JAEHR
Journal of Advances in Environmental Health Research
J Adv Environ Health Res, 2023; 11(2): 125-133. doi: 10.34172/jaehr.2023.16
http://jaehr.muk.ac.ir

Original Article

Determination and Classification of Qanat Water Quality Based on Groundwater Quality Indices in East of Tehran, Iran

Mohammad Bagher Salarian, **Mina Mackialeagha***, **Azita Behbahaninia**

Department of Environment, Agriculture Faculty, Roudehen Branch, Islamic Azad university, Roudehen, Iran

Article history:
Received: June 22, 2022
Accepted: August 21, 2022
ePublished: July 16, 2023

***Corresponding author:**
Mina Mackialeagha,
Email: mackialeagha@yahoo.com

Abstract
Background: Qanat is a valuable source of groundwater, the maintenance of which requires quantitative and qualitative monitoring. Since the qanat water is currently used in some parts of Iran for drinking and agricultural purposes, its quality management is of great importance. This study aimed to evaluate the water quality of the qanat in the eastern areas of Tehran.
Methods: Water sampling was performed in eight qanats in the east of Tehran in triplicate (mother well and one of the access shafts and outlet) during the summer of 2020. The measured parameters were pH, total dissolved solids (TDS), electrical conductivity (EC), CO_3^{2-}, HCO_3^-, Na^{2+}, Ca^{2+}, Mg^{2+}, K^+, Cl^-, NO_3, SO_4^{2-}, total hardness (TH) and total alkalinity (TA). The quality was assessed according to the standards introduced by the World Health Organization (WHO) and Food and Agriculture Organization. Groundwater quality index (GWQI) was used to classify the samples.
Results: The lowest (56.05) and the highest (2058.58) GWQI scores corresponded to qanats 5 (Elimon) and 8 (Aminabad) with good and very poor quality, respectively. There was a decrease in the water quality of qanats 8 (Aminabad), 7 (Sulaymaniyah), 6 (Mehdiabad) and 2 (Majidieh), respectively.
Conclusion: The quality of the qanats were in the range of good to very poor. The reasons for difference in water quality could be due to the direction of anthropological pollutants and geological structures. To control the water quality of the qanats in the east of Tehran, the quality monitoring network is recommended to be designed for various pollutants and optimized for long term.
Keywords: Water resources management, Groundwater, Qanat, Water quality, GWQI

Please cite this article as follows: Salarian MB, Mackialeagha M, Behbahaninia A. Determination and classification of qanat water quality based on groundwater quality indices in East of Tehran, Iran. J Adv Environ Health Res. 2023; 11(2):125-133. doi:10.34172/jaehr.2023.16

Introduction
To supply high-quality water is one of the most important needs of modern life.[1] Municipal and industrial wastewater and agricultural drainage have led to an increase in groundwater pollution, which has led to serious problems.[2,3] Qanat is the main method of groundwater extraction in arid and semi-arid regions.[4] The number of qanats in Tehran has been yet 572, which have been threatened through the digging of numerous tunnels to construct the subway, as well as the indiscriminate constructions by blinding the canals, thereby resulting in the reduction of their water supply and quality. In the past, qanats were the first sources of irrigation and the most ancient water supply technology. Preservation, maintenance and revival of qanats as well as their productivity in irrigation of gardens and general green space have been specially prioritized in the plans of Tehran municipality in recent years.[5]

The shallow depth of qanat and the high permeability of the soil make the qanats act as a drainage for surface water and wastewater.[6] Determining the quality of groundwater resources, such as qanat and well through satellite images has shown the key impact of land use change in groundwater depletion.[7,8] Therefore, natural and anthropological factors are involved in controlling the physicochemical properties of groundwater.[9-11]

Water quality index (WQI) is a technique used to evaluate the quality of water resources.[12] WQI is also an easy way to -classify water quality.[13] This index is one of the most effective tools for conveying information about the quality of water for citizens, government officials and policymakers.[14] Another indicator of water quality evaluation is the river pollution index (RPI) which is an integrated index used to find the level of contamination based on DO, BOD, TSS and NH3-N parameters.[15] An indicator that can be used to evaluate the quality of surface and groundwater is weighted arithmetic water quality index (WAWQI). In addition to the parameters

© 2023 The Author(s); Published by Kurdistan University of Medical Sciences. This is an open-access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

used in the WQI, total hardness parameters, magnesium, chloride, calcium and sulfate are also used in this index to evaluate water quality more accurately.[16] The WQI plays an important role in water quality researches because of its simple and understandable explanation of the results.[17]

Hosseini et al. assessed the quality of surface water of Chahnimeh reservoirs in Sistan and Baluchestan province, Iran in 2019 using WQI and hydro-geochemistry.[13] They found that the water quality of the wells was in the range of good to poor water categories based on the WQI value. Bahrami and Dastourani[18] evaluated the groundwater quality in the Plain of Sarayan in South Khorasan Province, Iran in 2019. Also, Eslami et al[19] determined the quality of groundwater resources in Kerman province, Iran using WQI. They demonstrated that the quality of water resources was at the poor and very poor level. Nasrabadi et al[20] studied the quality of groundwater in Tehran based on the World Health Organization (WHO) water quality index. They observed that water quality in 2012 was lower than in 2011. Moreover, the index value was higher in the eastern and southern regions than in other regions of the area.

In Eshtehard plain, Iran, Ranjbar and Soltani[21] showed that 42% of the samples were of excellent quality. Also, 10% were good, 10% were poor, 8% were very poor and 30% were unsuitable for drinking use.

In 2010, Coletti et al[22] studied the water quality index of the Das Pedras River basin, Brazil. They observed that the main source of water pollution in this basin was agricultural activities. Reza and Singh[23] used WQI to investigate the quality of 24 groundwater samples collected during summer and post-monsoon seasons in Orissa, India. They found that the groundwater quality was worse in the post-monsoon samples than summer.

