Sustainable Water Utilization in Arid Region of Iran by Qanats

F. Boustani

Abstract**—**To make use of the limited amounts of water in arid region, the Iranians developed man-made underground water channels called qanats (kanats) .In fact, qanats may be considered as the first long-distance water transfer system. Qanats are an ancient water transfer system found in arid regions wherein groundwater from mountainous areas, aquifers and sometimes from rivers, was brought to points of re-emergence such as an oasis, through one or more underground tunnels. The tunnels, many of which were kilometers in length, had designed for slopes to provide gravitational flow. The tunnels allowed water to drain out to the surface by gravity to supply water to lower and flatter agricultural land.

Qanats have been an ancient, sustainable system facilitating the harvesting of water for centuries in Iran, and more than 35 additional countries of the world such as India, Arabia, Egypt, North Africa, Spain and even to New world.

There are about 22000 qanats in Iran with 274000 kilometers of underground conduits all built by manual labor. The amount of water of the usable qanats of Iran produce is altogether 750 to 1000 cubic meter per second. The longest chain of qanat is situated in Gonabad region in Khorasan province. It is 70 kilometers long. Qanats are renewable water supply systems that have sustained agricultural settlement on the Iranian plateau for millennia. The great advantages of Qanats are no evaporation during transit, little seepage , no raising of the water- table and no pollution in the area surrounding the conduits. Qanat systems have a profound influence on the lives of the water users in Iran, and conform to Iran's climate. Qanat allows those living in a desert environment adjacent to a mountain watershed to create a large oasis in an otherwise stark environment.

This paper explains qanats structure designs, their history, objectives causing their creation, construction materials, locations and their importance in different times, as well as their present sustainable role in Iran.

Keywords**—**Iran, qanat, Sustainable water utilization.

I. Introduction

IRAN is a country in the Middle East, and the country covers a total area of 1.65 million km2 and a population of about 70 millions in 2007 estimate. The average annual rainfall is 250 mm and approximately 90% of the country is arid or semiarid. Overall, about two-thirds of the country receives less than 250 mm of rainfall per year [1].

The rainy period in most of the country is from November to May. In the dry period between May and October, rain is rare in most of the country. In other words, it seems that the temporal and spatial distribution of precipitation in Iran is volatile, as 90% of total precipitation occurs in cold and humid seasons and in northern and western parts of the country and only 10% occurs in warm and dry seasons and in central, southern and eastern parts. In many localities of Iran, there is no rainfall until sudden storms, accompanied by heavy rains, dump almost an entire year's rainfall in a few days. These torrential rains cause floods and local damages. One of the critical concerns of Iran is the evaporation and acute transpiration of surface water under solar radiation.

Water is an essential component of Iran's history and the success of its economy moving forward [2]. There is evidence of old hydraulic structures dating back thousands of years. To make use of the limited amounts of water, the Iranians developed man-made underground water channels called qanats. A qanat is a water management system used to provide a reliable supply of water to human settlements or for irrigation in hot, arid and semi-arid climates.

Fardin Boustani is Assistant Professor of Water Resources Engineering Department of Islamic Azad University, Marvdasht Branch, Marvdasht, Iran (e-mail: fardinboustani@gmail.com).

II. Evaluation of Qanats in Iran

The qanat system consists of underground channels that convey water from aquifers in highlands to the surface at lower levels by gravity. The qanat technology was used most extensively in areas with the following characteristics [3]:

- An absence of larger rivers with year-round flows sufficient to support irrigation.
- Proximity of potentially fertile areas to precipitation-rich mountains or mountain ranges.
- Arid climate with its high surface evaporation rates so that surface reservoirs and canals would result in high losses
- An aquifer at the potentially fertile area which is too deep for convenient use of simple wells.

A. Qanat Components

The following list shows the main components of a qanat:

Appearance: The place where water comes into view on the surface is called the appearance.

Gallery: The canal whose section resembles a horseshoe inside the ground enjoying a gentle slope for water conveyance from the aquifer to the appearance.

Dry zone: A Portion of the gallery between the wet zone and the appearance. This canal is gradually cut deeper due to the decline of the water table.

