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Qanat, traditional irrigation infrastructure system in Iran

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ABSTRACT

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. To make a qanat, one needs a source of water, which may be a real well, but can also be an underground reservoir (e.g., a cave with a lake) or a water-bearing geological layer, which can be recognized as a damp area in an otherwise arid region. When one has identified this source, a tunnel is cut to the farm or village that needs the water. Shafts are added for three reasons: as air supply, to remove sand and dirt, and to prevent the tunnels from becoming dangerously long. The shafts are not very far apart, and as a result, a qanat seen from the air gives the impression of a long, straight line of holes in the ground - as if the land has been subjected to a bombing run. Typically, the qanat becomes a ditch near its destination; in other words, the water is brought to the surface by leading it out of the slope. In fact, one creates an artificial artesian well and an oasis. 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. 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.

Introduction

Average rainfall in Iran (With 250 mm) is less than one-third of the global average annual rainfall and similar to that of arid and semi-arid countries of the world. 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. The Iranian plateau is largely desert. Most of Iran (excepting areas in the northwestern provinces and along the southern shores of the Caspian Sea) receives only six to 10 inches of rainfall a year. Other regions of the world with so little rainfall (for example the dry heart of Australia) are barren of attempts at agriculture.

Water is an essential component of Iran's history and the success of its economy moving forward [1]. 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 (Fig.1). 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. The first step is to find a water source and to dig a well (Fig.2) until the water is reached. Sometimes wells are over 20 meters deep. The next step is to protect the walls of the well by inserting cement rings, one on top of the other, to ensure its stability and durability. There are significant advantages to a qanat water delivery system including: (1) putting the majority of the channel underground reduces water loss from seepage and evaporation; (2) since the system is fed entirely by gravity, the need for pumps is eliminated; and (3) it exploits groundwater as a renewable resource. The third benefit warrants additional discussion tunnel connected to the surface by aseries of shafts which uses gravity to bring water from the water table to the surface. Qanats areusually dug where there is no surface water and were originally invented by Iranians.

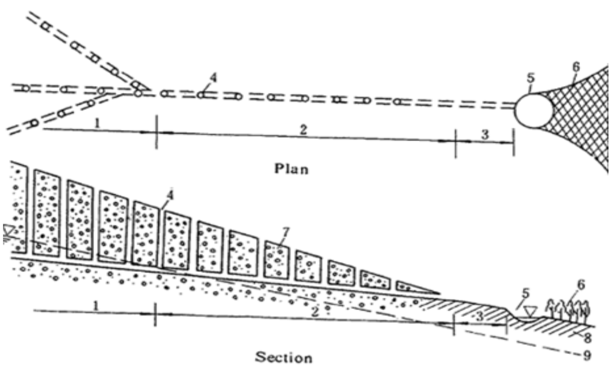

Fig 1. General Schematic for a Qanat. (1) Infiltration part of the tunnel,(2) Water onveyance part of the tunne,(3) Open channel,(4) Vertical shafts,(5) Small storage pond (6) Irrigation area,(7) Sand and gravel,(8) Layers of soil,(9) Groundwater surface

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Fig 2. Qanats & Water Wells. A anat is a system of water supply consisting of an underground

The qanat technology (Fig.3) is known to have been developed by Iranians sometime in the early 1st millennium BC spread from there slowly west- and eastward [2] and their use spread to India, Arabia, Egypt, North Africa, Spain and even to the New World. They are referred to by different names in different areas: in Afghanistan and Pakistan, they are known as *karezes*; in North Africa, as *foggaras*; and in the United Arab Emirates, as *falaj* [3]. What is astonishing is the number and length of these qanats. There are some 22,000 of them in Iran, comprising more than 170,000 miles of underground channels. [4] Equally astonishing, much of that network is still functioning, sometimes thousands of years after the channels were originally built. Indeed, until recently, qanats still supplied 75 percent of the water used in Iran, for both irrigation and household purposes. Most of the area that qanats serve to irrigate is arid and rainless. Without an effective and sustainable form of irrigation, such as is provided by the qanats, agriculture in those regions would have been impossible. For that reason, one cannot over-estimate the important role the qanats have played in Iran. To quote H. E. Wulff, :

… They have made a garden of what otherwise would have become an uninhabitable desert [5].

The value of a qanat is directly related to the quality, volume and regularity of the water flow. Much of the population of Iran and other arid countries in Asia and North Africa historically depended upon the water from qanats; the areas of population corresponded closely to the areas where qanats are possible. Although a qanat was expensive to construct, its long-term value to the community, and therefore to the group who invested in building and maintaining it, was substantial [6].

