Promoting a sustainable traditional technique of aquifer water acquisition common to arid lands: a case study of Ghassem Abad Qanat in Yazd Province (Iran)

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ABSTRACT

Qanats are a traditional technique used for aquifer water acquisition and irrigation in dry lands, common to the Middle East. They provide fresh water to communities of users by draining groundwater from aquifers. In Iran, authorities are reporting about 37,000 active qanats contributing about 11% of the country’s total groundwater supply. Yazd Province, located in the central part of Iran’s plateau, is among the driest regions of the country with more than one million people. It counts 3,193 known qanats with an annual discharge estimated today at about 350 million m³. Ghassem Abad qanat irrigates the agricultural lands of Ghassem Abad village in the Province of Yazd. Its water is managed by an administration headed by a mirab. This paper describes the qanat’s mechanism and provides an overview about qanats in Iran. It also promotes, through the study of Ghassem Abad qanat, the related water management system as an example of eco-friendly traditional knowledge leading to social equity and sustainability. It explains how water is distributed to stakeholders (through water shares and irrigation cycles). Nevertheless, and for its survival, the qanat of Ghassem Abad has to continuously deal with social and economic challenges. The farmlands are continuously menaced by urban expansion.

Key words | groundwater, Iran, irrigation cycle, qanats, sustainability, Yazd

INTRODUCTION

Despite the severe climatic conditions, many societies in arid regions defy their hostile environment and are able to adapt and settle in rural communities and cities. In the Middle East, societies have acquired a certain control of water. They practice agriculture by means of hydraulic works which allow them to irrigate their farms where water is very scarce. Among the spectacular hydraulic works common to these regions is the qanat.

Description and morphology of qanats

The qanat method is described by Beaumont (1971) as ‘a method for developing and supplying groundwater and consists of a gently sloping tunnel (...) which leads water by gravity flow from beneath the water table at its upper end to a ground surface outlet and irrigation canal at its lower end’ (as cited in Megdiche-Kharrat et al. 2017a). Tunnels are dug with a gradient varying from 1% to 3% till they emerge on the surface, and then continue as open-air channels (Costa 1985 as cited in Megdiche-Kharrat et al. 2017b). The cross section of the underground tunnel presents generally an elliptical shape of approximately 1.2 m height and 0.8 m width (Beaumont 1971 as cited in Megdiche-Kharrat et al. 2017a). In order to remove the spoil and to insure ventilation for diggers, a series of wells are dug then connected by the underground tunnels (Buhagiar 2007). The depth of the first well, commonly called the mother well, depends on the location of the water source; it varies from a few...
metres to over fifty metres (Megdiche-Kharrat et al. 2017b). Physically, a typical qanat has a number of different parts: the gallery or underground channel which shows two different sections, one for collecting water and the other for conveying water only; the mother well; the shaft wells; the outlet which is the first surface appearance of the underground channel; and the surface channels that distribute water to farmers (Semsar Yazdi & Labbaf Khaneiki 2013). Along their trajectory, some qanats are linked to hydraulic structures such as water reservoirs (Buhagiar 2007).

Origin and history of the system

The origin of qanats has aroused the interest of many scientists, among them, Lehmann-Haupt (1926) who worked on the Van Lake area in Turkey, Weisgerber (2003) who studied the origin of aflaj in Oman, Chauveau (2001) who conducted archaeological studies on qanats in al-Kharga oasis in Egypt, Salvini (2001) who worked on ancient hydraulic structures in Urartu, Lehmann-Haupt (1926) and Boucharlat (2003) who conducted archaeological studies on the qanats of Iran and Oman (as cited in Semsar Yazdi & Labbaf Khaneiki 2017). English (1968) states that the qanat technique originated about 2,500 years ago in the highlands of western Iran, northern Iraq and eastern Turkey. However, Costa (1983) believes that the technique was adopted first in Arabia and specifically in Oman; he assimilates the copper mining knowledge, employed in the mid-3rd millennium BC, to the one used to convey underground water.