Wet zone: It is referred to the infiltrating walls inside the gallery of a Qanat. The discharge rate is directly dependent upon the wet zone.

Shaft: The dry wells situated across the gallery in order to facilitate soil extraction as well as ventilation and dredging. The distance between two shafts was based on the depth of the qanat and the air passage. The nearer the shafts were to the mother well, the deeper they were.
Mother well: The farthest water infiltrating well is called mother well.

B. History of Qanats

Henry Gubler believes that around 800 BC coal miners in north eastern Iran improvised some canals in order to extract the water from the coal mines. The technology was gradually applied by farmers and spread all over the plateau of Iran. About 525 BC[4] it reached Oman and Saudi Arabia by Iranians and Persian campaigns conveyed this technology through Egypt about 500 BC. Qanat was introduced to Africans by Muslims and Yafuga (a Qanat) was created in Madrid by Muslims about 750 BC. The Spanish initiated qanats in Mexico in 1520 AD. From there, it was taken to Los Angeles in 1520 AD. This Hydraulic system was spotted in Chile, too. Creation of qanats in Asia enjoys great antiquity as well.

C. Geographical Distribution of Qanats in Iran

There are about 22,000 qauats in Iran although their number has diminished as the time passed and meanwhile it is due to a consequence of digging deep wells. There is still a considerable number of qanats in Iran, which are still in use. These qanats is about 274000 km long.

Qanats are stretched all over Iran country, particularly the arid and semi-arid zones. The provinces benefiting from qanats are as follows:

1) The Province of Yazd

Yazd, in the centre of Iran, relies extensively on qanat water due to its average annual rainfall of 60 mm and lack of permanent rivers Semsar etal [5]. Shirkoh mountain water deposits feed the aquifers, with adequate potential resources so that the Yazd-Adrian alluvial basin benefits from considerable water deposits. Consumption of underground water delivered by the qanats has been the only method for centuries because Yazd is an ancient city [6].

Qanats more than 1000 years old are still active. Yazd Province is proud that it still has numerous running qanats, particularly the mountainous ones. According to the census in 2001, there are 3091 qanats with an annual discharge of 339 million m^3 in Yazd. According to the total discharge of the underground water of the province, 1403 million m^3, some 24% comes from qanats [5], the rest being supplied by deep and semi-deep wells and springs.

2) The Province of Semnan

Shah-rud qanat is considerable due to its discharge in this province which exceeds 250 liters per second with a mother well enjoying 60 meters of depth. It is to be notified that this qanat is the only source of water in the town.

3) The Province of Khorasan

Bidokht and Saleh Abbad are the two well-known active qanats in Gonabad. Bidokht enjoys a mother well depth of 350 m. with a discharge of 150 liters per second irrigating 150 Hectares of the agricultural lands. Keikhosro is another qanat in Gonabad with 400 m. depth of the mother well according to Mr. Saed-lu. Mr. kurus believes that the biggest qanat gallery in Gonabad is 70 kms long. This is probably the one with a mother well depth of 140 meters according to Mr. saad-lu. It is believed that the sanabad qanat in Mashhad is 1200 years old and dates back to pre-Islamic-era.

4) The Province of Kerman

There is no unanimity regarding the longest qanat in kerman. For instance, Hashu-eieh located in Baghein (31 kms long with 22 liters discharge) is the longest qanat according to the authorities of the regional water organization. Mr. Safi-Nejad believes that the kerman qanat which is 40 km long with the depth of 120 m. of the mother well and 20 liters discharge per second is considerable. Mr. Petroshevski has recorded the Mahan qanat 50 km and Dr. Bastani- parizi believes that there is a qanat in kerman which is about 42 km long with a mother- well enjoying 145 meters of depth. The most splendid qanat of the province is called pa-ye-kam on the outskirts of Bam with a length of 4600 meters 4000 of which is the wet zone. The mother well is 47 meters deep. In Bam and Narmashir, Rashidi qanat in Barvat and Fazl-Abbad dates back to Rashid-Al-Din Fazlolah's Children and Gardun qanat precedes Mongols. Chupar is another qanat dating back to Annahita.

