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The management of water resources between traditions and sustainability: the Qanats of Shahrood Province (North-Eastern Iran)

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ABSTRACT:

This short note presents the preliminary characterization of some qanats located in the Shahrood Province, as a result of a join agreement between the University of L'Aquila, the Institute of Chemical Methodologies of the National Research Council and the University of Technology of Shahrood. These underground water supply systems by gravity, whose conception dates back three thousand years, are still of great importance to exploit groundwater resource, that is strategic in peri-desert and desert areas. Qanats are endangered by the increasing use of drilled wells, which have exacerbated aquifers' overexploitation. To overcome this issue, these ancient underground water works can effectively offer "sustainable withdrawals" (tapping only the upper part of aquifer), if strategically implemented and following rational groundwater uses, taking into account cultural heritage, tourism enhancements and other uses related to new technologies (greenhouses heated by low-enthalpy plants, qualitative and quantitative improvement of traditional, typical and new varieties of crops, such as: peaches, apricots, pistachios).

KEY WORDS: groundwater management, arid environment, conceptual model, cultural heritage.

INTRODUCTION

Many towns and villages in Iran are nowadays supplied by qanats. Qanat is a hydraulic and mining technology dating back thousands years (Todd, 1980), probably native of Middle East area and widespread in Asia and North Africa. This hydraulic system allows aquifer drainage, transferring groundwater by gravity from the spring to another area, where it can be used for agricultural, drinking and sanitary purposes. Qanats have been realized entirely by hand, starting from the outlet (water supply area) to the aquifer recharge points ("mother wells"), excavating several vertical accesses (shafts) and connecting them to each other with very low gradients (sub-horizontal) tunnels. The length of these works can range from several hundred meters to several tens of kilometers. The depth of shafts may exceed 200 m. To make drainage more effective, generally a qanat is made of two or more sub-horizontal branches, converging to a main tunnel ending at the outlet (Kazemi, 2004). Many researchers have investigated the possibilities on how these ancient hydraulic can meet modern needs and/or technologies (Salih, 2006), not neglecting their fascinating history and cultural heritage (Jomehpour M., 2009). As part of a scientific cooperation agreement between the University of L'Aquila, the Institute of Chemical Methodologies of the Italian Research Council (IMC-CNR) and the Shahrood University of Technology, some qanats of the Province of Shahrood were selected for the present study. The qanats selection was made in function of their use (e.g. drinking, irrigation, or mixed uses), thus related to socio-economic-cultural aspects, to the geographical position with respect to the Kavir desert and Alborz mountain range, and to the potential different drained water characteristics. A multidisciplinary approach was adopted in order to explore the potential of these hydraulic systems, enhance their water uses and their cultural/touristic value.

Several field activities have been undertaken: flow rates measurements at Qanat outlets, water chemical and physical-chemical parameters measurements, survey of the qanat shafts (position, depth, accessibility, conservation status) aimed at georeferencing, cataloging, and 3-D reconstruction of the qanats. Evaluation of Radon concentrations in the hand-dug shafts of the qanats and in their water. Moreover, some meteorological stations have been installed to acquire information on metereological data highly influencing the water/groundwater availability.

MATERIALS AND METHODS

The cultural, political and scientific aims are to preserve qanats' functionality: developping an integrated management of these resources with modern ones (drilled wells), trying to identify new uses (recreational, tourism, exploitation of geothermal potential) and rationalization strategies (e.g. use of water resources not only during irrigation period). To achieve these goals, it is important to know their engineering characteristics, water availability, geological and hydrogeological setting, lithotypes in which they have been dug, social-economic and cultural aspects, the risks and hazards they are exposed to. The information framework must be aimed at building a conceptual model able to take into account this complexity.

After a preliminary survey, three qanats were selected (Fig. 1): the qanat of Shahrood town (150,000 inhabitants), that supplies about a third of the urban water demand; the qanat of Beyarjomand, used to meet the local agricultural water needs; the qanat of Torud, which is the traditional water resource of the village (2000 inhabitants) located within the Kavir Desert.

On the estimates of water demand, fragmented and non-updated data have been collected. Urban water demand for the city of Shahrood is about 20 million cubic meters per year (over 50000 m^3/day). The qanat supplies an average of 16000 m^3/day (Bakhshi, 1998). For Torud and Beyarjomand sites, scarse reliable information are available, since no flow measuring devices are present at their outlets. In Beyarjomand, qanat water is used for irrigation only between March and June, most of the year water flows freely. Urban water demand in Torud and Beyarjomand is met by drilled wells.

