

The Tragedy of Ancient Qanats in Arid Lands and Kavir Borders, A Case Study from Abarkoh Plain, Central Iran

Nasser Arzani

Geology Department, University of Payame-Nour, P.O.Box: 81465-617, Esfahan, IRAN

e-mail: arzan2@yahoo.com

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Abstract

The scarcity of water in arid lands highlights the importance of qanats, whereas in the populated areas of the Kavir borders, groundwater utilization by deep tube wells stresses and gradually dries out the ancient qanats. This case study is from the history and fate of ancient qanats in Abarkoh Plain, where is located in the western part of the Gavkhoni-Abarkoh-Sirjan depression in central Iran. The studied area is a large Quaternary alluvial fan (more than 35 km long and 20 km wide) in the western border of Abarkoh depression, which terminates into a playa lake in the center of this depression. The reason for the drying up of ancient qanats has been studies based on the rock-facies analysis of the exposed geology and 1400 recently drilled samples from 94 shallow and deepwater wells. The Abarkoh qanats are constructed in the proximal to mid-fan deposits of the alluvial fans. The tube wells are also scattered in this area and in the distal part of the alluvial fans, where they grade into the playa lake sediments. The complex distribution of the basin-fill deposits (alluvial fan to playa sediments) mainly controlled the position, water discharge and quality of the aquifers. The recoverable groundwater is also within the karstified, coral-algal limestones of the Qom Formation, which occurs as shallow to deep, confined and unconfined aquifers under the mid-fan sediments. The relation between the depth of qanats (mother wells and galleries) and adjacent, recently drilled, deep tube wells, controlled their competition in water discharge. Drop in water tables, not only dried most of the qanats, but also changed the quality of water, due to the penetration of the salty water of the playa lake to the upper-hand aquifers.

This study highlights the contrast between the use of deepwater tube wells and the life of ancient qanats. The greatest effort and achievement in ground-water utilization by ancient people in arid lands and Kavir borders is under threat. This needs to be considered carefully because the level of underground water table in Kavir borders (salt-flat apron) and its effect on desertification is a well-known fact.

Keywords: *Qanats, Alluvial fan, Karst, Salt-flat, Abarkoh plain, Central Iran*

Introduction

The qanat (karez) systems, as a great achievement in groundwater utilization in arid lands and Kavir borders, were probably used first more than 2500 years ago in Iran (Papoli & Labaf, 2000; Bouayad, 2002; Mir Abolqasemi, 1998; Wulff, 1986). Qanat, which was devised to tap groundwater through gravity flow, includes a mother well and a series of vertical shafts connected by a gently sloping tunnel. The vertical shafts, which are up to 100 m deep, decrease in depth toward the appearance of the underground tunnel to the surface. A qanat can measure from several hundred meters to more than 100 kilometers.

The study area is located in central Iran and between $52^{\circ}, 40'$ to $53^{\circ}, 40'$ longitudes, and $30^{\circ}, 41'$ to $31^{\circ}, 30'$ north latitudes. The Abarkoh City, with about forty thousand population, is 140 km west of Yazd Province and its history comes back to *Silk Road*, passing by this city to Persopolis in Shiraz (Fig. 1).

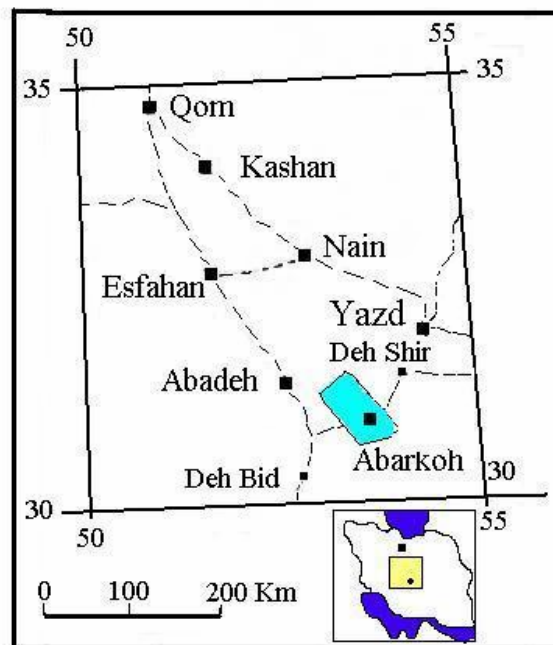


Fig. 1

Figure 1- Location map of the studied area.

