Qanats a Unique Groundwater Management Tool in Arid Regions: The Case of Bam Region in Iran

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ABSTRACT

For rational management of groundwater a holistic approach, linked to the sustainable management of the ecosystem must be developed. It is demonstrated that ancient methods of groundwater management, such as the qanats system, could provide a good example of human ingenuity to cope with water scarcity in a sustainable manner. The catastrophic earthquake of Bam has drawn the attention of researchers and professionals to a great human heritage related to the sustainable management of groundwater in arid zones and the development of a sophisticated culture of rational resource allocation.

INTRODUCTION

In recent decades it has become evident that groundwater is one of the most important and most vulnerable of earth's natural resources. Groundwater has a number of key advantages when compared to surface water. It is usually of higher quality, better protected from direct pollution, less subject to seasonal and perennial fluctuations, and much more uniformly spread over large regions of the world than surface water. Very often groundwater is available in arid and semi-arid regions where there is no surface water. Furthermore groundwater well fields can be constructed over time and at grassroots level in response to growing demand, while hydraulic structures for surface water use often require huge financial and labour intensive investment.

The importance of groundwater is gaining recognition because this resource supplies over 1.5 billion urban dwellers with water; is more suitable for low-cost rural water supply; is increasingly being developed for both large and small scale irrigation; and is reliable in periods of drought and infrequent annual recharge. The unsaturated part of an aquifer is increasingly being used as a safe and reliable storage facility in response to demands to improve Water Harvesting Techniques.

These advantages, coupled with groundwater's comparative insulation from direct pollution, have resulted in the widespread use of groundwater as the major or even the only source of domestic water in many countries in the world. Favouring groundwater in domestic use is not only very important in arid zones, but also in many regions where surface water is abundant. For example in groundwater use exceeds 70 percent of the total water consumption in many European countries.

In arid and semi arid countries, groundwater is widely used for irrigation. About one-third of the world's landmass is irrigated by groundwater; in the USA 45 percent of cultivated land is irrigated by groundwater, while percentages for Iran, Algeria and Morocco stand at 58, 67 and 75 percent respectively. In some arid and semi-arid countries such as Libya or Tunisia, groundwater is the only traditional source of fresh water for all purposes.

Groundwater's renewability as part of the hydrological cycle is the principle difference from other mineral resources. Nonetheless groundwater is closely related to other components of the environment; any changes in atmospheric precipitation inevitably cause changes in the groundwater regime, quantity and quality. And vice versa, changes in groundwater cause changes in the environment. Thus, intensive groundwater exploitation can cause a decrease of surface water discharge, land surface subsidence and a wilting of vegetation cover.

Groundwater and its formations are vulnerable to many forms of contamination, mainly by human activities although harmful substances are sometimes introduced by natural processes. Irrational groundwater abstraction can trap brackish groundwater in deep aquifers and draw in saline seawater in coastal areas. Sustainable groundwater management must be based not only on prevention of the overexploitation of groundwater resources but also on prevention of contamination.

Groundwater pollution is usually a direct result of pollution to the environment, mainly by sulphates, chlorides, nitrogen compounds, petroleum products, phenols, iron compounds and heavy metals. Oil products and industrial wastes, for example, has caused widespread pollution, while intensive use of pesticides and fertilizers increasingly threatens many aquifers.

Groundwater pollution is a serious problem which requires a global consensus on ways to halt current trends, including a strict 'Polluter Pays' policy with effective enforcement mechanisms. Determining the limits of admissible groundwater withdrawal is however a tricky question. On the one hand there is a need to harvest as much good quality groundwater as possible while on the other there is a need to avoid extreme depletion. This question is further complicated when considering non-renewable groundwater in arid zones with limited alternative water resources.

