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Physical, chemical and biological quality assessment of aqueduct (Qanat) water for drinking, agriculture and irrigation of urban green spaces

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ABSTRACT

BACKGROUND AND OBJECTIVES: The aqueduct is one of the most complex and amazing inventions of human history, created to meet the most vital needs of human society in arid and semiarid regions areas. If aqueducts are properly maintained, reconstructed, and restored, they can be valuable water supply system from ground water resources. The quality of the water in these sources will have a direct impact on the consumer of its consumption, so it seems necessary to check the water quality of these sources.
METHODS: This study investigated the state of five aqueducts in Tehran using parameters such as calcium, magnesium, phosphate, sulfate, turbidity, total hardness, nitrate, alkalinity, electrical conductivity, Biochemical Oxygen Demand, Chemical Oxygen Demand, total coliform and fecal coliform. Then the obtained values were compared with the permissible limits of the World Health Organization and the national standard of Iran. The data was analyzed using SPSS26 software and a one-sample t-test.
FINDINGS: The results of water quality during a one-year survey period showed that the parameters of alkalinity, electrical conductivity, total dissolved solids, sulfate, and nitrate were below the maximum desirable and permissible standards of the national standard of Iran and the World Health Organization, and therefore will not create any restrictions for drinking and agricultural use. Total hardness, phosphate, turbidity, calcium, magnesium, and chlorine have discrepancies with the national standards of Iran and the World Health Organization and these components must be adjusted for use. According to the one-sample t-test, there was a significant difference between the average and the permissible values of all parameters except magnesium at the 95% confidence level. All aqueducts except the America aqueduct had levels of fecal coliform that were higher than the maximum allowed by the environmental standards therefore, before using the aqueduct, it must be purified to control the environmental standards.. However, the total coliform, Biochemical Oxygen Demand, Chemical Oxygen Demand levels were not a problem. In addition, the water quality of these sources was placed in a group (C3S1) based on the Wilcox diagram.
CONCLUSION: The physical and chemical analysis of the studied aqueduct water showed that the water quality is suitable for the irrigation of green spaces and salt-resistant plants. The biological characteristics of the studied aqueduct water also revealed that these sources were polluted by domestic and industrial effluents. This issue will only grow worse with time, as the amount of rainwater decreases and the amount of pollution in the underground water sources increases.

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INTRODUCTION

Water is a limited and precious natural resource that is under severe pressure in many parts of the world. Climate change, rapid urbanization, and inappropriate urban planning policies have led to urban water-related problems such as flooding, water pollution, and water shortages (Nguyen *et al.,* 2019). In other words, the provision of new water sources in response to increased water demand due to the effects of climate change, reduced water quality, and increased demand for ecological flow protection involves many uncertainties. One of the most important environmental problems is the lack of water. This critical problem has increased in many parts of the world during the last decades and is expected to increase in the future due to socio-economic and climate changes (Kahil *et al*., 