Zarei and Khoshnamvand[24] used the WQI to assess groundwater quality in Shiraz, Iran in 2012. They reported that the measured physicochemical parameters of well water samples were at good level. Ghandali et al[25] investigated the quality of groundwater resources such as wells and qanats in Semnan watershed using WQI and geostatistics Techniques. According to their results, the northern watershed regions had better quality water than other regions.

Thu Minh et al[26] evaluated groundwater quality in Giang province, Vietnam. They used weighted groundwater quality index (GWQI) and fuzzy analytic hierarchy process (Fuzzy-AHP). They identified that the reason for the poor groundwater quality in this province was a collection of both natural and anthropological activities. In a hydrogeochemical study of groundwater quality in South India by Adimalla and Taloor,[27] the GWQI showed that 37.11% and 57.21% of groundwater samples were excellent and good for drinking uses, respectively.

Ebadati and Yousefi[28] investigated the water quality of qanats in the eastern part of Tehran. The results revealed that in most cases the quality of these groundwater samples was suitable for drinking uses according to national and WHO standards, and that biological contamination was exceeded in some cases.

A research group evaluated groundwater quality for drinking purposes in Sylhet district, Bangladesh in 2020. They claimed that the entropy-weighted water quality index showed acceptable results compared to GWQI due to its simplicity, accuracy and weight neglect.[29]

Vadiati et al[30] determined groundwater quality based on groundwater quality index (GQI), WQI and GWQI. The quality was classified into five categories based on GQI, five categories based on WQI and three categories based on GWQI.

Many of the qanats in Tehran have been currently exposed to environmental threats. Therefore, environmental studies and water quality monitoring of qanats are the main topics in urban planning and management. The qanats in the eastern part of Tehran are of special importance in this city because they are the main sources of water supply which are exposed to various pollutants from municipal, industrial and agricultural activities. Accordingly, to assess the quality of these groundwater resources in this area is of great significance, which is discussed in this research.

Materials and Methods

In the present cross-sectional study, basic information such as geographical location, identification details and discharge rate of studied qanats were obtained from Regional Water Organization and Agriculture-Jihad Organization of Tehran province. Eight qanats were identified in the east of Tehran, and three sampling stations per qanat were determined along the qanat route (i.e., mother well; one of the vertical access shafts and outlet) based on the influence of anthropological and natural contaminants. The samples were taken instantaneously during the drought season and summer. The measurements were performed according to *Standard Methods for the Examination of Water and Wastewater*. The parameters measured at each station were evaluated using GWQI and compared with WHO and national standards. Eventually, the water quality of each qanat was determined using the indices.

Study Area

The study area was the eastern part of Tehran, including municipal districts of 1, 4, 8, 13, 14, 15 and 20. The geographical location of qanats in the city is shown in Figure 1. The qanats' characteristics have been also presented in Table 1.

Water Sampling Procedure

The water quality of qanats in the East of Tehran in terms of physicochemical properties was determined by 12 parameters, including pH, total dissolved solids (TDS), electrical conductivity (EC), CO_3^{2-}, HCO_3^{-}, Na^{2+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, NO_3, SO_4^{2-}, total hardness (TH) and total alkalinity (TA).

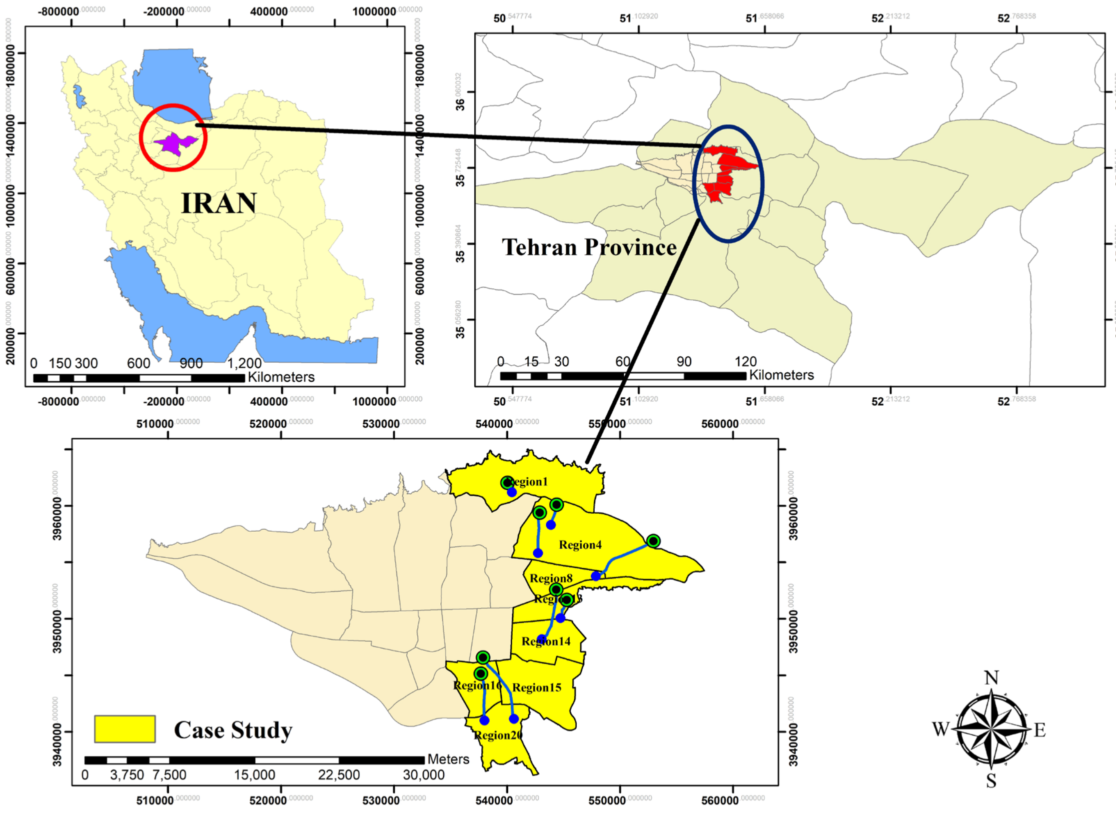

Figure 1. Location of the Studied Qanats in in Tehran and Iran

Table 1. Profiles of the Studied Qanats in East Tehran, Iran

Codes of Stations	Names of Qanats
W1	Azizieh
W2	Majidieh
W3	Qeytarieh
W4	Elimon
W5	Mobarakabad
W6	Mehdiabad
W7	Sulaymaniyah
W8	Aminabad