However, some scientists, relying on qanats dating from countries other than the Middle East, hypothesize that this technique was developed simultaneously and independently in several regions of the world as an adaptation response to climate aridity (Semsar Yazdi & Labbaf Khaneiki 2017). Today, qanats exist in many places around the world which have arid and semi-arid climates: in the Middle East (such as Iran and Oman), in North Africa (Tunisia, Algeria, and Morocco), in Mediterranean Europe (mainly in Spain and Italy), in the Americas and in Asia (such as in Afghanistan, China, Korea and Japan) (Al-Ghafri et al. 2003). Despite the diversity of their geographical contexts, qanats have more or less the same mechanism. However, they are characterized by a wide variety of terminology including: aflaj in Oman, khhattara in Morocco, mkoula or ngoula in Tunisia, foggaras in Algeria and galerias in Spain. They are most recorded in Iran.

Construction techniques of qanats

Goblot (1979) describes the construction of qanats as an expertise that requires advanced knowledge in fields that we would now call scientific and technical fields. Having the required knowledge about conditions for the formation and renewal of groundwater, fixing the route of the tunnel, digging it, and deepening the wells can only be the work of professionals who devote themselves entirely to it (Goblot 1979)). In fact, qanat construction is manual work undertaken by a specialized labor force, called muqanis in Iran and bayadir in Oman, and whose techniques have not evolved much since the construction of the first galleries (Beaumont 1971). This knowledge is transmitted and disseminated through oral and empirical teaching (Goblot 1979)). According to English (1968), the professionals of Iran inherited it from the slaves and captives of the Achaemenid and Sassanid kings; they are part of a community of nomadic craftsmen, travelers, who migrate from one place to another, forming teams of 3 to 6 workers, to build the qanats and repair them in order to keep them operational (English 1968). For the maintenance of qanats, they also need to periodically clear the deposited sediments formed by minerals in the tunnels.

Traditionally, qanat practitioners focus on some indications to locate a water-bearing zone in a desert in order to construct a qanat. They look for specific signs such as some types of plants and soil or the presence of a river bed that may indicate the existence of groundwater (Semsar Yazdi & Labbaf Khaneiki 2013). After choosing an area, often near a mountain slope, they start by digging the first well; they continue digging this shaft till the water level rises, then they stop and move to digging the other wells (Semsar Yazdi & Labbaf Khaneiki 2013). By the end and from the part near the irrigation area, they start digging a long tunnel joining the bottom of the wells till they reach the deepest one, then water start to drain out (Semsar Yazdi & Labbaf Khaneiki 2013).

These skilled workers use handcrafted tools in their work, which include: a winch on the surface called a noria, a pickaxe, a bucket (traditionally, a kind of goatskin
bag) and an oil lamp (Semsar Yazdi & Labbaf Khaneiki 2012). The latter is also used to estimate the amount of air in the tunnel; when the flame starts to extinguish, the muqani leaves the tunnel and digs another well (English 1968).

The construction of a qanat can take several years or even decades. English (1968) spoke of two qanats that were built in the mid-20th century in southern Kirman (Iran): the qanat of Hujatabad village and the qanat of Javadieh village, which took 27 and 17 years to build, respectively. The construction of the Javadieh qanat began in 1941 with a team that worked by day for 17 years to bring water to the surface; in 1958, when the qanat began to flow in small quantities, its owner hired a second team to work at night to improve the performance of the qanat (English 1968). The qanat of Javadieh is 3 km long, has two branches and, in particular, two mother wells of 50 and 55 m depth respectively (English 1968). English also talked about the cost of qanat construction in Iran, which is very expensive and can vary considerably from case to case regarding the depth, the soil quality, etc., and gave an estimate of 10,000 $/km (English 1968). The qanat of Javadieh cost US$35,000 and used to irrigate about 2,000 m² every 24 hours (English 1968). Another much longer qanat in Kirman, 40 km long with a mother well depth that reaches 90 m, cost about US$213,000 when completed in 1950 (English 1968).

Qanats in Iran

Iran has a variable but, in most parts of the country, arid climate. Yearly precipitation falls mostly from October through April; its averages are around 250 mm or less except in the Zagros Mountains and Caspian coastal plain where it counts at least 500 mm (Semsar Yazdi & Labbaf Khaneiki 2012). Rainfall exceeds 1,000 mm annually in the western part of the Caspian; however, some basins of the Central Plateau, where Yazd Province is located, receive 100 mm or less of precipitation yearly (Semsar Yazdi & Labbaf Khaneiki 2012).