2019). Semi-arid regions around the world experience lower rainfall and higher evaporation and transpiration rates. With water scarcity being a major concern in many arid and semi-arid regions, it is essential that the available water resources be properly managed (Priyan, 2021). Today, countries are trying to manage the supply and demand of current water resources or use unconventional water resources by using different methods, for example, improving water consumption efficiency and emphasizing saving at the regional level, planting crops with low water consumption (Cao *et al*., 2021; Mehdipour *et al.,* 2017), increasing the efficiency of irrigation systems and water distribution systems (Xiang *et al.,* 2021), reuse of sewage treatment plant effluent (Chfadi *et al.,* 2021), use of fog water (Correggiari *et al*., 2017) and desalination of salty waters (Qadir, 2020). Considering the climatic conditions of Iran, where the average rainfall in most regions is lower than the global rainfall, it can be said that water is one of the main concerns of Iranians and the biggest challenge facing people inhabitants of this country. Meanwhile, as the most interesting traditional irrigation system invented by Iranians, aqueduct is one of the environment-friendly systems that benefits both rural and urban communities in semi-arid climates (Abbasi *et a*l., 2013; Abizadeh, 2011). Access to sufficient quantities of good quality water is one of the basic needs of any society for survival, development of health and protection of the environment (Amanial, 2016). According to the Environment and Health Regulations approved by the Council of Ministers of the Islamic Republic of Iran in 1991, potable water is defined as water whose physical, chemical and biological factors are within the limits of approved standards and whose consumption does not cause any side effects in Short-term or long-term in humans (Islamic Council Research Center, 1991). One of the adverse effects of excessive nitrate and nitrite in drinking water is the creation of carcinogenic compounds and the prevention of the absorption of iodine (WHO, 2011). Hardness refers to the concentration of polyvalent metal cations in the solution, and can affect the taste of the water. The harder the water, the lower the toxicity of heavy metals in organisms (Javid *et al*., 2007). A hardness higher than 200 mg/liter causes deposits in the pipes, in the distribution network and also reduces the cleaning power of the water, and a hardness lower than 100 mg/liter and a pH lower than 7 cause corrosion of the pipelines (Mahvi, 2010). In the current study, coliforms are Gram-negative, spore-free, aerobic and facultative anaerobic bacilli that live in the colon of humans and warm-blooded animals and are tested for microbial water monitoring. The amount of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) are considered an important index when measuring wastewater pollution. This parameter is used to determine the pollution of aquatic environments in terms of foreign substances entering them, which can be observed in solution or suspended form. The BOD parameter in wastewater is the amount of oxygen required by microorganisms during the biochemical oxidation of the organic materials contained in it, or the rate of oxygen consumption in the water environment, considered an indicator of the purity of water and the presence of organisms. When the amount of BOD is up to 5ppm, the water is relatively pure, and increasing the amount to concentrations above 5 will also increase the impurity of the water and exceeding the amount of 20ppm will harm human health (Varsa *et al*., 2014). Many researchers have presented their experiences of studying the physical and chemical state of water in different regions in various articles, some of which will be mentioned.

