Extracting Electricity from Groundwater Flow; A New Environment Friendly Source of Energy Case Study: Iran

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Abstract- **In Iran, extracting energy from groundwater flow was an ancient technical tradition which unfortunately has been abolished in the wake of the advent of modern means of power generating. The subterranean irrigational canals called Qanat in Persia made it possible to build many watermills rotating with the force of groundwater. Qanat is a gently sloping subterranean canal, which tap a water-bearing zone at a higher elevation than cultivated lands. At present there exist some 32000 active qanats running all over Iran, discharging about 9 billion cubic meters groundwater a year. The head of water in a qanat canal with a discharge of 80 liters per second is such that the flow can spin a millstone weighing over 800 kilos, in a traditional way in which the friction is so high. In this paper we depict the possibility of replacing the abandoned traditional watermills with the modern optimized turbines to generate electricity in an environment friendly way. The qanat holding countries like Iran, Oman, Afghanistan, China and Iraq can consider the qanat system a new source of energy, which not only can supply water to the rural communities but also can provide them with cheap, renewable and clean electricity. In closing, we describe some considerable initiatives taken in Iran to make use of the groundwater flow in the qanat canals to generate electricity.**

I. WHAT IS QANAT?

Qanat is a gently sloping tunnel which drains the groundwater from aquifer and leads it to the surface by using gravity flow conditions. In fact Qanat benefits from the differences between earth surface elevations to convey water from upstream aquifer to the earth surface down slope. To function this way, Qanat enjoys a number of vertical shafts, a subterranean canal and an appearance. In other words, A qanat is a combination of some shaft wells and a horizontal tunnel with a gentle slope (less than surface gradient) being able to collect the seepage of groundwater and drain it out to the down slop lands.

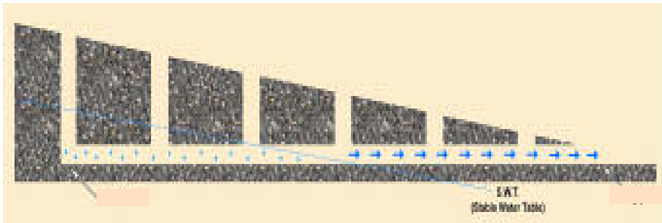
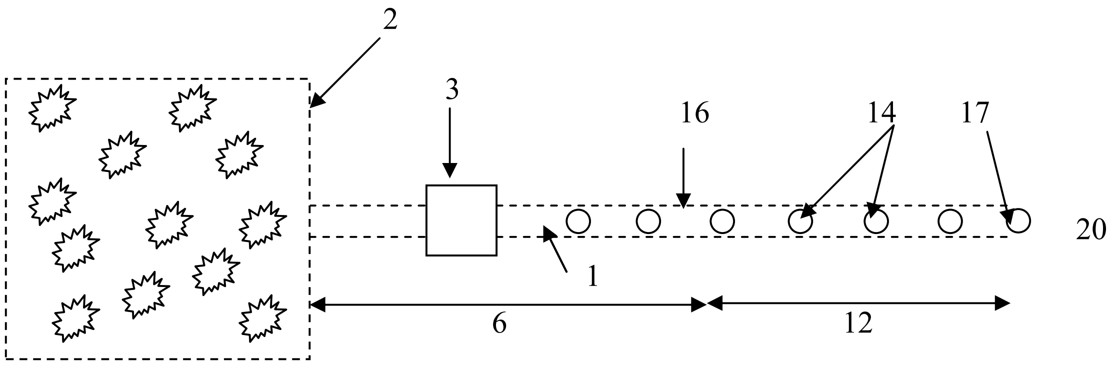


Figure 1. Longitudinal section of qanat

Therefore, qanat can be considered a groundwater drainage system that conveys the build up of groundwater to be used for drinking or irrigation. As shown in the picture below, a qanat is made up by two main sections; water production section and water transport section. That part of the qanat gallery which runs through water bearing zone is called water production section whose function is to collect the seepage. This water is transferred to the earth surface through water transport section which runs through dry zone.