In 2014, Iranian authorities reported the existence of about 37,000 active qanats, distributed variously throughout the provinces of the country, with an annual discharge estimated at 7 billion m³ (Semsar Yazdi & Labbaf Khaneiki 2014). The qanat of Zarch is the longest in Iran with a total length of 80 km; the deepest is the qanat of Gonabad that reaches 500 m in depth (Semsar Yazdi & Labbaf Khaneiki 2013); and the oldest is the qanat of Ya’qoubi situated in the city of Yazd and dating back 900 years (Zade et al. 2007). An important decrease in annual water discharge from the Iranian qanats has been noticed during the last decades: from 10 billion m³ in 1992 to 8 billion m³ in 2005 to reach 7 billion m³ in 2014. Thus, the qanats contribution to the country’s total groundwater resource represents only 11% (Semsar Yazdi & Labbaf Khaneiki 2013). Since important quantities of water are being insured by deep and semi-deep wells, and natural springs (66,154 million m³ in 2005) (Semsar Yazdi & Labbaf Khaneiki 2012), a yearly groundwater level drop of 41 cm has been noticed as a direct result of the deficit in the volume of aquifer reserves (Semsar Yazdi & Labbaf Khaneiki 2013).

Ghassem Abad qanat in Yazd Province

Yazd is the fourth largest province in Iran with an area of 131,575 km², in which more than one million people live (Zade et al. 2007). Located in the central part of the Iranian plateau, the region of Yazd is among the driest in the country with annual average precipitation that varies from 48.2 mm (in Yazd) to 354.1 mm (in Mehriz) over a statistical period of 22 and 24 years, respectively, until 2014 (Semsar Yazdi & Labbaf Khaneiki 2014). Shir-Kuh Mountain, a peak over 4,000 m in altitude, plays an important role in feeding the aquifers of this region which allows the Yazd-Adrian alluvial basin to benefit from considerable water deposits (Eslamian et al. 2017).

In Yazd Province, there are 3,193 qanats; they provide 24% of the total annual discharge of the underground water in the province which counts 1,403 million m³ (2001 census) (Eslamian et al. 2017). Today, their annual discharge is estimated at about 350 million m³ (Semsar Yazdi & Labbaf Khaneiki 2015). They represent an underground network that measures 2,663.4 km (Zade et al. 2007). Ghassem Abad qanat is among the most popular qanats of Yazd Province with a total length that reaches 23.35 km (Semsar Yazdi & Labbaf Khaneiki 2014). It is named after Abol-Ghassem Rashdi who built it about 300 years ago. It is said that he was a foreign merchant met in India by some people from the village of Ghassem Abad.
the merchant’s family name, he was probably from Oman. The qanat gathers two religious communities: Muslims and Zoroastrians.

Scope and aims of the study

This study comes from a PhD research in progress about qanats as an antique groundwater acquisition system and their associated social structures and generated landscapes. The scope of this research includes Middle Eastern societies with a focus on Iranian ones. Indeed, this paper considers the rural community of the village of Ghassem Abad in Yazd Province by studying its hundreds of years’ old water supplying system. The main aims of the study are: to give an overview about the present situation of Ghassem Abad qanat; to examine the qanat’s functioning and management from equity and sustainability perspectives; and to promote, through this chosen case study, this traditional gravity-flow groundwater supplying system as an eco-friendly and sustainable technique.

METHODOLOGY

Site selection

Iran is tagged by many historians and geographers as the origin of the qanat technology. It has the largest number of systems in the world (37,000 active qanats). In the province of Yazd, there are 3,193 qanats (Semsar Yazdi & Labbaf Khaneiki 2014). Yazd city accommodates the International Center on Qanats and Historic Hydraulic Structures, ICQHS-UNESCO. The center organized, with HydroCity, a workshop on Water and the City in November 2014. The first author participated at the workshop and conducted, along with other professionals, a field research on the qanat of Ghassem Abad village.

Data collection

First, general data about qanats in Iran and some particular qanats in Yazd were collected from a literature review and presentations at the ICQHS-UNESCO. Data about Ghassem Abad qanat were collected through interviews with stakeholders and the management body, as well as site visits and investigations. All photographs are courtesy of the first author.