Literature review

Zeini *et al*. (2008) examined the physical, chemical, and microbial condition of Ahrestan aqueduct water in Yazd by direct sampling from 5 different stations. The hardness of magnesium, chlorine, sulfate, and the alkalinity of carbonate, bicarbonate, and coliform were measured, and then compared the results with the relevant standards. It is found that the water of the mentioned aqueduct can be used for other purposes, such as fish breeding, animal consumption, drinking, in addition to agriculture (after filtration and chlorination, the water is safe to drink) and used to create tourist and recreational places. Golpaegani *et al*., (2012) using 189 water samples from deep wells of the Gorgan Plain, to evaluate the quality and hydrochemical evaluation of the main cations (K +, Na +, Mg2 +, Ca2 +) and main anions (CO32-, SO42-, Cl-, HCO32-) and the parameters (pH, electrical conductivity and total dissolved solids) were discussed. In examining the changes in the hydrochemical parameters of the Gorgan Plain groundwater, they came to conclusion that the trend of qualitative changes in the center and northwest of the plain is towards an increase in the concentration of chlorides, sulfates and salinity of the water, which it is caused by the spill of urban and industrial pollution and the infiltration of sea water in these areas. They also stated that 71.43% of the samples belong to the C3-S1 group according to the Wilcox diagram, which indicates high salinity and low sodium, and that the region's underground water is in a range from good to acceptable for drinking and also suitable for agriculture. Salameh Nezhad *et al.,* (2013) examining the process of physical, chemical and microbial changes such as turbidity, temperature, pH, Total Dissolved Solids (TDS), magnesium, calcium, phosphate, nitrated water of the aqueducts in the city of Taft using agricultural indicators and Water Quality Index (WQI), concluded that according to the Wilcox diagram, water from several stations for agricultural purposes is classified as C4S1, C3S1 and that only one station is in the bad class and the others are in the acceptable classification. They are also of very good quality based on the Sodium Absorption Ratio (SAR) level. The trend of changes in water quality for agriculture and public use in urban management from north to south of the Taft region is towards improving water quality, but as most parameters show a trend towards upside, changes in water quality generally tend to be unfavorable. In a study, Nasrabadi and Abbasi (2013) examined the groundwater quality in Tehran in 2013 and 2014 and compared their results with the World Health Organization method and concluded that the water quality in 2014 was lower than that of 2013 and to the East and South points of Tehran are of lower quality and in the ranking carried out, the northern region had the highest score in the correct range and the southern regions had the lowest scores in this range. They also stated that the over-abstraction of water wells and drought, as well as the input of non-geological pollutants such as sulphate and nitrate into the groundwater table have led to increased concentrations of pollutants and deterioration of the water quality. Using graphical methods such as Wilcox, Shuler and Piper diagrams, Soleimani Sardo *et al*. (2013) investigated the trend of water quality parameters and changes in the Chamanjir River in Khorram Abad, Lorestan. Studying of the Piper diagram, the calcium-magnesium type of water quality were introduced. According to Schuler's map, all water samples from the Chamangir River were of high quality and acceptable, and there were no drinking restrictions. In addition, the Wilcox plot showed that most of the samples were in the low salinity class (C2S1) and almost suitable for agriculture. In addition, during the experimental period, most parameters showed an increasing trend over time and a significant correlation at the 99% level. Mansouri and Barmaki Yazdi (2014) examined the physical and chemical parameters of the water in the central part of the Birjand aqueduct and examined the relationship between them using the Pearson correlation test and found that there was a significant correlation between temperature and nitrates at the 95% level and all physical parameters and the chemical meet health standards and presents no health problems for human consumption. Yazdanbakhsh *et al*, (2015) examined the quality of surface water runoff from Tehran's Firozabad canal for irrigation purposes. This research was conducted in an experimental laboratory. The results showed that the averages of BOD5, COD, pH and heavy metals measured, with the exception of nickel, comply with the Irrigation Effluent Standards of the Environmental Protection Organization of Iran. Electrical conductivity, total dissolved solids, SAR, chloride and boron were evaluated in a low to medium range and an acceptable sodium percentage for irrigation. The mean amount of turbidity, Total Suspended Solids (TSS) and the number of heat-resistant coliform and coliform bacteria were measured above wastewater standards for use in irrigation and agriculture. Jafari Aval *et al*.