II. QANAT BUILDING AND QANAT DIAGRAM

As it has mentioned, qanat is an underground gallery that conveys water from an aquifer or a water source to lower-elevation irrigated fields. In practice, a qanat consists of a series of vertical shafts in sloping ground, interconnected at the bottom by a tunnel with a gradient gentler than that of the ground. The first shaft is usually sunk into an alluvial fan to a level below the groundwater table. Shafts are sunk at intervals of 20 to 200 meters in a line between the groundwater recharge zone and the irrigated land. From the air, a qanat system looks like a line of anthills leading from the foothills across the desert to the greenery of an irrigated settlement.
The different parts of a typical Qanat are shown in the figure below, described as follows:



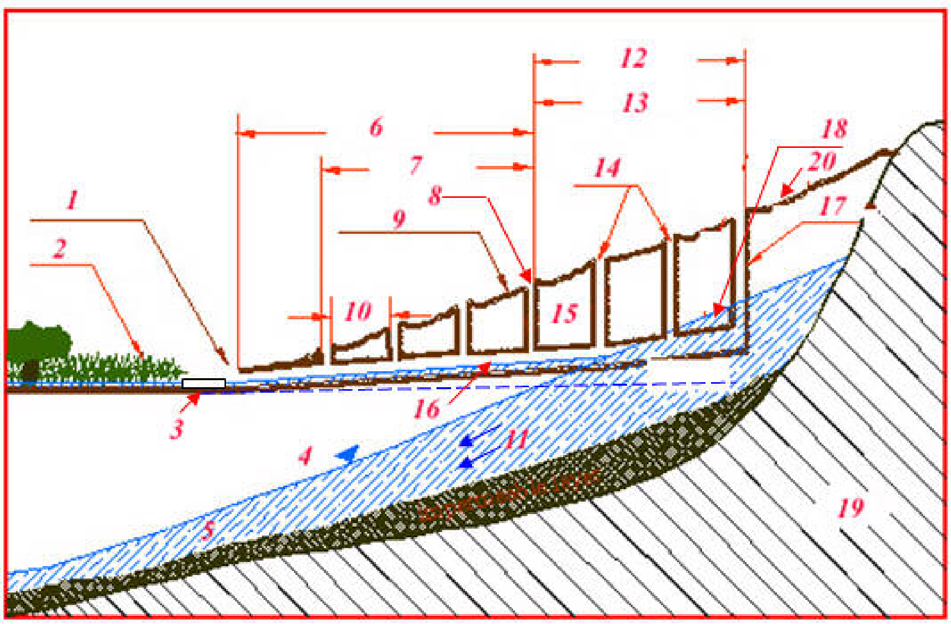


Figure 2. Qanat Diagram

1- Qanat exit point	11- Ground water flow direction
2- Irrigated land (farm)	12- Water production section
3- Pool	13- Yielding wells
4- Water table	14- Vertical shafts (wells)
5- Aquifer	15- Permeable layer
6- Water transport section	16- Qanat gallery
7- Dry wells	17- Mother well
8- Transition zone	18- Dynamic water table
9- Ground surface	19- Rock bed
10- Well distance	20- Infiltration zone

III. QANAT GALLERY

The Qanat gallery or tunnel is called in Persian "*Rahrow*" or "*Kooreh*", which is an almost horizontal tunnel dug to get access to groundwater reserve, and to transfer this water to the earth surface. The dimensions of the tunnel are taken to be such that the workers can easily go through and work in it. This tunnel is between 1.0 and 1.5 meters high, and its width is less than half the height. The tunnel and surface gradient is crucial in extracting energy from the water flowing down. If the earth surface and tunnel slope would be such that the tunnel and the earth surface intersect at a relatively short distance, the watermill can be constructed.

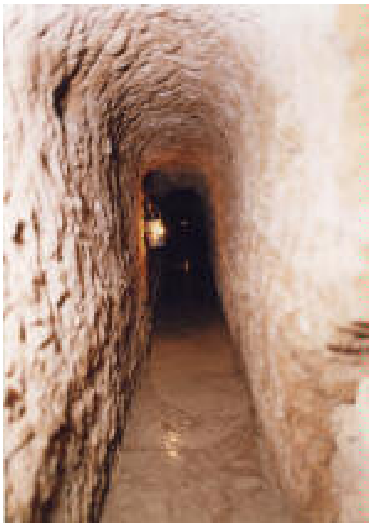


Figure 3. Qanat Gallery

IV. WATERMILL

Qanat related structures are ranked among the most interesting architectural structures, and most of them are relics of the past and considered historical heritage now. The most important qanat related structure built in Iran is watermill which is a structure constructed in order to grind grain. Its main parts are drop tower or water house, two millstones, rotor blades of watermill and an axis which connects rotor blades and upper millstone vertically.

The operation of watermill is based on the potential energy of water due to the depth of drop tower. The deeper drop tower, the more water's energy was generated. Sometimes the depth of a drop tower reaches to 10 meters in order to increase the water pressure.