RESULTS AND DISCUSSION

Physical data of the qanat of Ghassem Abad

The qanat of Ghassem Abad belongs to 108 owners (Semsar Yazdi & Labbaf Khaneiki 2014). The water provided by this qanat supplies about 31 ha of farmland with a discharge estimated at 40 L/s and, through a side branch connected to the main tunnel, this system also provides water for the qanat of Rahma Abad. In its path to the village, the qanat of Ghassem Abad goes first through the funeral site in which are constructed two towers, a water reservoir and some dwellings. Figure 1 shows the towers of silence, Dakhme in Persian,
which are circular enclosures, paved with stones with a slight slope towards the centre. The Zoroastrians used to place the bodies of their deceased there in order to be eaten by vultures for the sake of recycling what they consider impure, the body without a soul, and not worthy to be in contact with the sacred (air, earth, water and fire). What was left of the remains was removed to a hole in the centre and then destroyed with a very strong acid. The government ended this practice in the 1960s. The water reservoir was constructed about 600 to 700 years back; 35 steps allow access to water from the underground cistern. The dwellings were used as housing for the guards of the funeral site. Figure 1 shows also, in the background, the southwest mountain range that includes Mount Shir-Kuh; the melting of the snow of these mountains feeds the aquifers and, consequently, the qanats of this region.

The qanat of Ghassem Abad has 750 wells (Figure 2) and, along its course, it used to operate two watermills and fill two water reservoirs, including the one in the funeral site, which are all now nonfunctional. The watermills, built under the ground below the level of the qanat’s tunnel, used the flow of the water, descending in freefall, to turn the blades and thus rotate the upper millstone and grind wheat (Figure 3). The qanat emerges first at the Zoroastrian temple, Atash Kadeh which mean fire place (Figure 4). Table 1 outlines the physical data of Ghassem Abad qanat.

Management of the qanat

Qanat construction and maintenance rely on a team of three to six experts. The karshenas supervises the work and decides where to dig; the ostad kar or muqani is the master worker, who’s job is to dig in the underground tunnel; the gelband collects soil and debris; the lashe kesh drags buckets of debris to the nearest shaft; and the charkh kesh operates the well wheel and pulley (Semsar Yazdi & Labbaf Khaneiki 2012). The majority of qanats are
managed by an administration headed by a director within a private common ownership system. In Iran, the administration structure consists of a mirab (director), a number of assistants and deputies, besides an endowment document and a notebook including all details about the irrigation rights. Being a mirab is an inherited position passed from father to son. The mirab’s duty is to distribute water among the farmers and to look after the overall system (such as setting the qanat’s budget, assisting water share transactions, solving conflicts, etc.).

The current mirab of Ghassem Abad qanat is Mr Hamid Gholami, aged 43 years old (in November 2014). For generations and upon stakeholders’ recommendations, the Gholami family insured the management of the qanat; thus, Mr Hamid inherited this knowledge from his father. He asserts that being a mirab represents a hard responsibility with no income except two water shares per day. About 20 years ago the owning community of the qanat used to pay the mirab but nowadays the qanat is suffering from many problems including its low water discharge that can drop to 7 L/s.

**Water distribution system and diverse stakeholders**

The community has free access to drinking water; people can get their supplies directly through arranged access points to underground channels or from the water reservoirs installed on the qanat’s trajectories. Water for irrigation is distributed to stakeholders regarding the number of shares each one owns. For the majority of qanats, this number depends on the size of the owned lands irrigated by the qanat and/or their contribution to its construction (Al-Ghafari et al. 2003 as cited in Megdiche-Kharrat et al. 2017a). Water shares can be rented or sold. They are distributed on a time basis regarding an irrigation cycle that varies from one qanat to another. Farmers used to estimate their shares by a water clepsydra or through a complex sundial system in daytime; at nighttime, specifically in Northern Oman, farmers used a star system (Megdiche-Kharrat et al. 2017a). Nowadays, farmers use the modern watch to get their water rights.

The qanat of Ghassem Abad belongs to 108 owners and gathers communities of Muslims and Zoroastrians. Its water is divided into 1,560 shares owned as follows: 1,220 (80%) for Muslims and 340 (20%) for Zoroastrians. The share unit is locally called a jorreh, which is about 11 minutes and which correspond to a time unit measured by the water clepsydra commonly used in Yazd (Semsar Yazdi & Labbaf Khaneiki 2014). The irrigation cycle is 12 days, with each day named after the one who owns the most shares that day; an irrigation day is divided into eight sections and counts 130 shares in total (Table 2).