Fig. 1 - Location of the three study sites (Satellite photo: Google Earth; Geographic Map: Wikipedia).

The study sought to reconstruct the geometry of these hydraulic systems, to assess water availability and characteristics, and to identify associated structures such as old mills and checkpoints.

Surveys of qanats were carried out, locating areas and points of recharge ("mother wells").

Qanat branches were tracked starting from outlets and, as far as possible, a large number of shafts were identified by ID name, GPS position, photos, status (accessible, buried, dangerous), depth (distance between shaft head and bottom of the underground channel). In some shafts and at the outlets, water sample were collected to measure chemical-physical parameters (e.g. Temperature, Electrical Conductivity and pH; instrument: Horiba D-54, EC and Ph –meter).

Moreover, the presence of Radon in waters and inside the maintenance wells (shafts) was detected (instrument: E-Perm electret with SST configuration for water; LLT for the shafts.

Discharge flow measurements were performed along outlets channels (instrument: OTT C2).

In order to complete the information framework of the studied areas, three meteorological stations were installed (recorded parameters: temperature, relative humidity and rainfall data; instrument: Spectrum Technologies WatchDog Datalogger Model 450). Interviews with technical and qanats maintenance personnel were conducted to better understand management processes and related issues. At the same time, investigations on historical artifacts related to the hydraulic works were performed (named points of interests. e.g. mills and checkpoints located along their tracks).

Documents regarding both water works and geological information were also acquired.

Field data and geological maps were geo-referenced to implement 3D-reconstruction of water supply systems in GIS environments and to assist the definition of preliminary hydrogeological conceptual models. The acquired information was structured in a database implemented with MS Access, creating visual masks for outlets, shafts, "mother wells" and points of interest, reporting: (i) identification name, (ii) geographic data, (iii) status, (iv) photographic and/or bibliographic documentation, (v) physical-chemical parameters, (vi) discharge measurements. In addition, Visual Basic codes have been developed, creating KML (Keyhole Markup Language) files and custom 3D objects (COLLADA files) in order to be visualized in the Google Earth environment. For the implementation of 3-D shapes (shaft muck cones, shaft ducts, sub-horizontal tunnels, manholes, buildings), Google Sketchup application was used.

RESULTS

As already stated in the previous section, the selected qanats are located in different geographical positions. Shahrood qanat lies at the foothills of Alborz Mountains, Torud qanat is at the northern edge of Kavir Desert, while Beyarjomand qanat is located at an intermediate position. They share a common characteristic: they have been dug into powerful deposits of alluvial and eluvio-colluvial materials, in valley areas at the foot of important limestone/volcanic mountain ranges. The lengths of the qanat of Shahrood, Beyarjomand and Torud are respectively: 25, 10 and 8-10 km. While the Shahrood and Torud qanats are characterized by the presence of two drainage branches, Beyarjomand qanat has five branches of different order. In fact, these five branches can be traced back to two main ones, draining waters at different temperatures.

The measured water availability (December, 2009) for the studied qanats ranges between 40 L/s and 120 L/s (Shahrood: 120 L/s; Beyarjomand: 45 L/s; Torud: 52 L/s). Bibliographic reference (Kazemi, 2004) and collected interviews indicate a gradual decrease of flow rates over time.

The acquired values of physical-chemical parameters and Radon concentrations in the water are reported in tab. 1.

Water temperatures of qanats are quite variable but can reach values up to 20-25 °C (tab. 1). Temperature measured at the shafts (BJ171, BJ128, BJ053 and BJ117 in Tab. 1) is influenced by the sampling procedure (sampling bottle recovering may take some minutes). Water electrical conductivity varies between 450 and 5800 uS/cm. The Radon concentration in qanats water is quite low for the three different places, while this gas seems to be highly concentrated inside the shafts. In fact, the passive measuring devices (electrets in LLT configuration) suspended into these vertical ducts (one for each of the two branches of Beyarjomand qanat) were completely discharged after about 9 months of exposure (thus it was not possible a quantitative evaluation of Radon concentration).