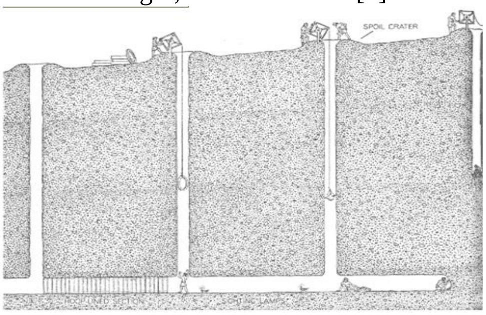

Fig 3. Qanats are ancient water supply systems constructed using a simple technology

Qanats were an important factor in determining where people lived (Fig.4). The largest towns were still located at low elevations on the floors of intermontane basins and in broad river valleys. Most of these early settlements were defended by a fortress and watered by hand-dug wells sunk into a shallow water table. *Qanats* enabled these settlements to grow by tapping water-rich aquifers located deep beneath neighboring alluvial fans. Qanats provide ecosystem goods and services such as water, staples, fruits and vegetable; and promote social cohesion through participation and cultural rituals. Qanat irrigated agriculture is threatened by silt sedimentation in canals, moving sand dunes, urban migration of youth, and decline of experts for managing such systems. There is a need to find approaches to maintaining these systems including their agro-biodiversity on a sustainable basis. There is a need to assess the policy, institutional and economic dimensions of qanat irrigation with reference to agro-biodiversity maintenance in the dry zones.

There are more than 27 terms for Qanat, being used in these countries:

“ Qanat” and “Kariz” in Iran, “ Falaj” pl “Aflaj” in Oman, “Kariz” or “Karez” in Afghanistan, Pakistan, Azerbaijan and Turkmenistan, “ Ain” in Saudi Arabia, “Kahriz” in Iraq, “ Kanerjing” in China, “ Foggara” in Algeria, “Khattara” or “Khettara” and “ Rhettara” in Morocco, “Galleria” in the Spain, “ Qanat Romoni” in Syria and Jordan, “Foggara” and “Khettara” and “Iffeli” in North Africa, “Galerias” in the Canary Islands, “ Mambo” in Japan, “Inguttati” in Sicily. Some other terms used for qanats are: Ghundat, Kona, Kunut, Kanat, Khad, Koniat, Khriga, Fokkara, etc.

Fig 4. Qanats in Abarkoh Basin. Iran

History and Origin Of Qanat

Qanats first appeared in the mountains of Kurdistan in western Iran, eastern Turkey, and northern Iraq more than 2,500 years ago in association with early mining in that region. Several factors explain this origin. Most importantly, perhaps, this region is one of the oldest mining and metallurgical centers in the Middle East. The need to dig tunnels in the search for minerals meant that the inhabitants of the region had mastered the basic technology necessary for *qanat* construction. *Qanats* differ little from the horizontal adits dug into hillsides by early miners. Indeed, these adits may well have been sloped to drain unwanted seepage as they are today. Additionally, and somewhat ironically, the earliest report of a *qanat* system is chronicled on a tablet narrating the destruction of the *qanats* which provided water to the city of Ulhu (modern Ula), located at the northwestern end of Lake Urmia by Sargon II in 714 BC [7]. Soon thereafter, Assyrian cities, particularly those located on the upper Tigris River, relied on *qanats* for drinking water. Somewhat later, the capital city of the Medes, Ecbatana (modern Hamadan) was watered by qanats as was Darius’s capital city of Persepolis [8,9].

Under the Achaemenids (550–331 BC), when Persian rule extended from the Indus to the Nile, *qanat* technology spread well beyond the confines of the Iranian Plateau. The Achaemenid rulers provided a major incentive for *qanat* construction by allowing *qanat* builders and their heirs to retain profits from newly-built *qanats* for five generations. As a result, thousands of new settlements were established and others expanded. To the west, *qanats* were constructed from Mesopotamia to the shores of the Mediterranean as well as southward into parts of Egypt and Arabia. They were particularly important sources of water in the foothills of eastern Iraq, the Syrian Desert, and the Hadhramaut. In the Yemen and in Oman, *qanats* are locally called *falaj* (plural: *aflaj*). To the east of Iran, where they are generally known by the Persian term *kariz*, *qanats* came into use in Afghanistan, the Silk Road oases settlements of Central Asia, and the Chinese province of Sinkiang (now Xinjiang), although whether this diffusion occurred under the Achaemenids or some later Persian dynasty is uncertain. Strangely, in the Turfan Basin, which has one of the most extensive *qanat* systems in the world, it is possible that many of the *qanats* were built by imported Turki laborers in the 1700s [10].