The water samples were collected in 250-mL bottles recently washed with acid/distilled water. At the time of sampling, each bottle was washed three times with sample water. Some physicochemical properties of water such as temperature, EC, TDS and pH were measured at sampling site using a portable HACK device with an accuracy of 0.01 µS/cm for EC and 0.01 for pH. After transporting the samples to the laboratory based on standard methods for water and wastewater sampling, the water samples were first filtered (0.45 µm) and their pH was reduced to below 2 with nitric acid and then analyzed by ICP-MS (inductively coupled plasma-mass-spectrometry) analytical technique to determine the concentration of the main cations. The main anions of water with nitrate were measured in the relevant laboratory. TH and TA were calculated from Equations (1) and (2), respectively.

$$\text{TH}\ (\text{CaCO}_3\ \text{mg/L}) = 50 \times (\text{Ca}^{2+} + \text{Mg}^{2+}) \quad (1)$$

$$\text{TA}\ (\text{CaCO}_3\ \text{mg/L}) = (\text{HCO}_3^{-} + \text{CO}_3^{2-}) \quad (2)$$

Where, the concentrations of calcium, magnesium, carbonate, and bicarbonate are in mEq/L.

The standards of drinking water quality were in accordance with WHO and the Food and Agriculture Organization (FAO) . They were used to compare the quality status of the measured parameters.

Groundwater Quality Index

One way to assess groundwater quality is to use GWQI, a method that combines different parameters of groundwater quality. It determines the combined effect of all quality parameters on water quality. This index is defined and calculated in different ways, though all these methods show the influence of different parameters of water quality. One of the advantages of GWQI is the flexibility of the available parameters. The number of input quality parameters for calculating this index varies, and its score is between 0 and 300 units. Using these numbers and GWQI quality classifications (Table 2), the groundwater quality is classified according to existing drinking standards.[31]

Therefore, the GWQI can be used as a reliable tool to assess and rank groundwater quality. In order to calculate WQI, the values of physicochemical parameters have been determined according to the relative importance of the parameters in the overall quality of groundwater.[32]

Results and Discussion

Characteristics and purposes of using the eight studied qanats are presented in Table 3.

Table 2. Water Quality Classification Based on GWQI Value

GWQI Values	Groundwater Quality
<50	Excellent
50-99.99	Good
100-199.99	Poor
200-299.99	Very poor
≥300	Unsuitable for drinking/Irrigation

Table 3. Specifications purposes of uses of sampled Qanats in East Tehran, Iran

No. of Qanats	Names of Qanats	Municipal Districts	Purposes of Uses
1	Mobarakabad	4	Irrigation of green space of Imam Ali
2	Majidieh	4	Irrigation of green space of Majidieh Park and sidewalks around Majidieh Park - Irrigation of small green spaces of houses
3	Azizieh	13	Green space irrigation
4	Qeytarieh	1	Irrigation of Green space of Qeytarieh Park
5	Elimon	20	Green space irrigation
6	Mehdiabad	8	Green space irrigation
7	Sulaymaniyah	8	Green space irrigation
8	Aminabad	15	Green space irrigation

Analysis of Physical-Chemical Properties of Qanats

Figure 2 illustrates the physicochemical properties of qanats studied in the east of Tehran at eight sampling stations.

According to Figure 2, the results showed that the maximum (7.76) and the minimum (6.49) pH values were related to qanats 1 and 8, respectively. The EC values varied from 428 to 1890 mS/cm. The mean EC value was 925 µS/cm, which is much higher than the standard for drinking water (600 µS/cm). The maximum and minimum EC values were observed in qanats 7 and 4, respectively.

The TDS value in qanat 2 was much higher than other qanats. This is probably due to the interaction of rock and water and municipal service activities. According to the WHO guidelines, the maximum TDS value in water should be 1500 mg/L, which was standard in all qanat. The maximum chloride concentration in the present study was in the range of 153 mg/L in qanat 5, which was within the standard limit of Iran (250 mg/L). The sulfate concentrations ranged from 152 to 255 mg/L, which was lower than the WHO standard (400 mg/L).

The standard limit of nitrate in drinking water according to WHO instructions is 50 mg/L. The results showed that nitrate concentration was in the range of 23.7 to 54 mg/L, with the maximum in qanat 5 and the minimum in qanat 7. The water hardness is caused directly by calcium and magnesium cations, and these cations are high in groundwater. In the studied qanats, the calcium concentration was between 0.3 and 5 mg/L and the