About meteorological data collected by the stations installed near the outlets of the three qanats, daily data have been recorded for the year 2009 (acquisition step: one hour). Available information concerns only air temperature and relative humidity, but not rainfall, since there have been problems trying to retrieve data from the devices. Relative humidity values show wide daily and seasonal variations from sensors full-scale (20,7%) to measures close to 100% for all the three sites (Average annual values of relative humidity RH: Shahrood, 44,9%; Beyarjomand, 39,5%; Torud, 30,5%). RH average annual values decrease from the area near Alborz Mountains (Shahrood - 44,9%) towards Kevir desert (Torud - 30,5%). Air temperatures have day and night shift of more than 10 degrees, while seasonally, they range from minimum values close to zero in winter reaching maximum values in summer, over 40°C. Seasonal average temperature values respectively for Shahrood, Beyarjomand and Torud, during 2009, are: 8,1, 9,50 and 13,0 °C in Winter; 16,1, 19,2 and 23,3 °C in Spring; 25,9. 27,7 and 32,7 °C in Summer; 13,1, 12,5 and 16,0 °C in Autumn. These values show how seasonal temperatures tend to increase moving towards the desert.

A qualitative comparison with rainfall data retrieved from websites (https://www.worldweatheronline.com/shahrood-weather-averages/hormozgan/ir.aspx), concerning the Shahrood Province, showed a good correlation between these two parameters. Figure 2 shows an example of 3D-reconstructions of the qanat systems obtained in GIS environment and the database interface developed for surveys acquired data.

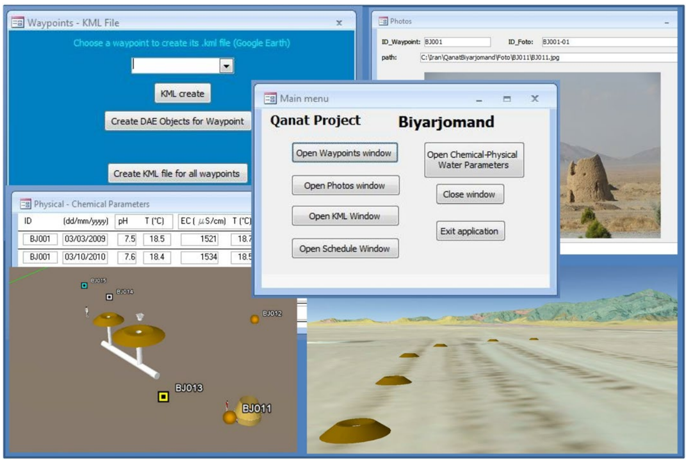

Fig. 2 - Example of database interface developed in the MS Access environment and 3D reconstruction of the structural elements of the supply system with overlapping of the geological map, represented by the false colors assigned to plain, mountains and foothills (Google Earth environment).

TABLE 1

Qanats water physical-chemical parameters (December, 2009). The electrical conductivity values are normalized at 25 ° C. SH: Shahrood; BJ: Beyarjomand; T: Torud. EC: Electrical Conductivity.

ID_Name	Date Time	T (°C) -pH-	pH	EC (uS/cm)	T (°C) -EC-	Rn (Bq/l)	Monitoring point description
SH-OUT	15/01/2009 11:00	12.9	8.10	474	13	5.79	Shahrood outlet
BJ171	16/01/2009 11:00	12.0	8.70	684	11.8		cold branch, first shaft (250 m) downgradient mother well (depth 90,6 m)
BJ128	16/01/2009 12:12	18.0	9.22	779	16.8		cold branch
BJ053	16/01/2009 15:30	19.9	8.14	911	21.8		warm branch (Rn measurement)
BJ117	16/01/2009 11:30	17.4	8.48	797	18.4		cold and warm branches confluence
BJ-OUT	16/01/2009 09:46	18.0	8.70	807	18.6	9.49	Biyarjomand outlet
T-OUT	17/01/2009 12:57	24.5	9.00	5840	24.4	0.96	Torud outlet

DISCUSSION

Groundwater in peri-desert regions in Iran, as the Shahrood Province, is a strategic resource, regardless of its intended use. Droughts and related water crises have multi-year duration, for example in the periods 1988-1990 and 1999-2001 (Foltz, 2002; Kazemi, 2004; Golian et Al. 2015; Madani et Al., 2016). In this context, qanats have some advantages compared to drilled wells, among which tapping only the upper part of aquifers and draining groundwater by gravity. On the other hand, groundwater withdrawals/drainage take place uninterrupted throughout the year.

This aspect raises use efficiency-related issues, especially for agricultural activities, which are in most cases seasonal based. The increasingly use of drilled wells and the uncontrolled withdrawals are damaging the qanats' functionality, bringing aquifers into over-exploitation. For a detailed comparison of advantages and disadvantages of these two technologies (qanats vs drilled wells), see Kazemi (2004). The measured qanats flow discharge rates are fairly significant (40-120 L/s). Construction features of their hydraulic structures (i.e. tunnel dimensions, traditional supply water distribution system at qanat outlets) make it reasonable to assume that these flow rates are stable over the seasons (otherwise they would have been destroyed by "flood" events).