The expansion of Islam initiated a second major diffusion of *qanat* technology. The early Arab invasions spread *qanats* across North Africa into Spain, Cyprus, and the Canary Islands. In most of North Africa, they were called *fughara*, and were built and maintained by a specialized caste of black slaves. In Morocco, *qanats* were referred to as *khittara* (or *rhettara*). *Qanat* use was especially intense in three areas of the Maghrib: on the borders of the Tademait Plateau just south of the Great Western Erg in central Algeria; on the northern slopes of the Atlas Mountains of Morocco, particularly near the city of Marrakech; and south of the Atlas in the Tafilalt of Morocco [11,12]. Interestingly, *qanat* technology may have been introduced into the central Sahara and later into Western Sahara by Jews or Judaized Berbers fleeing Cyrenaica during Trajan's persecution in AD 118 [13]. In Spain, *qanats* were used marginally in the province of Catalonia and at Madrid where they were called *gálerias* [14].They are important sources of water in Cyprus and on Gran Canaria and Tenerife in the Canary islands [15]. New World *qanats* are found in Mexico at Parrás, Canyon Huasteca, Tecamenchalco, and Tehuacán and in the Atacama regions of Peru and Chile at Nazca and Pica. The *qanat* systems of Mexico came into use after the Spanish conquest; those of the Atacama, however, may predate the Spanish entry into the New World [16,17].

Sustainable Structure of Qanat

The methods used for qanat building in Iran today are not greatly different from the system devised thousands of years ago [18]. The building project begins with a careful survey of the land. A qanat system is usually duf in the slope of a mountain or hillside. The qanat include some wells and one gallery with slope less than earth surface which drainage water from saturation layer or river or wetland by gravity. (Figures 5,6) shows all parts of qanat [19].The qanat becomes a ditch near its destination. The qanats depths reaches 30 m (the record is about 60m) and can cover distances of many km (the longest Iranian qanat is 70 km long.). A qanat, once built, can exist for a long time, but agriculture with qanats is extremely labor-intensive. Not only is it difficult to dig an underground canal, but it also needs a visit every spring to clean it out. Here, some of important elements of qanat were presented and was demonstrated by (Figures 5,6). 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.

Exit point of the Qanat:

Where the tunnel and the ground surface eventually intersect is the exit point of the Qanat which is called the "*Mazhar*" meaning where water appears.

Farm: the farm is a cultivated area which is less elevated than the exit point of the Qanat, irrigated by the water coming out of the Qanat. The extent of the cultivated area depends on several factors such as the Qanat discharge, soil quality, soil permeability, local climatic conditions, etc. If the water flowing from the Qanat is insufficient, the water is stored in a pool to increase the volume and head of water so that it can be delivered to the land at a higher flow rate and thus irrigate the farms. The irrigation cycle differs from area to area but is usually between 12 and 15 days. It should be noted that an irrigation cycle is a water management order according to which the shareholders take turns irrigating their farms. For example, if the irrigation cycle is 12 days, every farmer has the right to take his share just once every 12 days.

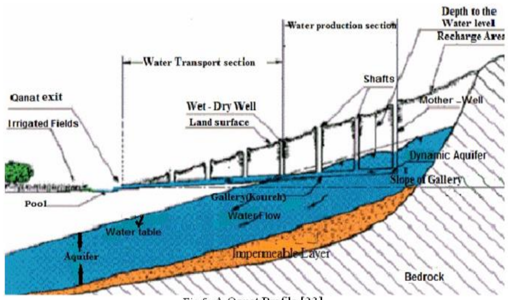

Fig.5. A Qanat Profile [23].

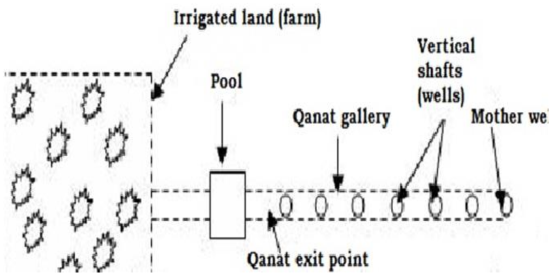

Fig 6. A Qanat Plan

Qanatoperation(Technical Features)

Qanats found in arid regions where in groundwater from mountainous areas, alluvial fan (Fig.7) 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.