(2017) monitored the water quality of the aqueducts in eastern Tehran. The monitoring was performed with regard to the environmental indicators. The research method was based on the collection of statistics and information based on documentary studies, field visits, sampling and experiments. The results revealed that all the aqueducts in eastern Tehran are almost similar in terms of water quality, but can be distinguished by some qualitative variables. Water chemical variables such as nitrates, sulfates, heavy metals, NH_3, Electrical Conductivity (EC), TDS, PH, Dissolved Oxygen (DO) showed that in most cases the water quality of the aqueducts is adequate for drinking by national and World Organization standards of Health, and in some areas, such as the village of Deh Khair in Shahr-e-Ray, they have more biological pollution than allowed. Also with regard to the index necessary for agricultural purposes, the results of the tests indicated the suitability of the aqueducts in the eastern part of Tehran. Hosseini *et al*. (2018) conducted a study on groundwater quality in the Abbas plain southeast of Dehloran city in Ilam province, found that the main hydrochemical level of the groundwater in the area is calcium sulfate ($Ca-SO_4$), and based on this, only there are a few wells which have potable water. According to the World Health Organization, only some wells are suitable for drinking and for irrigating soils with sufficient permeability to grow salt-tolerant plants. Golzar Khojasteh *et al*. (2019) and his colleagues conducted a study on the physicochemical status of drinking water sources in Asadabad City, Hamedan province from 2010 to 2016 and came to the conclusion that the measured parameters were within the range of the national standard of Iran, but some of the measured items were increased compared to 2016. By examining the physical and chemical properties of drinking water in the villages of Nayr, Pourfaraj and Mokhtari (2021) came to the conclusion that 13 of the parameters measured in the drinking water supply sources of these villages are less than the maximum desirable standard in 82 villages and less than the maximum permissible standard. Therefore they are subject to monitoring programs for water safety and environmental health. Kazemi *et al*. (2022) investigated the health risk of Total Chromium (CrT) in southern Khorasan aqueducts in eastern Iran. For this work, the concentration of CrT was measured in a total of 83 aqueducts in the summer of 2020. The samples were initially tested for temperature, pH, dissolved oxygen (DO), electrical conductivity (EC) and total dissolved solids (TDS) on the field. The results showed that the CrT concentration ranged from 1.79 to 1017.05 g / L-1 and a total of 25 stations showed that the CrT concentration was above WHO standards (50 µg L-1). The total amount of CrT in South Khorasan aqueducts exceeds the World Health Organization limit, increasing the risk of carcinogenicity for residents and, in turn, requiring greater efforts to provide sanitary groundwater to consumers. Sedeño et al. (2022) assessed the water quality of aqueducts in arid regions of south-central Mexico using several multivariate approaches. 24 aqueducts were analyzed to assess the quality of the water. Based on 24 physicochemical variables, a Water Quality Index (WQI) was developed on a scale from zero to 100, divided into five water quality classes. The results of the WQI scores showed that 12.5% of the aqueducts are of excellent quality. 25%, good quality; and the rest (62.5%) ranges from mediocre to unacceptable quality. The interpolation maps show better water quality in the northern part of the aquifer. Rezaei *et al*. (2019) assessed the groundwater quality and heavy metal pollution indicators in the watershed of Bazman, one of the cities of Sistan and Balochistan in southeast Iran. Evaluation and measurement of groundwater hydrochemical parameters such as pH, TDS, EC, Temperature (T), Redox (Eh) and DO, major cations. K+, Na+, Ca2 and Mg2+) and major anions (Cl-, HCO3-, SO42- and NO3-). In the present study, three main hydrochemical facies were identified in the water samples: Na-Cl, Na-HCO3 and Ca-Cl. In addition, four pollutant indices were selected to assess the extent of heavy metal exposure, the Heavy Metal Exposure Index (HPI), the Heavy Metal Evaluation Index (HEI), the Exposure Index (EI) and the new modified Heavy Metal Exposure Index (HPI), for 9 heavy metals (As, Ba, Cr, Cu, Fe, Mn, Ni, Se and Zn) in the study area. The indicators showed that most of the water samples have low and medium pollution, and the overall pollution level is not dangerous. Principal Component Analysis (PCA) and correlation analysis showed that anthropogenic sources (ie, surface runoff and agricultural fertilizers) and natural/geological processes (ie rock-water interaction) caused the change in physicochemical parameters in the catchment. The obtained results provide useful information for the management of water resources in areas like Bozman, which are especially exposed to human activities. In recent years, several studies have been carried out on the physical and chemical properties of aqueduct in different cities, but the decrease in precipitation and the increase in the discharge of domestic and industrial sewage into underground sources may lead to an increase the concentration of certain elements in the water. This doubles the need for more recent studies for the aqueducts of Tehran, and on the other hand, since these sources are partly used directly in the irrigation of urban green spaces (Neisiani *et al.,* 2016). These sources should also be studied biologically to assess their impact on human health. Due to the lack of aquatic resources, especially in arid and semi-arid regions, aqueducts can play an important role in fulfilling some water needs. Research on contamination of these groundwater sources is important for the study of microbiological pollution based on drinking water. Therefore, monitoring the water quality of these sources is very important. This study aims to measure the physical, chemical, and biological variables of aqueduct water and determine the consumption limit for different uses of 5 aqueducts (Qanats) situated in District 6 of Tehran-Iran. The current study have been carried out in Tehran in 2021-2022.