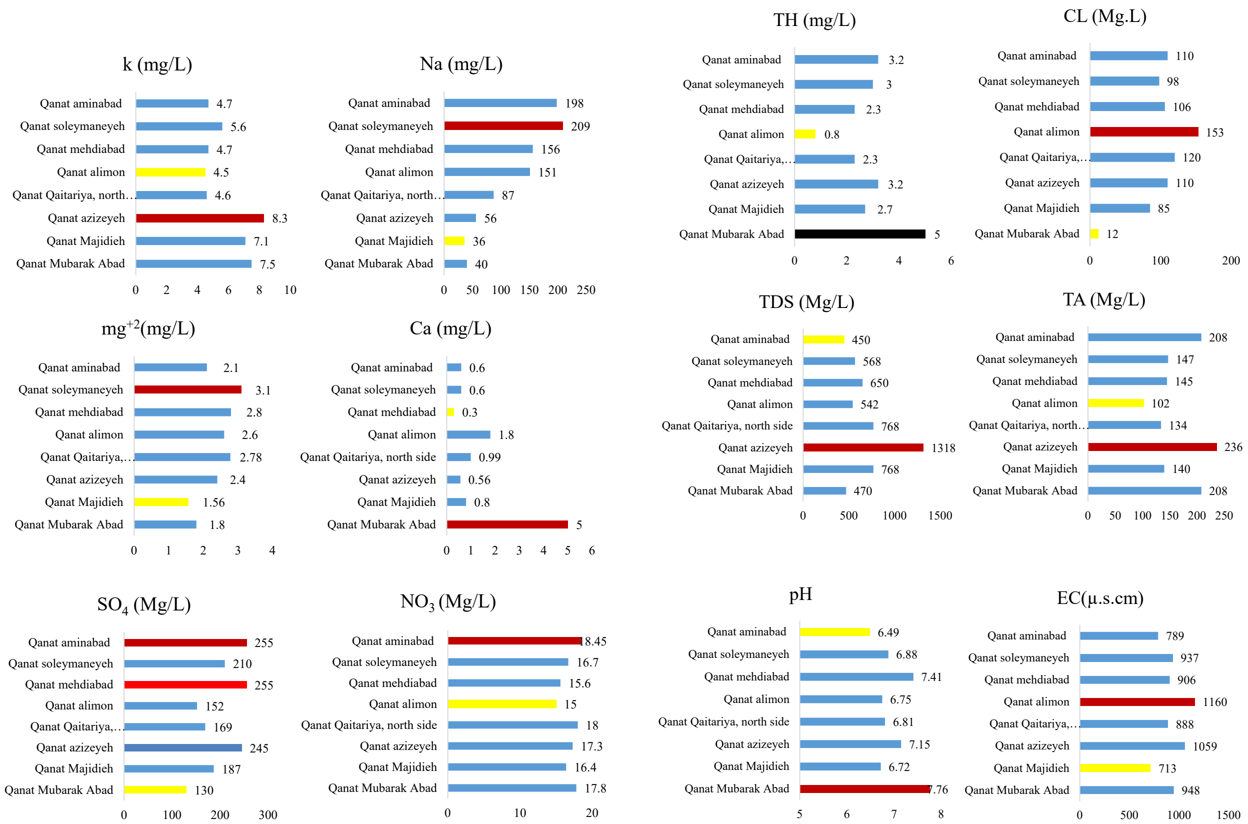

Figure 2. Changes in the Average Values of Physical and Chemical Parameters of Qanats in the Eastern Area of Tehran in Eight Stations

magnesium concentration was between 1.8 and 3.1 mg/L as $CaCO_3$. The maximum concentration of calcium (1.8 mg/L) was in qanat 5 and the maximum concentration of magnesium (3.1 mg/L) was in qanat 7, which produced a maximum TH of 230 to 400 that is less than the WHO (500 mg/L). Also, the maximum TH was for qanat 5. The concentration of sodium was between 36 to 209 mg/L which was lower than the WHO standard. The maximum TA, TDS and K^+were in qanat 3. The highest concentration of chlorine (153 mg/L) was observed in qanat 5. The potassium concentration varied from 4.5 to 8.3 mg/L among different qanats, with the highest and lowest concentration in qanat 5 and qanat 3, respectively.

Table 4 presents the mean values of physical and chemical parameters measured for the groundwater of qanats in the eastern area of Tehran.

Calculation of GWQI for Study Qanats

The water quality index was calculated for the studied qanats based on the GWQI. Table 5 provides the results of the qualitative classification of each qanat using the GWQI. According to Table 5, the lowest value of this index (56.05) was related to qanat 5 (Elimon) with good quality, which is used for irrigation of green space, whose quality is only influenced by natural origin and land. Also, chlorine has been the most important parameter affecting its quality. The highest GWQI value (203.58) was in qanat 8 (Aminabad) which had very poor quality. The water quality of qanat 8 is affected by the infiltration of effluents from industries, gardens, green space irrigation, agricultural lands and the entry of absorbing wells and municipal wastewater. The most important parameters affecting the index value have been HCO^{3-}, NO^{3-} and SO^{4-}.

As shown in Figure 1 and Table 5, the groundwater quality of qanats in the East of Tehran based on the GWQI value was in the ranges of good (about 50%), poor (37%) and very poor quality (13%). High GWQI values were related to the qanats 6, 7, 8 and 2, whose quality was affected by the entry of pollutants from various anthropological activities.

Table 4. Determining the Groundwater Quality in Qanats Studied in East Tehran, Iran, and Comparing the Parameters of Each Qanat With FAO and WHO Standards Based on the Average Values of the Parameters Measured for Each Qanat