This is also confirmed by field site evidences as from a previous study (Kazemi, 2004). On the opposite, many authors denote a significant negative trend over the years, due to the decrease of the, already low, rainfalls (e.g. annual average rainfall in Shahrood for the period 1950-2002: 152 mm; Kazemi & Mehdizadeh, 2003). Modarres and Sarhadi (2009), considering a set of 145 precipitation gauging stations in Iran, highlight how annual rainfall is decreasing at 67% of the stations, while the 24-hr maximum rainfall is increasing at 50% of the stations. Considering the qualitative aspects of groundwater drained by the qanats, electrical conductivity values can be related to the location of each qanat with respect to Alborz mountains range and the Great Salty Desert (Kavir means "salty marsh"). In fact, such data increase from the mountains southwards the desert. Water temperature values, compared to air temperature data, suggest the possible use of qanat waters for low-enthalpy geothermal purposes and/or production of greenhouse crops.

The very low Radon concentration in water allow its risk-free use, while potential risks must be studied for qanat maintenance personnel (*moq-qani*).

Geological information, field surveys and 3-D reconstructions allowed to propose the following common conceptual model (Fig. 3), contributing to detail the one proposed by Kazemi (2004) for the qanat of Shahrood. Inter alia, the sketch emphasizes the areas of system recharging, drainage and tunnel losses, potential pollution points and possible interference due to drilling wells. It should be noted that qanat length is often conditioned by the need to transfer water resources to areas where soil characteristics are more suitable for agricultural activities.

The survey highlighted two valuable aspects regarding possible actions to be undertaken for a rationalization in the use of qanat groundwater resources. The first one is the strategic need, for the qanats of Torud and Beyarjomand, to use the favorable flow rates available (40-50 L/s) also during non irrigation periods (autumn and winter). The second one is the thermal difference between temperatures of qanats water (18 - 24 ° C) and the average air winter temperatures (8,0 - 13,0 ° C), which, coupled with the unused winter water availability, represents a considerable potential for geothermal low enthalpy applications (greenhouses) or recreational use (SPAs). The Shahrood qanat supply system have to be harmonized with drilled wells withdrawals in order to mitigate the effects of droughts or water scarcity events. Winter qanat surpluses could be destined for the developing of agricultural technologies, located in town surroundings.

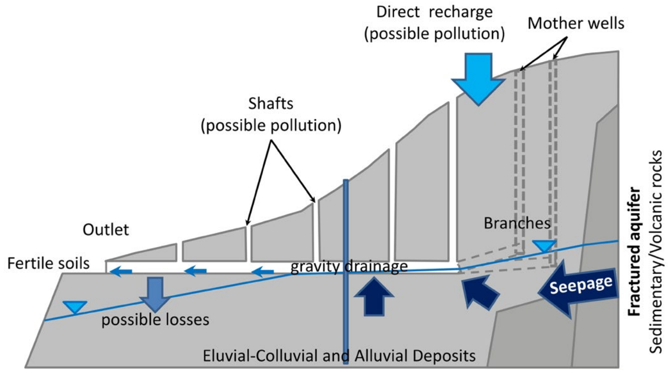

Fig. 3 - Conceptual model of the studied qanats (model update of the proposed conceptual model for the qanat of Shahrood - Kazemi, 2004.

CONCLUSIONS

Despite the increasingly widespread recourse to drilled wells to tap groundwater, qanats still play a pivotal role in water supply resources, especially in areas located near deserts. Wells withdrawals are depressing groundwater levels, decreasing (or, at worst, preventing) the sub-horizontal gravity drainage of these traditional water works. The performed investigations identified some potential novel uses for the studied qanats. For Torud and Beyarjomand sites, considering the remarkable flow rates available in winter (40-50 L/s, when water demand is lower and traditional agricultural activities stop) and thermal differences between qanats water temperatures and winter air temperatures (respectively 11.4 °C and 9.1 °C), the main agricultural use of their resources, low enthalpy geothermal exploitation systems (also in cogeneration, with solar energy) may be implemented aimed at creating greenhouses for winter crops and/or SPAs. The Beyarjomand site has also some tourism potentials due to the old mills located along the ancient ending part of the qanat. The Shahrood qanat is a strategic resource for the urban drinking water supply, it needs to be harmonized with drilled wells withdrawals. Winter and spring surpluses could supply the irrigated areas owing to the Center of Agricultural Excellence located north-east of the town. The conducted surveys led to setup a procedure for the characterization and recording of qanats in the Shahrood area, which can be improved with the future development of the mentioned international collaboration.

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