MATERIALS AND METHODS

This research is a cross-sectional descriptive study aimed at examining the physical, chemical and biological parameters of water and their comparison with the national standard of Iran and the World Health Organization in 5 aqueducts (America, Behjat-Abad, Abbas-Abad, Russia and Yusuf-Abad Aqueducts) in District 6 of Municipality of Tehran (Fig. 1).

For this purpose, seasonal sampling of each aqueduct was carried out in 2019 and 2020. A total of 80 samples were collected in 1.5 liter sterile polyethylene containers. For each point, 2 containers were filled with water and one sample was acidified with pure nitric acid to a pH of less than 2 and prepared for heavy metal measurement, while the other samples were prepared for anions and cations measurement based on methods presented in the 1998 Standard Method Book (Walter, 1961). For each sample, 15 parameters were measured, including pH, BOD, COD, turbidity, EC, TDS, phosphate, sulfate, nitrate, total hardness, chlorine, calcium, magnesium, total intestinal group, fecal intestinal group. PH, electrical conductivity and water temperature were measured at the sampling site. Minor element concentration was measured by graphite furnace atomic absorption method and anion concentration was measured by spectrophotometric titration (Garduño *et al*., 2011), cation concentration (Mg by titration) was measured in laboratory. Eq. 1 was used to obtain the Sodium Absorption Rate (SAR), which is an indicator for determining the suitability of water for use in irrigation and agriculture and measures the alkaline cations in water. This indicator is considered a standard for warning about soil salinization (Sattari *et al*., 2020).

$$\textbf{SAR}=\frac{\mathbf{Na}^{+}}{\sqrt{\frac{1}{2}\left(\mathbf{Ca}^{2+}+\mathbf{Mg}^{2+}\right)}} \quad (1)$$

Data analysis was performed using SPSS26 software and the statistical test used was the one-sample t-test. To determine the acceptable range of cations, anions, DS and EC, water chemistry and pH from the World Health Organization Physical Properties Standard (WHO, 2011) and of Iran's national standard were used (Table 1).

RESULTS AND DISSCSIONS

Since the water of the studied aqueducts can be used individually, the average, minimum and maximum value of each parameter for the US Embassy , Behjat-Abad, Russia, Abbasabad and Yusuf-Abad aqueducts were compared with the maximum desired and permissible values of National standards of Iran and the World Health Organization. PH is one of the most important physicochemical properties of water. The average of this parameter is below the limit established by the World Health Organization and the national standard of Iran. Statistical analysis performed using the one-sample T-test on the data from this study showed that there is a significant difference between the mean pH values and the maximum desirable and permissible values of the national standard of Iran and the World Health Organization (P = 0.000). Fig. 2 shows that all channels have a pH below the permitted limit. Another physical-chemical property of water is electrical conductivity, which is a measure of a solution's ability to conduct electricity. Because this capacity is

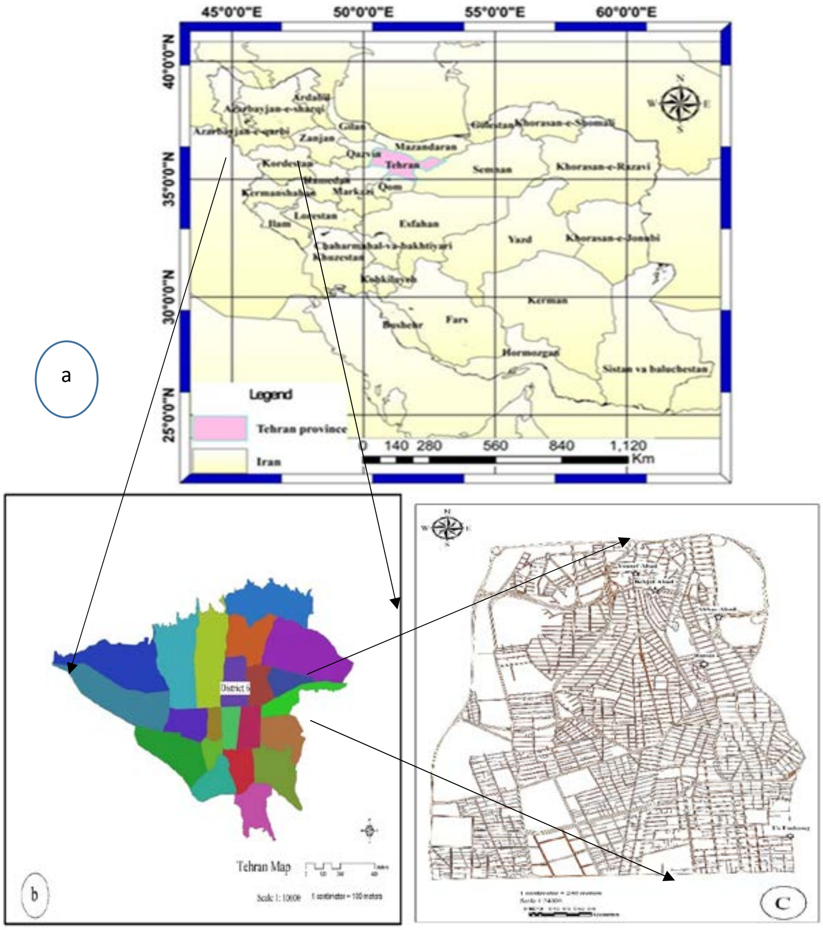

Fig. 1: The study location- a) Iran, b) Tehran Districts, C) 5 aqueducts

Table1. Permissible values of measured parameters according to the national standard of Iran and the WHO (WHO, 2011)