	Parameters												
	Na^+(mg/L)	K^+(mg/L)	Ca^{2+}(mg/L)	Mg^{2+}(mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Cl^- (mg/L)	TH (mg/L)	TA (mg/L)	TDS (mg/L)	EC (µS/cm)	pH	HCO_3 (mg/L)
WHO	200	12	75	50	250	11	250	500	120	500	500	8.5-6.4	120
FAO	919	2	400	60	960	10	610	2000	-	2000	2	8.5	610
Qanat 1 (Ave)	40	7.5	5	1.8	130	27.8	12	300	208	470	948	7.76	144
Drinking water	*	*	*	*	*	×	*	*	×	*	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 2 (Ave)	36	7.1	0.8	1.56	187	49.4	85	270	140	768	713	6.72	146.22
Drinking water	*	*	*	*	*	×	*	*	×	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 3 (Ave)	56	8.3	0.56	2.4	245	48.3	110	320	236	1318	1059	7.15	125.44
Drinking water	*	*	*	*	*	×	*	*	×	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 4 (Ave)	87	4.6	0.99	2.78	169	48.6	120	230	134	768	888	6.81	121.33
Drinking water	*	*	*	*	*	×	*	*	×	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 5 (Ave)	151	4.5	1.8	2.6	152	54	153	400	102	542	1160	6.75	130.11
Drinking water	*	*	*	*	*	×	*	*	*	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 6 (Ave)	156	4.7	0.3	2.8	255	35.6	106	230	145	650	906	7.41	153.33
Drinking water	*	*	*	*	*	×	*	*	×	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 7 (Ave)	209	5.6	0.6	3.1	210	23.7	98	300	147	568	937	6.88	128.66
Drinking water	×	*	*	*	*	×	*	*	×	×	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*
Qanat 8 (Ave)	198	4.7	0.6	2.1	255	34.45	110	320	208	450	789	6.49	182
Drinking water	*	*	*	*	*	×	*	*	×	*	×	*	×
Irrigation water	*	×	*	*	*	×	*	*	*	*	×	*	*

* Suitable; × Unsuitable.

Table 5. Classification of Groundwater Quality in Qanats Studied in East Tehran, Iran, Based on GWQI With Natural and Anthropological Origin

No. of Qanats	Calculated GWQI Value	Quality Classification	Origin of Contamination: Anthropological or Natural	Significant Measured Parameters	Reason for Origin
1	64.55	Good		Ca, pH	Weathering of common minerals in most Qanat rocks, and the geological structure of qanat,Acidic atmospheric sediments that have also increased acidity through rainwater transport.
2	114.71	Poor	anthropological	NO_3-SO_4-TDS	Clay texture, sewage of absorbing wells and fertilizer consumption in the green space of these areas, Increasing the concentration of human population and green space in these areas in turn increases fertilizer consumption and wastewater production.
3	66.10	Good		K	Weathering of common minerals in most qanat rocks, and the impact of regional structures and the dissolution of minerals in groundwater and the geologically structure of qanat, and the presence of carbonate and bicarbonate ions due to the dissolution of gypsum in qanat.
4	60.47	Good		None	Low number of industries in the region, geological composition of the region, reducing the infiltration of municipal wastewater into water resources, geographical and environmental conditions prevailing in the region
5	56.05	Good		Cl	Weathering of common minerals in most qanat rocks, and the geological structure of qanat due to the ancient age of qanat
6	119.37	Poor	anthropological	NO_3-SO_4	Use of chemical fertilizers in forest park lands due to the vastness of green space and gardens and parks in District 8, Domestic wastewater and the absence of sewage system and treatment system in the area, Surface runoff due to the absence of engineering and sanitation network for the disposal of surface water and wastewater, Dissolution of a significant amount of solutes as surface water passes through the earth's crust, and other factors such as: topographic condition and slope of the study area, geological structure, non-observance of proper distance between wells, water and sewage wells in some areas, shallow wells, industrial uses.
7	193.07	Poor	anthropological	SO_4-NO_4-Mg-Na	Sewage of residential areas, surface runoff, worn texture in the areas as well as the geological structure of the area, non-observance of proper distance between water wells and sewage wells and agricultural and garden lands
8	203.58	Very poor	anthropological	HCO_3- NO_3-SO_4-	Infiltration of effluents derived from industries, gardens, agricultural lands and wells of water parks and municipal sewage into qanat water

Water Quality Status of the Studied Qanats According to International Standards

The results showed that the parameters affecting water quality in the most of the sampling stations were lower than the permissible level of drinking water according to the WHO standard. Also, the average values of these parameters in some stations (qanats 2, 7 and 8) were at high level. Excessive pumping of underground water and improper management of their exploitation reduced the quality of water resources.[18] Zarei and Khoshnamvand[24] also used WQI to evaluate the quality of groundwater aquifers in Shiraz in 2012. They found that the measured physicochemical parameters had good quality, and were not problematic in terms of health for drinking and other uses. They also showed that the parameters were lower than the standard allowable for groundwater. Ebadati and Yousefi[28] investigated the water quality of qanats in the eastern part of Tehran. They found that the qanats were slightly different in terms of water quality so that their water quality was suitable for drinking in most cases according to national standards and the WHO, and that biological pollution was exceeded in some cases. The results of this research indicated that from the northeast of Tehran to the southeast of the city, the load of pollution and water salts increases due to the decrease in the depth of the underground water level. The average nitrate concentration in qanat 5 exceeded the WHO and FAO limits for drinking. High levels of nitrate in groundwater lead to acute blood deficiency in children and reduce the ability of vessels to carry oxygen.[5]

The mean concentration of sodium in qanat 7 was higher than the WHO standard. Sodium ions can be present naturally in water due to some phenomena such as evaporation, use of salt on roads in cold seasons, agricultural and anthropological activities, and clay weathering. In addition, ion exchange of sodium and calcium as well as other cations can increase the concentration of sodium in water. Connate water, seawater, and salt domes have high level of sodium.[33] The presence of sodium ions in irrigation water or soil can impair soil permeability to water. This is an additional effect of sodium that has direct impact on some plants which may be toxic for them. Symptoms of toxication are gradually occurring leaf-tip necrosis and leaf scorch. Concentrations above 911 mg/L generate toxicity in plants.[34]

According to the FAO standard, potassium exceeded the permissible limit in all qanats. The most important and common source leading to the increase in the concentration of these two ions in the studied qanats can be attributed to the nitrogen and potassium fertilizers used in agricultural and horticultural activities.