5) The province of West Azarbayjan

The longest qanat of Bostan – Abbad is Dagh – Cheshmeh located in a village named Estyar. It is 8000 m. long and its mother well is 20 meters deep. Vakil & Cheshmeh Armanistan Qanats are the longest ones in Azar shahr. They both enjoy a length of 6000 m. and the mother wells are 15 & 30 meters deep respectively. The deepest recorded mother well of the region (115 m) belongs to Hassan Abbad and Bareh-khuni of Mamaghan. Kalantar Qanat in Tabriz and is more than 10000 meters long.

D. Qanat Construction

Traditionally qanats are built by a group of skilled laborers, muqannīs, with hand labor. The profession historically paid well and was typically handed down from father to son. The critical, initial step in qanat construction is identification of an appropriate water source. The search begins at the point where the alluvial fan meets the mountains or foothills; water is more abundant in the mountains because of orographic lifting and excavation in the alluvial fan is relatively easy. The muqannis follow the track of the main water courses coming from the mountains or foothills to identify evidence of subsurface water such as deep-rooted vegetation or seasonal seeps. A trial well is then dug to determine the location of the water table and determine whether a sufficient flow is available to justify construction. If these prerequisites are met, then the route is laid out aboveground [3].

Equipment must be assembled. The equipment is straightforward: containers (usually leather bags), ropes, reels to raise the container to the surface at the shaft head, hatchets and shovels for excavation, lights, spirit levels or plumb bobs and string. Depending upon the soil type, qanat liners (usually fired clay hoops) may also be required.

Although the construction methods are simple, the construction of a qanat requires a detailed understanding of subterranean geology and a degree of engineering sophistication. The gradient of the qanat must be carefully controlled too shallow a gradient yields no flow too steep a gradient will result in excessive erosion, collapsing the qanat. And misreading the soil conditions leads to collapses which at best require extensive rework and at worst, can be fatal for the crew [3].

Construction of a qanat is usually performed by a crew of 3-4 muqannīs. For a shallow qanat, one worker typically digs the horizontal shaft, one raises the excavated earth from the shaft and one distributes the excavated earth at the top.

The crew typically begins from the destination to which the water will be delivered into the soil and works toward the source (the test well). Vertical shafts are excavated along the route, separated at a distance of 20-35 m. The separation of the shafts is a balance between the amount of work required to excavate them and the amount of effort required to excavate the space between them, as well as the ultimate maintenance effort. In general, the shallower the qanat, the closer the vertical shafts. If the qanat is long, excavation may begin from both ends at once. Tributary channels are sometimes also constructed to supplement the water flow[3].

The qanat's water-carrying channel is 50-100 cm wide and 90-150 cm high. The channel must have a sufficient downward slope that water flows easily. However the downward gradient must not be so great as to create conditions under which the water transitions between supercritical andsubcritical flow ; if this occurs, the waves which are established result in severe erosion and can damage or destroy the qanat. In shorter qanats the downward gradient varies between 1:1000 and 1:1500, while in longer qanats it may be almost horizontal. Such precision is routinely obtained with a spirit level and string.

E. *Maintenance*

Qanat routes need to be regularly cleaned and maintained: They are subject to damage and destruction by flash floods. To prevent shafts from being filled with sand, they are covered by stone slabs or other objects. Moqannies carry castor-oil lamps to test the ventilation underground. If the air does not keep the flame alight another shaft is sunk. They clear the deposited sediments formed by minerals at the bottom of the aqueducts.

III. Goals of Construction of Qanats

The main goals of constructing qanats have been to provide hygienic drinking water and irrigation for agriculture. The availability of water has resulted in prosperity both socially and economically. The purposes of qanats include:

1-to supply fresh water to arid zones;

2-to allow the population to live in desert areas (e.g. Kavirs);

3-to allow the development of saline and alkaline lands;

4-to harmonize population distribution in arid and semi-arid zones;

5-to water storage by Ab Anbar

An Abanbar is a traditional qanat fed reservoir for drinking water in Persian antiquity.