Parameter	Unit	WHO	National Standard of Iran	
			Maximum allowed	Optimal maximum
pH	-	6.5-8.5	6.5-9	6.5-8.6
Turbidity	NTU*	-	5	1
EC	µS/cm	1500	-	-
TDS	mg/L	-	1500	1000
PO4	mg/L	-	0.2	0.1
SO4	mg/L	200	400	250
No3	mg/L	20	50	-
TH	-	-	500	200
CL	mg/L	200	400	250
Mg	mg/L	50	-	30
Ca	mg/L	75	-	300
Na	mg/L	200	-	-
K	mg/L	12	-	-
$HCO3^{-}$	mg/L	150	-	-

*Network Termination Unit

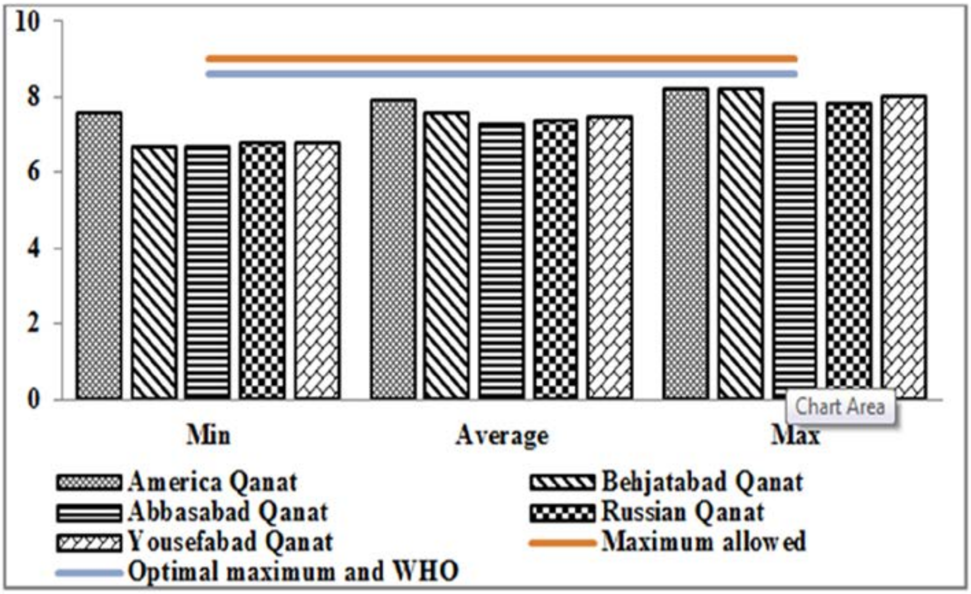

Fig. 2: pH and its comparison with the WHO and the National Standard of Iran

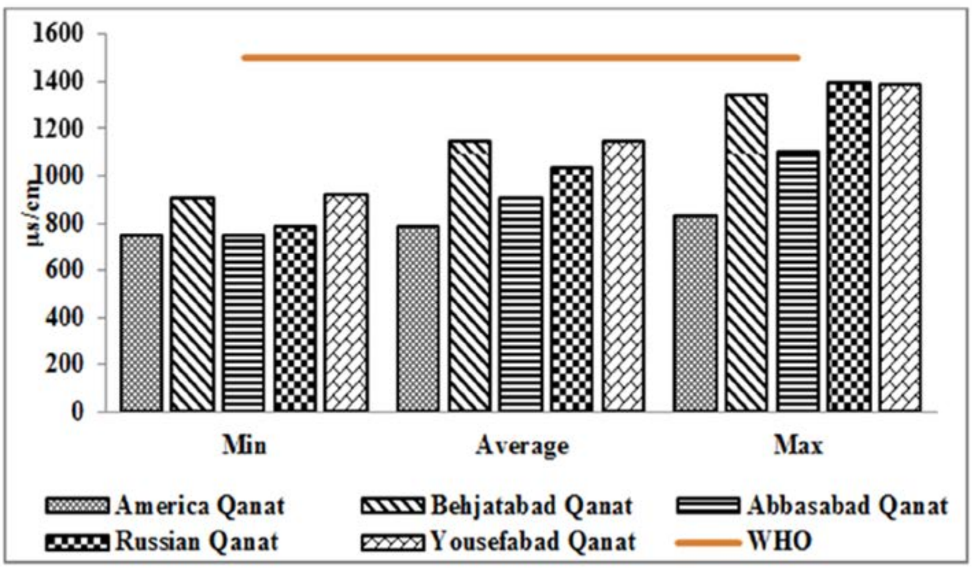

Fig. 3: EC level and its comparison with the WHO and the National Standard of Iran

a function of the presence of ions in a solution, the measurement of this parameter is a good indicator of total dissolved substances in water (Amanial, 2016). The Iranian national standard has not specified a limit for this parameter, but the World Health Organization has specified a maximum of 1500 µs/cm for it (WHO, 2011), with all samples below the permitted limit (Fig. 3). Statistical analysis performed using the one-sample T-test on the data showed that there is a significant difference between the mean EC values and the World Health Organization values at the 95% level (P = 0.000).