Theoretically groundwater constitutes the bulk of the world's freshwater resources, but its actual accessibility is qualified by logistical issues of extraction. It is repeatedly reported that about 2,500 to 3,500 BCM of groundwater are annually renewable, out of which only 750-800 BCM per year are currently used (Takeuchi and Murthy, 1994). Most of the 750-800 BCM per annum of global groundwater withdrawals are used for irrigation of agricultural crops (Shah et al, 2000). During the last two decades, there has been a significant increase in the use of groundwater for irrigation particularly in India, the USA, China, Pakistan, Iran and Mexico which are reported as the largest consumers of groundwater (Poste, 1999). In these countries, farmers are pumping groundwater faster than its natural replenishment rate, causing a continuous drop in groundwater tables and depletion of the resource.

In arid and semi-arid zones groundwater plays a key role in all forms of development and it is extracted,in many countries, by deep mining of fossil water. In Libya and Saudi Arabia, for example, massive water mining schemes were developed in the 1980s and 1990s. In the Arabian Peninsula abstraction from deep aquifers has caused an alarming depletion of non-renewable groundwater aquifers but in urban areas there are equally alarming increases in the level of contaminated groundwater because of leakage from water and wastewater networks and excess irrigation.

UNESCO and other international bodies recognizes the importance of groundwater as a vital natural resource. Groundwater was a key component in the International Hydrological Programme (IHP: 1975 to date). In the Fifth Phase of IHP (1996-2001) groundwater was adopted as the principal priority of the programme, playing a prominent role in at least two of its eight themes: "Groundwater Resources at Risk" and "Integrated Water Resources Management in Arid and Semi-Arid Zones". This focus continues in the current phase of the IHP (2002-2007), which contains initiatives related to shared aquifers (ISARM), a centre for Global Groundwater Assessment (IGRAC), developing isotope hydrology techniques (JIIHP), management of groundwater in arid and semi arid zones (G-WADI), regional networks on Wadi Hydrology and Groundwater Protection in the Arab region, regional centres for training water resources management in arid and semi arid zones in Egypt and Chili, and an International Centre for Qanats and Historic Hydraulic Structures in the city of Yazd in Iran.

As with any natural resource, the *management* of groundwater involves reconciling supply with demand. This paper focuses on the capacity of ancient systems of groundwater management to adapt to changing demands in the face of both rapid growth in human demand and the shock of a natural disaster. Special attention is given to the qanats of the city of Bam and the impact of the devastating earthquake of December 2003.

DEFINITION OF QANATS

A qanat is a system of water supply consisting of an underground tunnel connected to the surface by a series of shafts which uses gravity to bring water from the water table to the surface (Fig. 1). Qanats are usually dug where there is no surface water and were originally invented by Iranians.

The main, or mother, well, is generally excavated in the mountains, penetrating deep into the water table. Water runs down a slightly sloping tunnel, gradually increasing in volume until it emerges near farms or communities. Water from qanats is brought to the surface where the soil has been enriched by sediments from alluvial fans. Cultivated land and settlement sites are situated downwards from the point where the water surfaces. The immediate outlet, *mazhar*, is the point where people take water and it is generally located in the main square of a village. The water outlet point is very important; it is well kept and cemented and water use is monitored. A tunnel, or *payab*, channels water under the residential area to the cultivated land. A sloping corridor with steps leads from the surface to the *payab*. The first *payab* is located in the main square and is used for taking drinking water. A network of smaller *payabs* runs from the main *payab*.

