basins to allow sediments and small rocks to settle. Their dimensions are 5.1 m × 4.7 m × 1.3 m, and 5.1 m × 4.8 m × 3 m respectively. They are built at the end of the main channel that directs the run-off to the reservoir.

5. Al-Obal village

There are five reservoirs, three of which are used for both domestic purposes and supplementary terrace irrigation. One is exclusively for irrigation, and one for domestic purposes only.

a. A small reservoir (Yemeni dialect Arabic: *birka*) is located to the north-east of the village. The run-off water for this reservoir comes from the top of the mountain. The capacity of this reservoir is 81 m^3 (9 m × 4 m × 2.3 m). The water is used for domestic purposes and for irrigation.
b. A second small reservoir can be found near the school of the village. The run-off water is derived from the immediate area around the reservoir. The capacity is 166 m^3 (10.8 m × 4.4 m × 3.5 m). The water serves domestic purposes as well as irrigation of crops.
c. A third small reservoir is to the south of the village, and – as with the first one – the catchment area extends to the top of the mountain. The capacity is 33 m^3 (3.2 m × 4 m × 2.6 m). The water is used for domestic purposes and irrigation.
d. The fourth birka to the east of the village also receives its water from run-off from the top of the mountain. The capacity is 75 m^3 (5 m × 5 m × 3 m), and the water is used exclusively for irrigation. The reservoir was constructed by a local farmer, and he reported that he spent approximately 350,000 YR (about $2,000) on it.
e. Run-off from the mountain also fills a large reservoir (Yemeni dialect Arabic: *sud*) in the middle of the village. Its capacity is 10,000 m^3 (50 m × 20 m × 10 m). The water is used for domestic purposes only.

Assessment of the Reservoir Capacities

From the above data for the reservoirs located in the watershed study area, we can summarize the figures in the following way:

- The total storage volume of water is 16,571 m^3.
- The total population of the villages is 3,621 inhabitants.
- The average water consumption for drinking is 3 to 4 litres per capita per day, which amounts to approximately 100 litres per month. The total water demand for drinking purposes for the entire population is therefore 100 × 3621 = 362,100 litres per month, i.e. 362 m^3.
- The water demand for domestic use is 20 to 30 litres per capita per day, equalling 600 to 900 litres per month. For the entire area, the water demand for domestic use therefore amounts to 750 × 3,621 = 2,715,750 litres per month, i.e. 2,716 m^3.
- The watering needs for livestock is 10 to 15 litres per animal per day, equalling 300 to 450 litres per month. The total number of livestock in the study area is 767 (goats, sheep, cattle and donkeys), and the water demand of the animals is thus 375 × 767 = 287,625 litres per month, i.e. 288 m^3.

This results in a total water demand for one month of 3,366 m^3, i.e. 40,392 m^3 per year. Since the reservoir storage capacity is 16,571 m^3, the reservoirs can cover the needs for only 5 months of the year. The shortfall of water for domestic use and drinking purposes is therefore 23,821 m^3 per year, aside from the need for water for supplementary irrigation.

The numbers of reservoirs needed to cover the shortfall of water for domestic use, with an average reservoir capacity of 500 m^3, is 47 reservoirs. Given an average cost for each reservoir of approximately 2,000,000 YR (= $11,000), the total cost for providing these reservoirs would be about 94,000,000 YR (= $517,000).

Spring Flow Resource Management in the Watershed

There are a number of situations where channels drawn from base spring flow (Yemeni dialect Arabic: *ghayl*) provide an enormous boon for the sustenance of the fields. While the discharge rate of these springs is too low to have the water flow directly into channels, it is sufficient to fill a reservoir and then unplug it for irrigation. The springs documented in the study area are as follows:

1. Bani Boram

The water source is from Ghayl Arshan in the district of Jabal al-Taweel (Figure 4). The capacity of the reservoir fed by the spring is 180 m^3 (12 m × 5 m × 3 m). The discharge rate is at 14.9 m^3 per hour, reflecting a flow of 248 litres per minute (approximately 4 litres per second). This is sufficient to allow the reservoir to be filled and used (emptied) twice a day, once in the morning and once at night, so that the total volume of water from this ghayl is about 360 m^3 per day. The number of farmers served by Ghayl Arshan is 355. The area irrigated in this way amounts to about 1,500 labn (local land measure, 1 *libna* = 64 m^2, pl. *labn*), which equals 9.6 hectares.

Figure 4. Ghyle Arshan (spring) (photo courtesy of Dr. A. Bruggeman).

The main irrigated crop is coffee plants, in addition to vegetables (onions, salad greens) and qat. The rotation cycle is 18 days, which means that each farmer has the right to receive water from the ghayl once every 18 days. Therefore, 20 farmers per day can irrigate using water from the ghayl. The rotation system is monitored by a muqaddim who ensures that the different users receive equitable water shares.

2. Ghayl Ubar Joher:
The capacity of the two reservoirs served by this ghayl has a total of 105 m^3 (9 m × 5 m × 1.5 m = 67.5 m^3, and 5 m × 5 m × 1.5 m = 37.5 m^3 respectively). The reservoirs can be filled (and emptied) 4 times per day (Figure 5). Therefore the total daily volume of water from this ghayl is about 420 m^3. The discharge rate is 17.5 m^3 per hour, which is 292 litres per minute (approximately 5 litres per second). The rotation cycle for the farmers is 21 days. The irrigated area is about 1200 labn, which amounts to a total irrigated area of 7.7 hectares. The irrigated crops are coffee plants and banana trees. As in Bani Boram, it is the muqaddim's responsibility to monitor the rotation system.

Figure 5. Ghyle Oper Joher (photo courtesy of Dr. A. Bruggeman).

3. Ghayl Nad
The capacity of the storage reservoir is 70.7 m^3 (9.3 m × 7.6 m × 1 m). The reservoir is filled twice a day, so the total amount of water is about 141 m^3 per day. The potential discharge rate is at 5.8 m^3 per hour, meaning 97 litres per minute (approximately 1.6 litres per second). Coffee plants, bananas and sorghum are the main irrigated crops. The water rotation between the farmers is on an 18-day cycle. The irrigated area is about 2,500 labn, so the sum total amounts to some 16 hectares of irrigated farmland.

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. Since the beginning of the Holocene, the environment in this area has been fragile. Human ingenuity devised ways to sustain settlement in these marginally arid regions, through construction of terraces and diverse water harvesting structures. Over time, these techniques have proven to be effective.

Neglect of these water harvesting systems, however, as a result of relatively poor economic return, threatens to destroy the entire ecosystem. Because of water scarcity, low income from terraces that depend purely on direct rainfall, and high labour intensity of the agricultural activities, there is an increasing tendency to abandon this 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. The test cases presented in this study may serve as an example of how to preserve traditional mountain terrace agriculture in all of Yemen.

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