The geographic position of the Abarkoh Plain comprises the western part of Ghavkhoni-Abarkoh-Sirjan depression, bounded by the Dehshir highlands in the east and Hambast Mountains in the west (Fig. 2 & 3). A large alluvial fan (about 35 km long and 20 km wide) originating and cross-cutting the Hambast range and with a gradual change in slope reaches the playa lake in the middle to eastern part of Abarkoh depression.

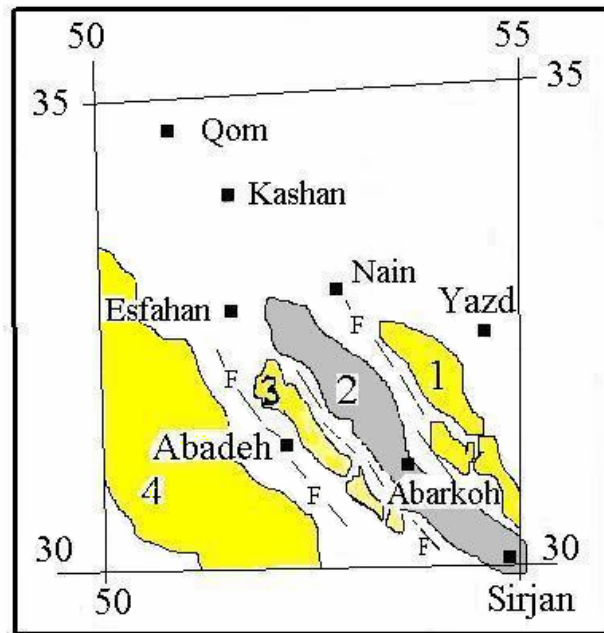


Figure 2- Ghavkhoni-Abarkoh-Sirjan depression in Central Iran.

1- Deh Shir Mountains and fault in the east of Abarkoh depression. 2- Abarkoh depression. 3- Hambast Mountains and Abadeh fault in the east of Abarkoh depression. 4- Zagross mountains (see Amidi, *et al.*, 1983, Geological map of Abadeh , 1/250000 sheet, Geol. Soc. Iran).