**Problems faced by the qanat of Ghassem Abad**

The qanat of Ghassem Abad faces several problems, particularly the following:

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical data of the qanat of Ghassem Abad in Yazd (Iran)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Ghassem Abad</td>
</tr>
<tr>
<td>Founder</td>
<td>Hajj Abol-Ghassem Rashdi</td>
</tr>
<tr>
<td>Age</td>
<td>300 years</td>
</tr>
<tr>
<td>Location</td>
<td>Southern Yazd city</td>
</tr>
<tr>
<td>Geographical context</td>
<td>Plain</td>
</tr>
<tr>
<td>Main supply region</td>
<td>Village of Ghassem-Abad</td>
</tr>
<tr>
<td>Mother well depth</td>
<td>114 m</td>
</tr>
<tr>
<td>Qanat total length</td>
<td>23.35 km</td>
</tr>
<tr>
<td>Tunnel length</td>
<td>17.43 km</td>
</tr>
<tr>
<td>Side branches Length</td>
<td>5.95 km</td>
</tr>
<tr>
<td>Number of shafts</td>
<td>750 (deteriorate to fair condition)</td>
</tr>
<tr>
<td>Number of underground derivations</td>
<td>2 (1 side branch for water supply to the qanat; 1 divider for supplying another qanat – Rahmat Abad qanat)</td>
</tr>
<tr>
<td>Location of first surface emergence of the tunnel</td>
<td>Zoroastrian temple (Atash Kadeh) of Ghassem Abad</td>
</tr>
<tr>
<td>Number of watermills</td>
<td>2 (non functional, one in good condition – National Heritage listed – and the other in a deteriorated condition)</td>
</tr>
<tr>
<td>Number of water reservoirs</td>
<td>2 (non functional, one in good condition – touristic site – and the other in a deteriorated condition)</td>
</tr>
<tr>
<td>Total farmland area</td>
<td>31 ha</td>
</tr>
<tr>
<td>Qanat discharge:</td>
<td></td>
</tr>
<tr>
<td>In 1998</td>
<td>40 L/s</td>
</tr>
<tr>
<td>In 2014</td>
<td>20 L/s</td>
</tr>
</tbody>
</table>

Source: Data collected from field work, interviews and adapted from Semsar Yazdi & Labbaf Khaneiki (2014).
Table 2  |  Water distribution system of the qanat of Ghassem Abad

<table>
<thead>
<tr>
<th>Type</th>
<th>Irrigation cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period of irrigation cycle</td>
<td>12 days (for 1,560 shares)</td>
</tr>
<tr>
<td>Share duration (joreh)</td>
<td>11 min 15 s</td>
</tr>
</tbody>
</table>

Source: Data collected from interviews and adapted from Semsar Yazdi & Labbaf Khaneiki (2014).

- A decrease in the qanat water discharge (from 40 L/s to 20 L/s over the past 16 years). Farmers complain about a shortage of water for irrigation mainly due to the lowering of the water table after successive droughts and overexploitation by means of pumped wells, both deep and semi-deep wells. In 2005, the whole country counted 163,812 wells with a total discharge of 44,894 million m³ (Semsar Yazdi & Labbaf Khaneiki 2014).

- Illegal qanat water exploitation: some owners installed pumping devices to increase the water amount of their shares.

- Today, the irrigation cycle dramatically moved from 12 days to 6 days for an important decrease in the area of the agricultural lands.

- Ghassem Abad farmlands are menaced by urban sprawl (poor production therefore low farming incomes, in addition to increasing land pricing for housing).

- Fair management and maintenance of the qanat's ground tunnels and shafts: it involves hard manual labor that needs much experience, with difficult access to the tunnel due to the shafts' bad condition or complete destruction, and with low incomes, etc.

- Prohibited access for the administration body to the part of the qanat passing through the Yazd University campus.

- Some shafts disappeared under the new urban area, thus a new replacement branch of the tunnel was constructed to ensure the functioning of the qanat.

- Youth disinterest which makes expertise in the field hardly transmittable through the generations.