When qanat's water reaches to the water house, it pours down the well and hit the blades. The water pressure which changes to velocity, make the blades rotate, imparting energy to the rotor and to the upper millstone. The lower millstone is motionless. Therefore the friction between the upper and lower millstones turns the wheat into flour. Sometimes, several watermills might be operated by the water of only one qanat.

According to the way in which watermill draws on the energy of water, the watermills can be classified into two groups as: a) potential watermill b) kinetic watermill

The two types of watermill are based on the difference between the heights of water input and output. In kinetic watermills the axis is horizontal, drawing on the water flow directly, whereas in potential watermills a difference between the heights of water inflow and outflow should be built artificially, such that the required energy to run the watermill would be generated. This type of watermill with vertical axis is the same as built in the qanat gallery.

Figure 4. Watermill

As mentioned a qanat is a subterranean canal to convey groundwater on to the earth surface, and this canal is intended to surface just near the cultivated area or village where the water is to be used. But in many cases the water table is such that the exit point of qanat does not show up just where the workers want, but some distance upslope from the village. Thus the workers have to channel this water again by digging a well and an almost horizontal tunnel from the exit point to wherever they need water. When the water is transferred through such an underground canal, the water less evaporates and it is less likely to take water illegally on its way to the village.

When the water is to be re-channeled, first a shaft well is sunk, from the bottom of which a tunnel is dug up, stretching out to the earth surface near the village. This shaft well can be drop tower for a watermill underground where the build up of water in the well can provide adequate water pressure to rotate the millstone. At the bottom of the well, a small hole is made such that water can spout out of it and hit the rotor blades of the watermill. Thus the rotor blades would turn and the movement would be imparted to the upper millstone by a shaft which passes through a hole in the lower millstone and then turns the upper one horizontally. There is a gap through which wheat can be put between the two millstones whose friction turns the wheat into flour. The distance between the two millstones is adjustable by a handle so that the wheat can be grinded soft or hard. The vertical axis that imparts the spin of rotor to the upper millstone is braced such that its bottom turns on a piece of iron stone which is fixed in a hole in a tree trunk. The bottom of the axis is so sharpened and covered in a metal cap that the friction between the axis and the iron stone at its base would be minimized.

Nowadays this technology has been abolished, because wheat is subsidized and purchased by the government, and is grinded in big factories. So the villagers no longer need the underground watermills to grind wheat. Nevertheless the idea of this paper – generating electricity – was inspired by the abandoned watermills, and we place turbine on the way of groundwater though this time its product is electricity not flour.

V. Qanat Turbine

According to the classification of the hydropower projects, generating electricity of qanat is among the group of "Pico-Hydro" which includes the projects generating between several hundreds watts and 5 kilowatts to supply electricity to the regions out of the range of power network for domestic and limited uses. We conducted a study in the province of Yazd in Iran on the potential that the qanats have to generate electricity. In this area some 3200 qanats are running, most of which enjoy a head less than 8 meters, so it seems that the suitable turbines for these qanats are Francis, Kaplan and the propeller turbines. Taking into account the diagram 1 that depicts the suitable turbines in relation to the qanats head and discharge, the turbines of Kaplan and Banki Michell have the most efficiency, because most of the qanats in this province enjoy a head less than 8 meters and a discharge below 1 cubic meter per second. This diagram also helps find out the limits of the electricity less than 10 megawatts. In terms of a low discharge (below 150 liters per second) which is applicable to the province of Yazd, the optimum type of turbine can be determined by the two following diagrams. In case we take the minimum electricity to be some 400 watts just to provide power needed for light and ventilation in the qanat itself, the qanats with low discharge require a head of 10 meters, which can not be found in Yazd. But in terms of the qanats with relatively high discharge and low head, the turbines of Powerpal and Nautilus seem suitable.

In closing we can conclude that: 1) the maximum electricity extracted from such turbines is 1 kilowatt, but considering the length of qanats which is tens of kilometers it is quite possible to install a series of turbines along the tunnel to get more electricity. 2) those qanats whose discharge is below 45 liters per second do not meet the requirements of this project, because this project is in line with the product of net head multiplied by discharge, so in case of lower discharge we need higher head which can not be higher than 8 meters considering the structural condition of the qanats in Yazd.

Due to these requirements, out of 3200 qanats in the province of Yazd, 100 qanats whose discharge is over 45 liters per second providing appropriate head have been singled out. Each of these 100 qanats can house one or several turbines, such that the total electricity generated by them would amount to thousands of kilowatts.