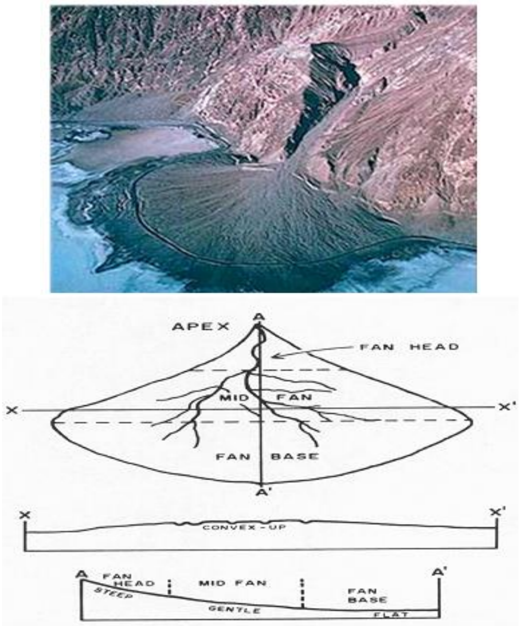

Fig 7. The geomorphology and facies association of the alluvial fans mainly controlled the position and discharge of the aquifers. Alluvial megafan, which provide the best water resources for long-profile Qanats, are very sensitive areas to discharge of aquifers. Mountain front, small alluvial fans (less than 6 km in fan radius, an example from Death Valley an example from Central Iran).

Qanats are constructed as a series of well-like vertical shafts, connected by gently sloping tunnels. Qanats tap into 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. Qanats allow water to be transported over long distances in hot dry climates without losing a large proportion of the water to seepage and evaporation. It is very common in the construction of a qanat for the water source to be found below ground at the foot of a range of foothills of mountains, where the water table is closest to the surface. From this point, the slope of the qanat is maintained closer to level than the surface above, until the water finally flows out of the qanat above ground. To reach an aquifer, qanats must often extend for long distances. Qanats are sometimes split into an underground distribution network of smaller canals called kariz. Like qanats, these smaller canals were below ground to avoid contamination. In some cases water from a qanat is stored in a reservoir, typically storing night flow for daytime use.

An Ab Anbar is an example of a traditional qanat fed reservoir for drinking water in Persian antiquity. The qanat technology is used most extensively in areas with the following characteristics:

- 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.

The great advantages of transporting water underground in this way are obvious. As the qanats are often dug into hard subsoil and, when necessary, lined with relatively impermeable clay hoops, there is little seepage, no raising of the water-table, no waterlogging, no evaporation during transit – and hence no salinisation or alkalisation in the area surrounding the conduits. Nor do they provide a niche for the vectors that transmit the water-borne diseases that so seriously affect the population of areas irrigated by modern technological means. What is particularly important, as Pazwash points out in *Civil Engineering*, is that the discharge from qanats *"is fixed by nature"*. [20] They can only provide water produced naturally by a spring in a mountain area and then transport it by the force of gravity. As a result, the aquifer is not depleted and the quality of its water is maintained. By contrast, the amount of water extracted in a modern irrigation system by pumps and other technological means "is determined by man, who, in a modern economy, will be under pressure to extract the maximum amount possible, thereby depleting the aquifer and reducing the quality of the water." [21]. Gunter Garbrecht, Chairman of the Working Party on History of the International Commission for Irrigation and Drainage, makes the same point. Qanats "tap the groundwater potential only up to, and never beyond, the limits of natural replenishment and, as a consequence, do not unbalance the hydrological and ecological equilibrium of the region. " [22]. 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

Conclusion

In the early part of the first millennium B.C., Persians started constructing elaborate tunnel systems called *qanats* for extracting groundwater in the dry mountain basins of present-day Iran. *Qanat* tunnels were hand-dug, just large enough to fit the person doing the digging. Along the length of a qanat, which can be several kilometers, vertical shafts were sunk at intervals of 20 to 30 meters to remove excavated material and to provide ventilation and access for repairs. The main qanat tunnel sloped gently down from pre-mountainous alluvial fans to an outlet at a village. From there, canals would distribute water to fields for irrigation. These amazing structures allowed Persian farmers to succeed despite long dry periods when there was no surface water to be had. 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 semiarid 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 .Many *qanats* are still in use stretching from China on the east to Morocco on the west, and even to the Americas.

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