Sulfate concentration was higher than the WHO standard in qanats 6 and 8. Sulfate often enters into drinking water from the dissolution of gypsum or other sulfate-containing mineral deposits. A high concentration of sulfate affects the taste of water, and sometimes sulfate ions are reduced by bacteria in the water to produce H_2S. Sulfate is one of the ions with the least toxicity. Sulfate levels below 961 mg/L are beneficial for plant growth, and higher concentrations disrupt protein and nucleic acid synthesis, leading to toxicity in plant.[35]

TA exceeded the limit in all qanats except for qanat 5 according to WHO standard. Also, TDS exceeded the WHO standard in all qanats except for qanat 8. In addition, EC was higher than the WHO and FAO standards in all qanats. However, other parameters were within the allowable range of international standards. Kargar et al[36] investigated the microbial and chemical quality of Shorbolein qanat water in Yazd, Iran in 2005. They reported that the parameters namely pH, EC, TH, nitrate, PN, total coliforms and fecal coliforms were 7.86, 614 µS/cm, 266.6 mg/L $CaCO_3$, .78 mg/L, 116.2/100 mL and 54.2/100 mL, respectively. Except for pH, the levels of other parameters were different from our results, which confirms that the effects of geological formations on the physicochemical quality of qanat are different in the two regions. Zia and Qatani[37] investigated the hydrogeological and hydro chemical characteristics of qanats in Balade, Ferdows, Iran. They concluded that the electrical conductivity of the studied qanat water varied between 440 and 1150 µmhos/cm. They also found that changes in water quality depended on the lithology of the qanat catchments and the amount of rainfall. The lowest electrical conductivity of water was related to the qanats of Shoghad and Qandab which were discharged from granite rocks, and the highest electrical conductivity of water was related to qanats of Zene, Gavbili and Asbi discharged from marl formations at the outlet of the basin. Ghandali et al[25] investigated the quality of underground water in Semnan, Iran in 2018, and found that the quality of water resources decreases in the south of the studied basin due to geological factors and the presence of lime in this area.

Groundwater Quality of Qanats Based on GWQI

As seen in Table 5, the groundwater quality of the qanats in the East of Tehran based on GWQI as well as the reasons for their qualitative changes were as follows:

Qanat 1 (Mobarakabad) was at the third rank in terms of water quality. It was also in the category of good quality with a value of 64.55. The reason for the presence of various anions and cations in the water of this qanat can be attributed to its natural and tectonic origin. Qanat 2 (Majidieh) was at the rank of fifth in terms of water quality and categorized at poor quality level with a value of 114.71. The main reason for the qualitative changes was the anthropological origin due to the clay texture in some parts of the qanat, as well as the conduction of pollution caused by the effluent of absorbing wells and drainage of fertilizer used in the green space of the area. Qanat 3 (Azizieh) was ranked fourth in terms of water quality and categorized at good quality level with a value of 66.10. Qualitative changes in this qanat were due to natural and tectonic origin. Qanat 4 (Qeytarieh) was ranked second in terms of water quality which was in the category of good quality with a numerical value of 60.47. The water quality change of this qanat was also due to natural and tectonic origin. Qanat 5 (Elimon) had first rank in terms of water quality and was in the category of good quality with a numerical value of 56.05. The presence of various ions and cations in the water of this qanat was because of natural and tectonic origin. Qanat 6 (Mehdiabad) was ranked sixth in terms of water quality and categorized at poor quality with a numerical value of 119.37. The water quality of this qanat has anthropological origins so that a decrease in quality can be attributed to the diversion of sewage in residential areas, surface runoff, worn-out texture in the areas and non-observance of proper distance between water wells, sewage wells and agricultural and garden lands in the area of this qanat. Qanat 7 (Sulaymaniyah) was in the seventh rank in terms of water quality which was in the category of poor quality with a numerical value of 193.07. The water quality of this qanat can be related to anthropological origin, so that the route of sewage in residential areas, surface runoff, worn-out texture in the areas and non-observance of appropriate distance between water wells and sewage wells are within the area of this qanat. Qanat 8 (Aminabad) was ranked in eighth level in terms of water quality and in the category of very poor quality with a numerical value of 203.58. The reason is the presence of different ions and cations in the water of this qanat with anthropological origin.

Hosseini et al[13] investigated the application of WQI and hydro-geochemistry for surface water quality assessment of Chahnimeh reservoirs in the Sistan and Baluchestan Province, Iran. They revealed that the WQI zoning index showed a decrease in water quality in April compared to September, which can be attributed to a decrease in water level due to lack of water flow into reservoirs, high evaporation in the region and the continued entry of anthropological pollutants. Also, Aali et al[38] found similar results in water quality zonation of Chahnimeh reservoirs using WQI. Regarding the decrease in groundwater quality in the studied qanats in the East of Tehran, result of the research was consistent with our results; the low water quality in qanats 2, 6, 7 and 8 was caused by the introduction of anthropological pollutants.

Bahrami and Dastourani[18] assessed the groundwater quality of the Plain of Sarayan in South Khorasan Province, Iran in 2019, using WQI. They observed that most of the study areas had good water quality. On average, 70% of the areas had good water quality and 30% had excellent water quality. In comparison with 2012, the numerical value of WQI in 2017 was better, which can be attributed to the additional extraction of groundwater aquifers to supply drinking and even agricultural water, leading to changes in groundwater quality. In addition to the quality, it is also effective in depletion of groundwater aquifer, which results in salinity of water resources and instability of groundwater aquifers.[24] Therefore, the increasing use of groundwater from the studied qanats in the East of Tehran has also caused a decrease in quality and an increase in their anions and cations. In the study by Coletti et al,[22] the main source of water pollution in the studied river basin was attributed to agricultural activities. In the present study, the cause of low water quality was anthropological factors, including the direction of agricultural drains. Thu Minh et al.[26] evaluated the groundwater quality using Fuzzy-AHP. They showed that the reason for low groundwater quality in the study area was the factors related to natural and anthropological activities. Adimalla and Taloor[27] and Bhuiyan et al.[39] revealed that groundwater quality is influenced by geogenical and anthropological activities.