VI. Conclusion

Qanat which is an environment friendly technique and does not bring about any environmental backlashes is able to merge with another green technology; hydro turbine which generates electricity in harmony with nature to satisfy the small local demands. This initiative has two advantages: 1) it gives a new function to the ancient qanats and increases their chance to survive. 2) it can improve the economical conditions of the locals by giving rise to a new income source, taking into account that the Iranian government has a policy to purchase electricity from whoever can generate it through an environment friendly method like wind or water turbines.

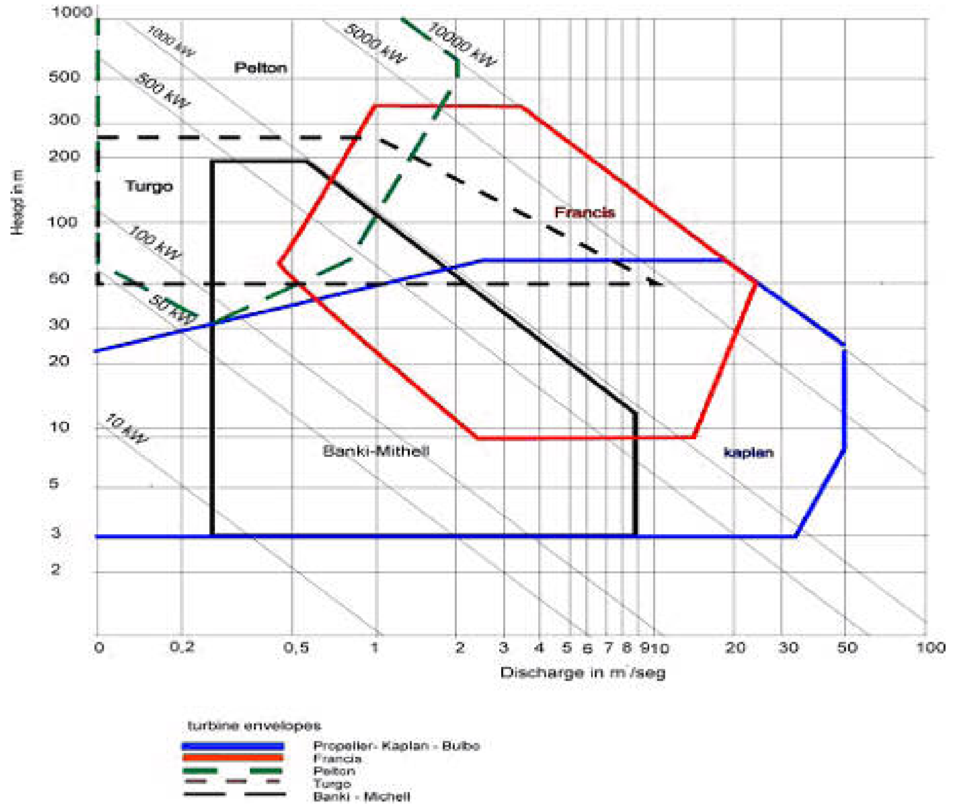


Diagram 1. turbines suitable for different ranges of head and discharge

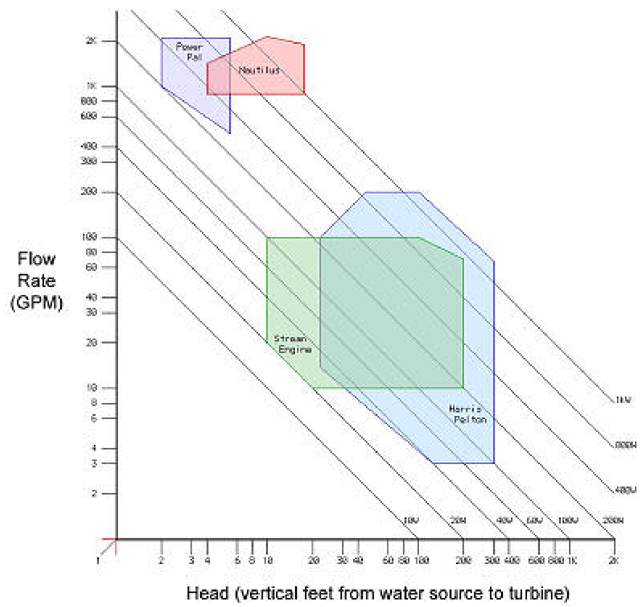


Diagram 2. Effective operating parameters for various water turbines, showing relation of head and flow to expected power out put of each