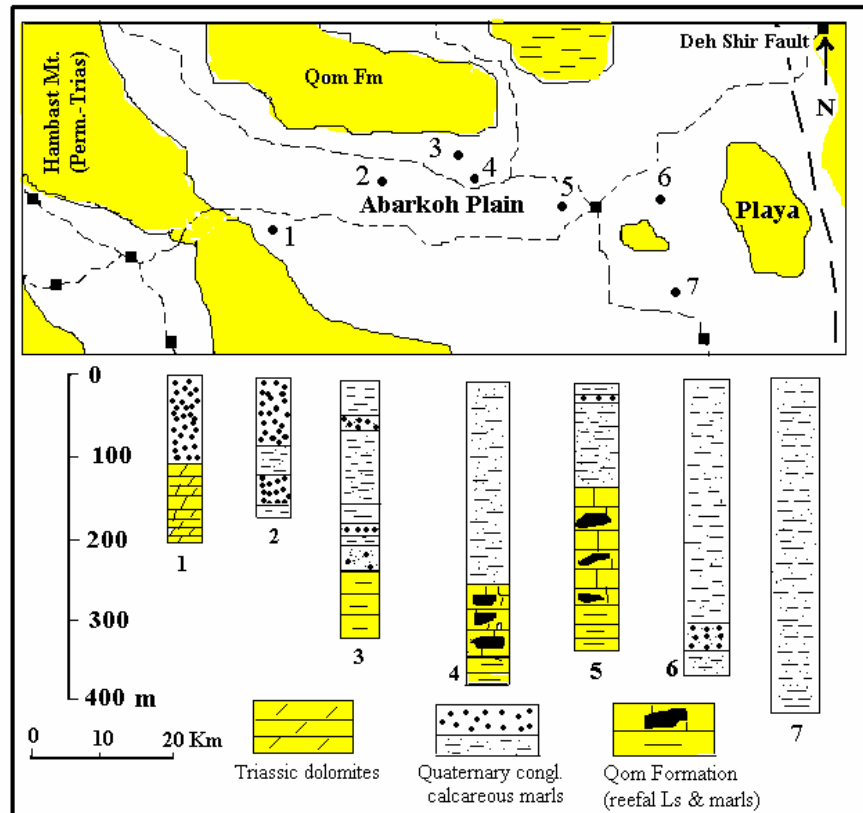


Fig. 3

Figure 3 - The general geology and sedimentological logs of the selected drilled wells in Abarkoh Plain. Well numbers 1 to 7 are from the proximal to distal part of the alluvial fan. Karstic limestones of the Qom Formation are under the alluvial fan sediments in the middle of the fan (see text for details).

In Abarkoh Plain, ground water is found in the Quaternary basin-fill, alluvial fan sediments as well as in the shallow to deep buried, karstified limestones of Qom Formation. The latter are whitish-cram coral-algal limestones (Bozorgnia, 1966; Stocklin, 1977).

Qanats, as an efficient method for the control between the amount of run off and underground water budget in arid lands and Kavir borders,

have long been constructed with an extremely labor-intensive, as well as, an enormous capital cost. Unfortunately, this has been overlooked by the replacement of tube wells and dug wells. Groundwater utilization by deep wells resulted in gradual drying of qanats due to the unbalanced water budget of aquifers and their discharge. The geographic position of the Abarkoh Plain, which is located in the western border of Kavir, emphasizes the importance of water resources management in this area. The mean annual rainfall of the Abarkoh Plain is about 50 mm and qanats, as a traditional technology in water use, is of crucial importance for sustainable water utilization in such an arid climate. It would be a great pity if the qanats system, which stands out as an impressive example of a determined and hardworking peoples achievement and an underground irrigation system, which is in harmony with the environment, is allow to fall into drying (Fig. 4).

The production of a drainage system would rely on many geological, as well as hydrological factors. This study emphasizes the importance of geology, especially, rock facies, structural and paleogeographic controls on the type of aquifers and as the result, understanding and predicting the ways which may restore the life of ancient qanats in Kavir borders.

Geomorphologic controls

The Abarkoh drainage basin, with about 5500 Km² in area, is located in the eastern part of the Gavkhoni-Abarkoh-Sirjan depression and is bounded by highlands. The Abarkoh Plain (about 700 km² in area) is in the west to middle of the drainage basin and is covered by a large Quaternary alluvial fan. This fan originates and crosscut the Permian-Trias highlands (Hambast range) in the west. It gradually changes in slope, over a horizontal distance about 35 km, until it reaches the Abarkoh Playa Lake in the center of Abarkoh depression (Fig. 3). The apex of this alluvial fan is 1600 m above sea level, whereas the lowest part of the playa is about 1440 m above sea level. This geomorphology controls the drainage from the highlands in the west and toward the lower part of the Abarkoh plain. The slope of the water tables in the Abadeh and Eghlid Plains (about 9000 km² in area) are also partially toward the east and as the result, they interconnect to Abarkoh Plain,

through a valley called *Ghashar* (30 km west of Abarkoh). Here is the apex of the alluvial fan, where the valley is floored with very coarse alluvium, deposited by passing floods.