Conclusion

Due to population growth and industrial as well as agricultural development, groundwater resources are increasingly exposed to pollution. So, it is important to pay attention to their quality changes. The present study evaluated the quality of groundwater in the qanats located in the east of Tehran, Iran in 2020 using GWQI. According to the Water quality classification based on GWQI value, nearly 50% of the studied water samples were in the range of very poor to poor quality and the rest were in the range of good quality. The results of water quality zoning based on GWQI showed a decrease in the water quality of qanats 8, 7, 6 and 2. According to the results of this study, the sources of groundwater pollution were household wastewater, absorbing wells and chemical fertilizers applied to municipal parks and agricultural lands. It was found that the qanats located in the northern areas of the study basin had better quality than other areas. From south to the study basin, and along the route from the mother well to the outlet, the water quality decreases. It is due to the existence of incompatible uses in the qanat area, leakage of municipal sewage or urban runoff into the qanats, proximity to absorbing wells and sometimes irrigation of green spaces and parks in the path of the studied qanats. To control groundwater quality of the qanats in the East of Tehran, the quality monitoring network is recommended for a variety of pollutants and then optimized for the long term. In addition, it is necessary to determine the boundaries of the area in order to control the entry of various pollutants.

Authors' Contribution

Conceptualization: Mina Mackialeagha.
Data curation: Mohammad Bagher Salarian.
Formal analysis: Mohammad Bagher Salarian.
Investigation: Mohammad Bagher Salarian.
Methodology: Mohammad Bagher Salarian.
Project administration: Mina Mackialeagha.
Resources: Mohammad Bagher Salarian.
Software: Mohammad Bagher Salarian.
Supervision: Mina Mackialeagha.
Validation: Azita Behbahaninia.
Visualization: Azita Behbahaninia.
Writing–original draft: Mohammad Bagher Salarian.
Writing–review & editing: Mina Mackialeagha.

Competing Interests

The authors declare that they have no conflict of interest regarding this research.

Ethical Approval

Not applicable.

References

1. Hassanpur Kourandeh H, Fataei E. Investigation and qualitative classification of heroriver water by Canadian Water Quality Index (CWQI). Adv Environ Biol. 2014;8(5):1442-8.
2. Sabetjo M. Aqueduct Important Role in Protecting the Environment. Qanat National Conference; 2010; Gonabad. p. 12-24.
3. Hajjabbari S, Fataei E. Determination cadmium and lead pollution resources of Ardabil plain underground waters. Open J Ecol. 2016;6(9):554-61. doi: 10.4236/oje.2016.69053.
4. Zeini M, Ghaneian MT, Talebi P, Sharifi S, Sheikalishahi S, Goodarzi B, et al. Investigation of physical, chemical and microbial characteristics of Ahrestan subterranean canal (SC) water in Yazd district for water resources conservation and sustainable development. Tolooe Behdasht. 2008;7(1-2):36-42. [Persian].
5. Nakhaei M, Vadiati M. Application of fuzzy inference model to evaluation of qanat water quality for drinking and agricultural purposes (case study: Tehran province). Adv Appl Geol. 2012;2(4):44-52. [Persian].
6. Mirani Moghadam H, Karami GH, Bagheri R. Investigating the flow mechanism and groundwater origin of Gonabad plain qanats using hydrochemical and isotopic methods. Scientific Quarterly Journal of Geosciences. 2020;29(116):183-92. doi: 10.22071/gsj.2019.167977.1603. [Persian].
7. Zare Aghbolagh J, Fataei E. The study of changes in Ardabil plain groundwater level using GIS. Adv Sci Technol Res J. 2016;10(29):109-15. doi: 10.12913/22998624/61938.
8. Abbasi A, Taghavi L, Sarai Tabrizi M. Qualitative zoning of groundwater to assessment suitable drinking water using GIS software in Mohammad Shahr, Meshkinshahr, and Mahdasht in Alborz province. Anthropogenic Pollution. 2021;5(1):138-49.
9. Fataei E, Ajami F. The changes of heavy metals values in groundwater drinking water networks. MAGNT Res Rep. 2015;3(2):840-6. doi: 14.9831/1444-8939.2015/3-2/MAGNT.83.
10. Ghomi Avili F, Makaremi M. Predicting model of arsenic transport and transformation in soil columns and ground water contamination (case study: Gorgan plain, Iran). Anthropogenic Pollution. 2020;4(1):57-64. doi: 10.22034/ap.2020.1884347.1058.
11. Farhadi H, Fataei E, Kharrat Sadeghi M. The relationship between nitrate distribution in groundwater and agricultural landuse (case study: Ardabil plain, Iran). Anthropogenic Pollution. 2020;4(1):50-6. doi: 10.22034/ap.2020.1885788.1059.
12. Fataei E, Seyyedsharifi SA, Seiiedsafaviyan ST, Nasrollahzadeh S. Water quality assessment based on WQI and CWQI indexes in Balikhlou river, Iran. J Basic Appl Sci Res. 2013;3(3):263-9.
13. Hosseini H, Shakeri A, Rezaei M, Dashti Barmaki M, Shahraki M. Application of water quality index (WQI) and hydro-geochemistry for surface water quality assessment, Chahnimeh reservoirs in the Sistan and Baluchestan province. Iran J Health Environ. 2019;11(4):575-86. [Persian].
14. Magesh NS, Chandrasekar N. Evaluation of spatial variations in groundwater quality by WQI and GIS technique: a case study of Virudunagar district, Tamil Nadu, India. Arab J Geosci. 2013;6(6):1883-98. doi: 10.1007/s12517-011-0496-z.
15. Hoseinzadeh E, Khorsandi H, Wei C, Alipour M. Evaluation of Aydughmush river water quality using the national

sanitation foundation water quality index (NSFWQI), river pollution index (RPI), and forestry water quality index (FWQI). Desalin Water Treat. 2015;54(11):2994-3002. doi: 10.1080/19443994.2014.913206.