### Qanat and equity

The free access to fresh water from the qanat for all community leads to social equity. Also, the income of Ghassem Abad qanat supports charity actions independently of ethnic and religious belonging. The administrating body (mirab, assistants and deputies) of the qanat distributes water shares fairly among farmers regarding ownership of land and water (separate ownerships). The manager of the qanat is also a farmer; he receives, as a wage, two water shares per day. This insures his direct involvement and commitment to the good functioning of the qanat. However, the traditional methods for measuring the time allocated to the shares may lead to some inaccuracy in water allocation.

### Qanat and sustainability

The Brundtland Report defined sustainable development as ‘development which meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED 1987 cited in Eslamian et al. 2017). Thus, water resource projects are considered sustainable only if they ensure sufficient quantities and standardized qualities of water at acceptable prices, capable to meet the demands of the region in the present and in the future (Eslamian et al. 2017). Furthermore, qanats came in to existence some thousands of years ago; they operate within a socio-economic system that has guaranteed their sustainability, hence their survival till the present day: ‘they still exist because they are sustainable’ (Labbaf Khaneiki 2015). This proves also that qanats are capable to adapt to climate change (Eslamian et al. 2017).
Water flows in qanats naturally by gravity due to a very low gradient that does not exceed 3%, its rate depending on the groundwater’s natural flow, thus, preventing the tapped aquifer from overexploitation (Eslamian et al. 2017). Qanat technology is considered sustainable compared to unsustainable deep well technology (Eslamian et al. 2015). Indeed, it is known for being in balance with groundwater reserves and offers a water usage adapted to environmental conditions, besides the role it plays in human settlement development in dry regions. The qanat system ensures a perfect harmony between farming and the local climate. It guarantees sustainable solutions for overcoming drought. As technical solutions, owners extend the gallery by digging back into the aquifer and farmers adjust their water usage by readapting the area of their cultivated lands and the types of crops. As management solution, to some extent, they update the irrigation cycle (rotation) regarding seasons and environmental conditions. For example, when the volume of the water provided by a qanat decreases considerably because of drought and in order to ensure the irrigation of every corner of the cultivated areas, each farmer receives twice his usual share but once every two rotations (Semsar Yazdi & Labbaf Khaneiki 2012).

Also, because of the traditional techniques of construction, maintenance and management that rely mainly on manpower, qanat systems cause no pollution. Also, the qanat is able to produce green energy. But its major limitation is that it is expensive to build and produces relatively small amounts of water (Eslamian et al. 2015).

CONCLUSIONS

Groundwater resources are being overexploited in many areas around the world to meet increasing demand due to population growth combined with expansion in agricultural activity, especially those relying on irrigation; this results in several consequences including the permanent deterioration of the aquifer system and its associated environmental impact such as land subsidence and water quality decline (Eslamian et al. 2017). Moreover, to meet the growing demand for water, societies in the Middle East have tended to abandon their traditional and sustainable water supply systems, such as qanats, in favor of more productive modern systems (Eslamian et al. 2017), which is not without consequences on both the environment and society itself. Indeed, qanats are sustainable and environment-friendly gravity-flow water supply systems common to arid and semi-arid regions; their management as a private common ownership system has already built, from indigenous knowledge and over years of practice, the integrity of the water resource, as well as the integrity of people and related institutions (Megdiche-Kharrat et al. 2017a).

The qanat system ensures, to a high extent, equity in access to water for multi-stakeholders. It also maintains life-sustaining ecosystems and has ensured energy, and continues providing food for growing generations where water is a very scarce resource. Within the context of a global water crisis and inequity in access to fresh water among communities worldwide, qanats, in their various forms, must be taken as successful solutions to learn from. They must be protected, reconsidered and revived as clever groundwater acquisition and fair social management solutions that ensure a sustainable usage of the resource (Megdiche-Kharrat et al. 2017b).

Already, in some Middle Eastern countries such as Iran and Oman, some qanats and aflaj are classified as national and world heritage monuments. Many actions are conducted by governments and organizations to protect this heritage; but, still much effort is needed to raise awareness among people and local communities about the importance of these systems and to safeguard and implement this knowledge which is the result of years of practice and expertise in facing the challenges of modernization. The qanat involves not only the physical system, but also a cultural frame and a social lifestyle very compatible with local environments.

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