6- to Cooling in desert climate

Qanats used in conjunction with a wind tower can provide cooling as well as a water supply. A wind tower is a chimney-like structure positioned above the house to catch the prevailing wind. The tower catches the wind, driving a hot, dry breeze into the house; the flow of the incoming air is then directed across the vertical shaft from the qanat. The air flow across the vertical shaft opening creates a lower pressure and draws cool air up from the qanat tunnel, mixing with it. The air from the qanat was drawn into the tunnel at some distance away and is cooled both by contact with the cool tunnel walls/water and by the giving up latent heat of evaporation as water evaporates into the air stream. In dry desert climates this can result in a greater than 15°C reduction in the air temperature coming from the qanat; the mixed air still feels dry, so the basement is cool and only comfortably moist (not damp). Wind tower and qanat cooling have been used in desert climates for over 1000 years.

7- to ice storage

In 400 BC Persian engineers had already mastered the technique of storing ice in the middle of summer in the desert. The ice was brought in during the winters from nearby mountains in large quantities, and stored in specially designed, naturally cooled refrigerators called Yakhchal (meaning ice pits). A large underground space with thick insulated walls was connected to a qanat, and a system of windcatchers was used to draw cool subterranean air up from the qanat to maintain temperatures inside the space at low levels, even during hot summer days. As a result, the ice melted slowly and ice was available year-round.

8-to drive underground water mills

In cases where the gradient is steeper, underground waterfalls may be constructed with appropriate design features (usually linings) to absorb the energy with minimal erosion. In some cases the water power has been harnessed to drive underground mills.

There are significant advantages to a qanat water delivery system including: Allows water to be transported long distances in hot dry climates without losing a large proportion of the source water to seepage and evaporation. Qanats are constructed as a series of well like vertical shafts connected by gently sloping tunnels. This technique:Taps into a subterranean water in a manner that efficiently delivers large quantities of water to the surface without need for pumping.

The water drains relying on gravity, with the destination lower than the source, which is typically an upland aquifer.

The rate of flow of water in a qanat is controlled by the level of the underground water table. Thus a qanat cannot cause significant drawdown in an aquifer because its flow varies directly with the subsurface water supply. When properly maintained, a qanat is a sustainable system that provides water indefinitely.

IV. Conclusion

The United Nations and other organizations are encouraging the revitalization of traditional water harvesting and supply technologies in arid areas because they feel it is important for sustainable water utilization. A qanat is a gently sloping subterranean conduit, which taps a water-bearing zone at a higher elevation than cultivated lands. A qanat is a water management system used to provide a reliable supply of water to human settlements or for irrigation in hot, arid and semi-arid climates and allow the population to live in desert area.

A qanat system has a profound influence on the lives of the water users. It allows those living in a desert environment adjacent to a mountain watershed to create a large oasis in an otherwise stark environment.

The advantages of transporting water underground in qanat system are obvious Qanats are subterranean tunnels that tap the groundwater and lead the water entirely by Gravity. As the qanats are often d ug into hard subsoil and, when necessary, lined with relatively impermeable clay hoops, there is little seepage, no raising of the water-table, no water logging, no evaporation during transit .The rate of flow of water in a qanat is controlled by the level of the underground water table .It exploits groundwater as a renewable resource.

Thus qanats are environmentally sustainable water harvesting and conveyance techniques trough which groundwater can be obtained without causing damage to the tapped aquifer in the arid regions of Iran.

References

[1] Chavoshian, S.A., An overview to trans boundary and shared water resources management in Iran, technical challenges and solutions. Proc. of the Int. Conf. on Role of Water Sciences in Trans boundary River Basin Management, Thailand, pp. 189 195, 2005.

[2] Boustani, F.,Role of water in ancient civilization in Iran. Proc. of Int. Conf. on water culture and water environment protection, China, pp.69 72, 2005.

[3] www.waterhistory.org

[4] www.en.wikipedia.org/wiki/Qanat

[5] Semsar, Y. A. and Tafti, M., An analysis of the actual situation of qanats of Yazd city. Proc. of Int. Conf. in qanats, Iran ,pp 78 96,2000.

[6] Motiee,H. al., Assessment of the contributions of traditional qanats in sustainable water resources managemen. International Journal of Water Resources Development, 22(4) (December 2006), pp. 575 588, 2006.