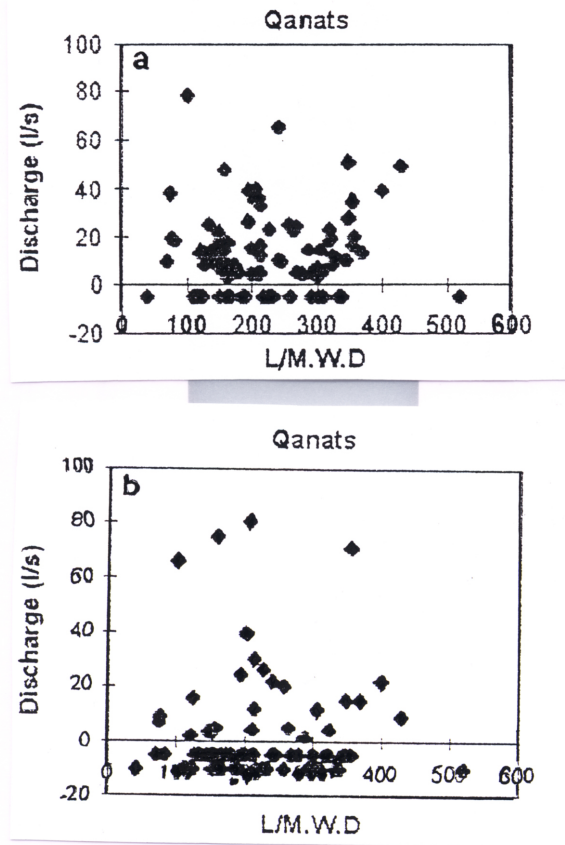


Figure 4- Water discharges (lit/sec.) versus the ratio between the length (L) and mother well depth (M.W.D) of the qanats in the Abarkoh Plain. The negative discharge represents those qanats, which have been dried out during 1972-1980 (a) and 1971-1997 (b).

Rock-Facies Controls

In the west of Abarkoh Plain, the basin-fill sediments, which are up to 100 m thick, comprise the coarse conglomerates of the proximal alluvial fan and rest on the sharply dipping Permian-Triassic limestones

and dolomites (Fig. 5). The proximal fan sediment grade into the calcareous marls with crosscutting channel-fill to flood-sheets sandstones to conglomerates of the medial fan. They rest on the whitish, coral-algal limestones and or green marls of the Qom Formation. In the middle to eastern part of Abarkoh depression, the mid-fan sediments laterally change into the thick calcareous marls and single channel fill sandstones to conglomerates of the distal part of this fan. They in turn grade laterally into the thick (up to 500 m) playa lake sediments (Fig. 3). The source of sediments of the Abarkoh alluvial fan is not only from the highlands bordering the west of the Abarkoh Plain, but also originates, mainly, from the neighboring plains of Abadeh and Eghlid in the west. The gravelly to muddy mixtures of carbonates and argillaceous sediments were transported from such a large drainage basin to the Abarkoh basin. Periodic flash floods carried even coarse gravelly grain over a large distance and toward the distal part of the Abarkoh alluvial fan.

The exposed gravel or conglomerate beds of the latest Quaternary alluvial fan of Abarkoh is characterized by the gray, sorted, stratified lobes of the cross-bedded sediments in the proximal fan to the very sorted sediments of the channels in the mid to lower fan (Fig. 5). The gravelly grains are almost Permian-Triassic limestones and dolomites. These polymictic conglomerates are carbonate cemented. Unsorted, not stratified, gray tabulate bodies, which are limited in extent, are also present in the proximal fan sediments. The detrital matrix of this ortho- to matrix-supported, paraconglomerate is almost composed of carbonate grains. They typify periodic debris flow, which are common in some fans (Miall, 1996; Reading, 1996). Toward the mid fan and about 10 km from the apex, the conglomerate layers (up to 10 m thick) are enclosed in the thick (up to 40 m), calcareous marls. They also replaced laterally by sandy deposits (or sandstones) to very coarse silts. Conglomerates are also present in deep subsurface in the some part of the distal part of the fan, where it reaches the mud to salt flats of the Abarkoh Playa Lake (Fig. 3). The coarsening upward sequences, which are very common in many proximal alluvial fan basin-fill



Figure 5- Field photographs of the alluvial fan sediments of the Abarkoh Plain. (a) The apex of the alluvial fan and the valley (called *Ghashar*) floored with the gravelly sediments. The Permian-Trias highland is to the north. (b) The cross-bedded conglomerates of the middle to upper part of the distal fan. (c) The conglomerates of the lower proximal to middle fan.