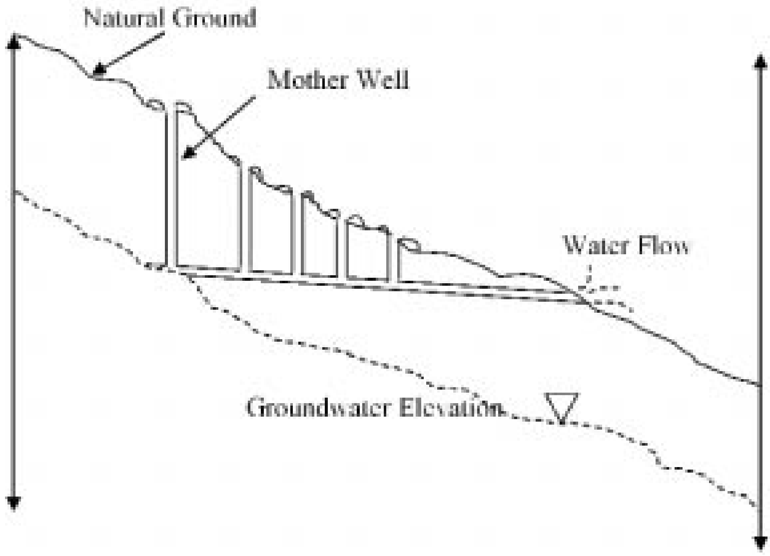

Figure 1 A Typical Qanats System

Qanats are also known as 'Karez' (Afghanistan), 'Galeria' (Spain), 'Khotara' (Morocco), 'Aflaj' (Arabian Peninsula), 'Foggara' (North Africa), 'Kanerjing' (China), 'Auon' (Saudi Arabia/Egypt), reflecting the widespread dissemination of the technology across ancient trading routes and political maps.

QANATS AND GROUNDWATER MANAGEMENT

Qanats are mostly dug in places where there is no permanent and reliable water on the surface. Techniques for digging qanats date back some 5000 years or more in Iran and the structure has tremendous social as well as practical significance. Comprehensive, integrated and multi-dimensional systems of water use were developed in many villages and towns and were regulated by customary laws, some of which were written down. Different qanats sometimes have different systems of water use for domestic consumption and for irrigation.

The following key issues are essential when using qanats as a groundwater management tool:

1) It is important to make sure that the water table is adequate to ensure permanency and sustainability of water supply as the first step in the planning phase;
2) Practical knowledge of local groundwater should be secured among local moghannis (qanat diggers). Although this is empirical and based on land formation, colour and smell of the soil and mountain rocks, natural slope of the land and specific vegetation, experience also plays an important role.
3) Modern geological techniques, Geographical Information Systems (GIS) and Remote Sensing (RS) instruments can contribute to the restoration and reconstruction of qanats. To enable people to incorporate modern scientific approaches in their traditional knowledge networks requires preparatory research, training and appropriate support.

4) The recharge process of the supplying aquifer should be known, conserved and continuously enhanced through artificial recharge if necessary. There are places where special dams were built in order to enrich the water table. The Iranian qanats of Jandaq for example, are fed by two ancient dams, one of which is claimed to be the second largest "Underground Dam" in the world, at 25m long, 1.5m wide and 7m deep.
5) In some areas of Central Iran, around Khoor, people dug wells 3-5 meters deep and 5-7m wide and filled them up with large stones found on flood beds. They directed the floodwaters to these artificial pools to enrich the water table. This ancient recharging innovation can still be used to replenish groundwater in many places.
6) Qanats can be used as an educational facility for students, technicians, professionals and researchers as well as the general public.

QANATS IN THE WORLD AND IN IRAN

Qanat technology exists in more than 34 countries in the world, but most are concentrated in present day Iran, which has about 32164 active systems with a total discharge of about nine billion cubic meters (m3) (Fig. 2). The first recorded qanats were dug in the north-western areas of Iran and date back to 800 BC (Western calendar).

Since Iran has few perennial rivers and surface water resources, many of its communities have depended on qanats for thousands of years. This unique and environmentally sustainable system has created cultural and natural ecosystems that ideally addressed the specific needs of each community. Digging qanats involves a huge amount of work and engineering skills originally developed in Iran and exported across the world.