16. Tokatli C. Drinking water quality assessment of Ergene River Basin (Turkey) by water quality index: essential and toxic elements. Sains Malays. 2019;48(10):2071-81. doi: 10.17576/jsm-2019-4810-02.
17. Aazami J, Kianimehr N, Zamani A, Abdollahi Z, Zarein M, Jafari N. Water quality assessment of Ghezelozan river in Zanjan province using NSFWQI, IRWQI and Liou. J Environ Health Eng. 2019;6(4):385-400. [Persian].
18. Bahrami F, Dastourani M. Quality assessment of groundwater in the plain of Sarayan using water quality index (WQI). Iranian Journal of Irrigation & Drainage. 2019 Oct 23;13(4):1064-74. [Persian].
19. Eslami F, Shokoohi R, Mazloomi S, Darvish Motevalli M, Salari M. Evaluation of water quality index (WQI) of groundwater supplies in Kerman province in 2015. J Occup Environ Health. 2017;3(1):48-58. [Persian].
20. Nasrabadi T, Abasi Maedeh P. Evaluation of Tehran city groundwater quality by WHO water quality index. Human & Environment. 2013;11(26):1-12. [Persian].
21. Ranjbar A, Soltani J. Groundwater Quality Assessment of Eshtehard Plain Using Water Quality Index (WQI). The First Specialized Conference and Exhibition of Environment, Energy and Clean Industry; 2013; Tehran, Iran. [Persian].
22. Coletti C, Testezlaf R, Ribeiro TA, de Souza RT, Pereira DD. Water quality index using multivariate factorial analysis. Rev Bras Eng Agric Ambient. 2010;14(5):517-22. doi: 10.1590/s1415-43662010000500009.
23. Reza R, Singh G. Assessment of ground water quality status by using water quality index method in Orissa, India. World Appl Sci J. 2010;9(12):1392-7.
24. Zarei A, Khoshnamvand M. Investigation of Drinking Water Quality Indicators of Deep Wells (Case Study: Shiraz). First National Conference on Environmental Protection and Planning; 2012; Hamedan, Iran. [Persian].
25. Ghandali M, Shayesteh K, Sadi Mesgari M. Groundwater quality zoning for agricultural and drinking usage using water quality index and geostatistics techniques in Semnan watershed. J Water Soil Sci. 2019;23(1):187-98. doi: 10.29252/jstnar.23.1.14. [Persian].
26. Thu Minh HV, Avtar R, Kumar P, Tran DQ, Ty TV, Behera HC, et al. Groundwater quality assessment using fuzzy-AHP in An Giang province of Vietnam. Geosciences. 2019;9(8):330. doi: 10.3390/geosciences9080330.
27. Adimalla N, Taloor AK. Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using geographic information system (GIS) and groundwater quality index (GWQI) techniques. Groundw Sustain Dev. 2020;10:100288. doi: 10.1016/j.gsd.2019.100288.
28. Jafari Aval Y, Ebadati N, Yousefi H, Kalantari B, Mirzaei M. Distribution and monitoring of aqueducts water quality for water resources management. Iranian Journal of Ecohydrology. 2017;4(1):39-52. [Persian]
29. Towfiqul Islam AR, Siddiqua MT, Zahid A, Tasnim SS, Rahman MM. Drinking appraisal of coastal groundwater in Bangladesh: an approach of multi-hazards towards water security and health safety. Chemosphere. 2020;255:126933. doi: 10.1016/j.chemosphere.2020.126933.
30. Vadiati M, Asghari-Moghaddam A, Nakhaei M, Adamowski J, Akbarzadeh AH. A fuzzy-logic based decision-making approach for identification of groundwater quality based on groundwater quality indices. J Environ Manage. 2016;184(Pt 2):255-70. doi: 10.1016/j.jenvman.2016.09.082.
31. Singh CK, Shashtri S, Mukherjee S, Kumari R, Avatar R, Singh A, et al. Application of GWQI to assess effect of land use change on groundwater quality in lower Shiwaliks of Punjab: remote sensing and GIS based approach. Water Resour Manage. 2011;25(7):1881-98. doi: 10.1007/s11269-011-9779-0.
32. Ramakrishnaiah CR, Sadashivaiah C, Ranganna G. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. E J Chem. 2009;6(2):523-30. doi: 10.1155/2009/757424.
33. Bouwer H, Bouwer H. Groundwater Hydrology. New York: McGraw-Hill; 1978.
34. Abrol IP, Yadav JS, Massoud FI. Salt-Affected Soils and Their Management. Food and Agriculture Organization; 1988.
35. Watkins CB, Brown JM, Dromgoole FI. Salt-tolerance of the coastal plant, *Tetragonia trigyna* Banks et Sol. ex Hook. (climbing New Zealand spinach). N Z J Bot. 1988;26(1):153-62. doi: 10.1080/0028825x.1988.10410107.
36. Kargar MH, Ehrampoush MH, Ghaneian MT, Shiranian M. Study of Chemical and Microbial Quality of Shorbolein Qanat Water. 8th Environmental Health National Conference; 2005; Tehran. [Persian].
37. Zia H, Qatani H. Hydrogeological and Hydrochemical Study of Qanat Baladeh Ferdows. Qanat Baladeh Ferdows National Symposium; 2019; South Khorasan, Iran. [Persian].
38. Aali T, Rezaei MR, Siamardi SJ. Qualitative Zoning of Water Reservoir Chahnimeh in Year 2013 Based on Water Quality Indices. The 1st National Conference on Environment, Energy and Biodefense; 2013; Tehran. [Persian].
39. Bhuiyan MAH, Bodrud-Doza M, Towfiqul Islam AR, Rakib MA, Rahman MS, Ramanathan AL. Assessment of groundwater quality of Lakshimpur district of Bangladesh using water quality indices, geostatistical methods, and multivariate analysis. Environ Earth Sci. 2016;75(12):1020. doi: 10.1007/s12665-016-5823-y.