(d) The conglomerate layer rests on the calcareous marls of the distal fan (30 km from the apex) (see text for details).

sediments, are not present. However, the fining or coarsening of grains toward the upper parts of the single lobes in the proximal fan or in the enclosed conglomerates within the marls of the middle to distal fan is present. The distal-fan sediments comprise yellowish calcareous marls up to 400 m thick. The rounded carbonate pebbles (up to 3 cm in size) are also scattered in these marls. These are Permian-Triassic carbonate fragments. The studied alluvial fan is a braided plain type (classification of Golloway & Hobday (1996)) which grades downward into the meandering channels and flood plains (Figs. 6). The large drainage basin, which fed the Abarkoh alluvial fan, transported the sediments by periodic flash floods. Sediments in alluvial fans are transported in three ways: stream flow, debris flow, and mudflow. In arid regions, the most significant stream flow occurs in flash floods (Miall, 1996; Reading, 1996).

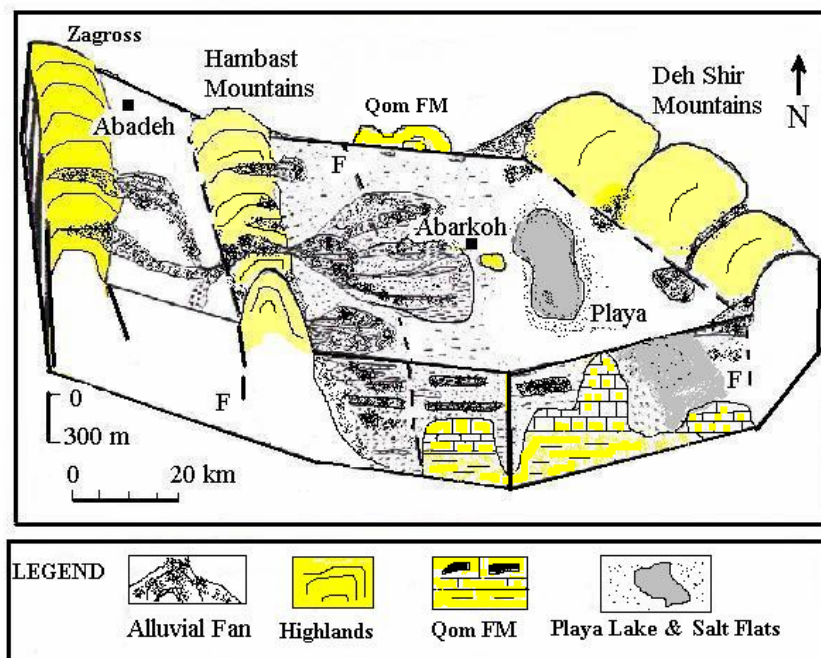


Figure 6- The sketch model of the distribution of the sub-surface sediments in Abarkoh Plain (see fig. 3 and based on the study of surface geology and 1400 sediment samples from 94 drilled wells).

The vast area combined with the gentle slope and rock-facies change of the main alluvial fan of Abarkoh, provided the ideal condition for water to be tapped from the alluvial fan deposits to the qanats and/or tube wells. Six major aquifers are present in the Abarkoh Plain (Table 1). Four of these aquifers are within the proximal to distal parts of the Abarkoh alluvial fan. Qanats either constructed in upper parts of the alluvial fan (in highlands, aquifers type 1 in table 1) or middle fan (lowlands and toward the center of the depression, aquifers type 2 in table 1). Qanats in highlands are mostly created through very coarse alluvium (gravels or carbonate-cemented conglomerates). They have a shallow (less than 30 meter) mother well and a short tunnel (less than 1000 meter). These types of qanats were mostly stable and active through time and the competition of lowering of water tables by new dug wells were not so straggling. At least, those qanats located near the apex of the main alluvial fan have this history. On the other hand, those qanats constructed in lowlands, with more than 10 kilometer in tunnel length, were passing through different rock facies (coarse alluvium to fine-grained, calcareous marls) and were subtle to lowering of water tables (Fig. 4).