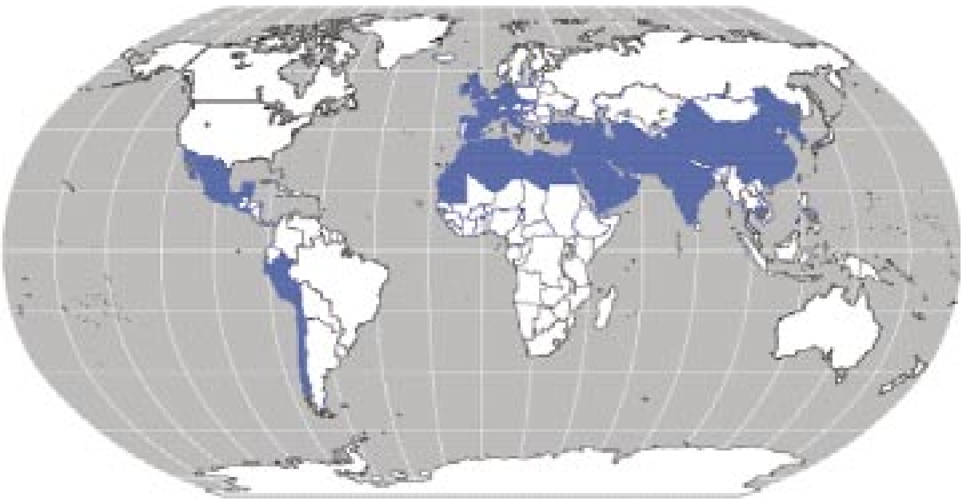

Figure 2. Distribution of Qanats in the World (Blue colour)

The qanats of Iran have a special niche in the cultural, social, economic, political and physical landscapes of the country. Without these kinds of hydraulic structures, thousands of villages and towns would not have been theme at all. Although life in Iran has changed radically over the centuries, qanats have maintained their importance and significance at the heart of community well-being and survival of many communities in that country.

QANATS OF BAM

On December 26, 2003 a powerful earthquake struck Kerman province in south-central Iran (Fig. 3), killing 26,000 people, injuring many more and almost totally destroying the historical structures of the city of Bam. The earthquake also brought world attention on the wealth of that region's hydrogeological, archaeological and geo-historical culture, which had been well known to the ancient world but forgotten in the global rush towards modernity.

Fig. 3. Location Map of Bam

Within days after the disaster a huge international relief effort was launched. At first, efforts were focused on saving lives and providing emergency services but once the situation had stabilized, attention moved to broader interventions to strengthen traumatized communities' cultural and social capacities to cope with the disaster and to rebuild the infrastructure necessary for them to re-establish their livelihoods and their lives.

Studies undertaken soon after the earthquake revealed thousands of hectares of archaeological remains; these had not been disinterred by the violent actions of the earthquake but had been scattered across the surface, abandoned for hundreds of years. Ongoing archaeological investigations reveal that the area is even more significant than had been believed when UNESCO was preparing the Bam dossier for submission to UNESCO's World Heritage Centre. The Bam area seems to contain the oldest extant qanats in Iran and perhaps in the world.

The technical advantages of the natural setting of Bam, which is located on a plain between two ranges of mountains, were progressively understood and exploited by men who played if not the leading role, at least a significant part in the process of the invention and development of qanats.

WATER RESOURCES IN BAM

According to available records 170km of semi-confined aquifer stretches across the middle areas of the Bam-Narmashir plain leading to a confined part beside a shallow unconfined aquifer (Fig. 4). The water table, in 1993-95, had been accessible at 85m in the north and 32m in the south at the inlet section and about three meters at the outlet section. This hydraulic balance is now disturbed due to the decline of the water table.