Recently drilled shallow and deep wells (up to 400 m deep) in the middle to distal part of the alluvial fan, passed down the alluvium and reached the karstified carbonate aquifers (aquifers type 5 & 6 in table 1). These water reservoirs comprise coral-algal, limestone of Qom Formation, which is exposed in the area and confined underground between the green marls of Qom Formation (below) and Quaternary, yellowish calcareous marls on top. The water temperature of deep confined aquifers is different from those of the shallow wells. However, water samples analysis of deep karst aquifers shows similar elemental concentration to samples from shallow wells (Table 1). It is concluded that fresh water may have percolated down deep and retained through fractures and faults forming confined aquifers. These aquifers were probably a major source and feeding point for some qanats, which water pumping from recent deep wells certainly drop their water level and dries some qanats.

Structural controls

The inherent morphology of an alluvial fan results in a predictable distribution of recharge, lateral flow, and discharge zones in the shallow, unconfined to moderately confined fan aquifer gravels and/or sands. This has been complicated with the displacement (faulting) of the rock facies, corresponding to the different parts of the alluvial fan or the underlying bedrocks. The east-west trending faults, which cut the Permian-Trias highlands in west of Abarkoh depression, conducted

the underground waters from the Abadeh and Eghlid Plains to the lower Abarkoh Plain.

Gravels and sands (deposits of the upper part of the fan or the channel-filled sediments), which are permeable and have the highest recharge, are displaced and enclosed with the impermeable calcareous marls of the flood plain sediments. This brings about many perched and/or locally confined flow aquifers. This is complicated in the middle to distal fan sediments, especially near the Abarkoh City, where the karstified limestones underlay the impermeable alluvial fan, marly facies (Fig. 3, 6; Table 1).

Competition of qanats and tube wells

More than 103 qanats with about 270 Km of tunnels, which were active since 1971 in Abarkoh, are presently seen as less than 19 qanats (total annul discharge of about 17 Mm³). Meanwhile, the number of shallow and deep tube wells and dug wells increased from less than 150 to more than 850. The bloom of the usage of shallow and deep (more than 200 m deep) dug wells, especially in 1980,s soon abandoned most of the lowland qanats. The qanats, whose mother wells were in the north plain of Abarkoh, were most affected. Here the interaction of structural controls (such as faults), combined with the type of Quaternary, basin-fill deposits, highly stressed the life of qanats and their competition with the new deep tube wells. The presence of shallow and deep perched and confined aquifers added to the history, so that, after not more than a few years (1998-2002) more than 10 long qanats dried out. Not only the qanats are abandoned, because of the fall in water table, but also some of deepwater wells are fallen in disuse. The latter is because most of the deep wells belong to poor farmers and they have not enough money to invest. The problem is more severe in the lower part of the main alluvial fan, where the salt flat of the playa begins after the city of Abarkoh (15-25 km toward east). The fall in the water table and the penetration of the salty water of playa changed the quality of utilized groundwater (Table 1). This affected the irrigated lands and also corroded the metallic pump tubes. Unfortunately, this brought along a real crisis in water resources and the distribution of cultivated lands, so that, the green belt, against

Kavir advancement, is gradually missing. Rural population is decreasing and villages get empty. These hints may call attention for the revitalizing traditional technology and/or keep a balance between the new and old methods of water harvesting in arid lands and Kavir borders.

Conclusions

- 1- Qanats can not compete in water discharge with the deep tube wells. More than 103 qanats with about 270 Km of tunnel, which were active since 1971 in the Abarkoh Plain are presently active as less than 19 qanats. They replaced by tube and dug wells, the number of which increased to 850.
- 2- The drop in the water tables dried most of the qanats, as well as replaced the shallow wells with deep tube wells (about 400 meter deep). Aquifers in the distal fan were highly affected by this drop and as the result the greenbelt in front of the Kavir broken-up into local points and enhanced the Kavir advancement.
- 3- The geomorphology and facies association of the alluvial fan mainly controlled the position and discharge of the aquifers. The studied alluvial fan is braided plain type, the extent, lateral and vertical facies change of which, shows flash flood sedimentation.
- 4- The common flash-flood sedimentation, the rare occurrence of the mass-flow (debris flow) and especially the presence of the carbonate pebbles scattered in the distal marly facies of the Abarkoh Plain, indicate sedimentation in an arid climate.

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