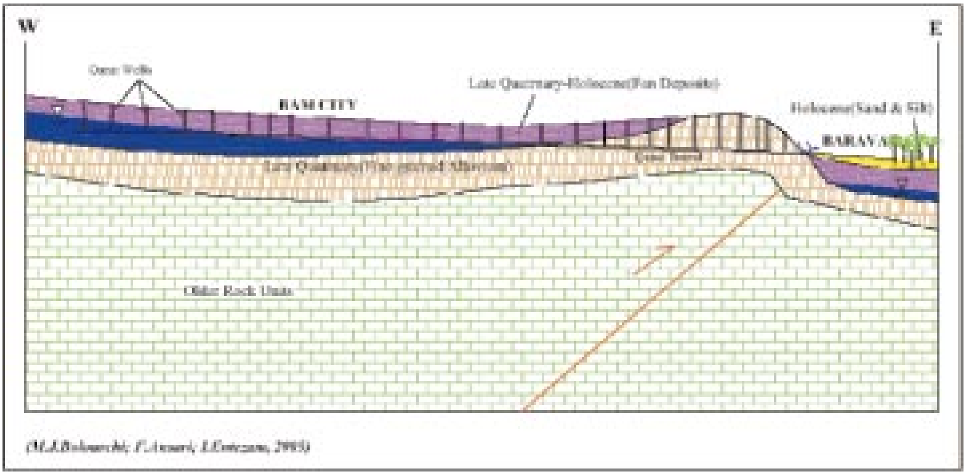

Fig. 4. Schematic Geological Cross Section of the Bam Region

Generally speaking, sediment content in the southern Bam-Narmashir basin is less than the north. The closer we get to the Barez mountains; the deeper the water table becomes. Analysis carried out in the summer of 2002 showed that the electrical conductivity (EC) of Doulat-Abad Qanat was 297 micromous/cm while the Jahr-Sadat-Abad Qanat suffered from an extreme EC value of 4,940 micromous/cm. One of the reasons for this seemed to be the movement of groundwater through different formations and the development of a steep hydraulic gradient.

Bam District is a typical desert oasis with an average annual rainfall of about 60mm; in recent years this has decreased. This means that crops and trees required irrigation, especially in the hot spring and summer months. Perennial surface water is non-existent, though there are few permanent dry riverbeds (wadis) and incidental floods during the rainy season.

The groundwater situation is quite complex. The district is surrounded by high mountains that receive precipitation, both as rain and snow, which infiltrates into the alluvial fan and recharges the aquifers overlying the impermeable, fine-grained alluvial deposits. This situation was ideal for the construction of shallow wells and qanat systems. The area has the oldest qanats of Iran and one of the greatest densities of qanats in the whole country. There are some 375 lines of old traditional qanats and 950 wells of different depths in various parts of the district, about 118 of which are in the Bam-Baravat region. The discharge rates of the qanats vary widely, mostly in the range of 50-200 $l.s^{-1}$, while discharges from those wells are in the range of 15-50 $l.s^{-1}$. These two means of exploiting groundwater provide millions of m^3 for irrigation. Water quality is generally good and water salinity is not a problem for the types of crops grown there.

The Bam Fault Scarp has helped to trap groundwater in the upper terrace, where Bam city is located, and has formed a sort of underground dam that keeps recharge water in the aquifer and contributes to the qanat systems. Recent geological studies have shown that the 2003 earthquake did not result in significant displacement of the fault scarp; therefore, it is not expected to have changed groundwater status in the area.

UNESCO'S CONTRIBUTION TO THE QANATS OF BAM

Prior to the earthquake the qanats of Bam played a major role in groundwater management and irrigation of the area, providing over 50 percent of the annual water requirement. The earthquake caused extensive damage to many parts of the qanats system.

UNESCO Tehran Cluster Office took the initiative of supporting the efforts of restoration and future management of the qanats of Bam in close collaboration with the Geological Survey of Iran, the Iranian Cultural Heritage and Tourism Organization (ICHTO), UNDP, the International Centre for Qanats and Historic Hydraulic Structures and the Ministry of Jihad-e-Agriculture. Six teams of experts were commissioned to prepare comprehensive technical reports on the current status and future prospects of the qanats of Bam from the points of view of engineering, management, culture, archaeology, geology, agriculture and socio-economic. Their results were discussed and integrated in the findings of a workshop, the goal of which was to define a holistic strategy for the repair and management of the qanats of Bam which could be seen as a pilot for other regions and countries. This forum, which was held in Bam itself, also provided an opportunity for the people of Bam to express their views and concerns.

CONCLUSION

Groundwater management, particularly in arid regions, should be viewed holistically and linked to the sustainable management of the ecosystem. Only through consideration of the interaction between the groundwater and other environmental components can it be possible to elaborate a long-term program for rational groundwater use and protection. Ancient methods of groundwater management, such as the qanats system, provide an excellent demonstration of human ingenuity to cope with water scarcity. The catastrophic earthquake of Bam has drawn the attention of researchers and professionals to a great human heritage related to the sustainable management of groundwater in arid zones and the development of a sophisticated culture of rational resource allocation.

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