TDS is one of the most important chemical parameters in water, which indicates the presence or absence of different types of mineral salts and ions such as chloride, sulfate, phosphate, calcium, magnesium, potassium, iron, etc. (Omer, 2019). The average of this parameter in all samples was equal to 748.02, which has a significant difference with the maximum desirable and permissible level of the national standard of Iran at the level of 95% (P=0.000). The total amount of dissolved solids in each aqueduct is less than the maximum desired and allowed by the national standard. The World Health Organization has not specified the specific value of this parameter (Fig. 4). Based on the results, it can be concluded that the hardness of the America aqueduct is lower than the optimal value, and the hardness of other aqueducts is higher than the optimal value. In addition, Behjat-Abad, Russia and Yusuf-Abad aqueducts have values exceeding the maximum limit (Fig. 5). The World Health Organization has not provided a virtual value

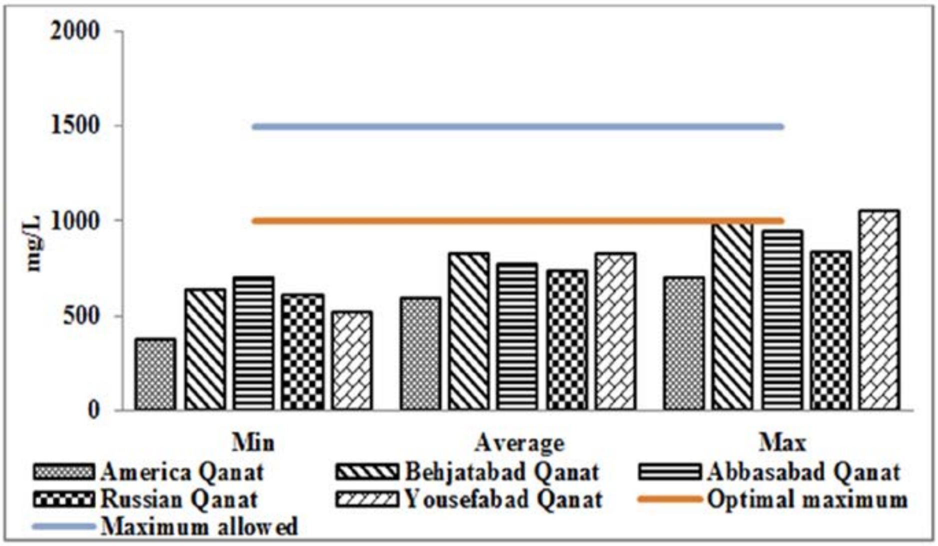

Fig. 4: TDS level and its comparison with the WHO and the National Standard of Iran

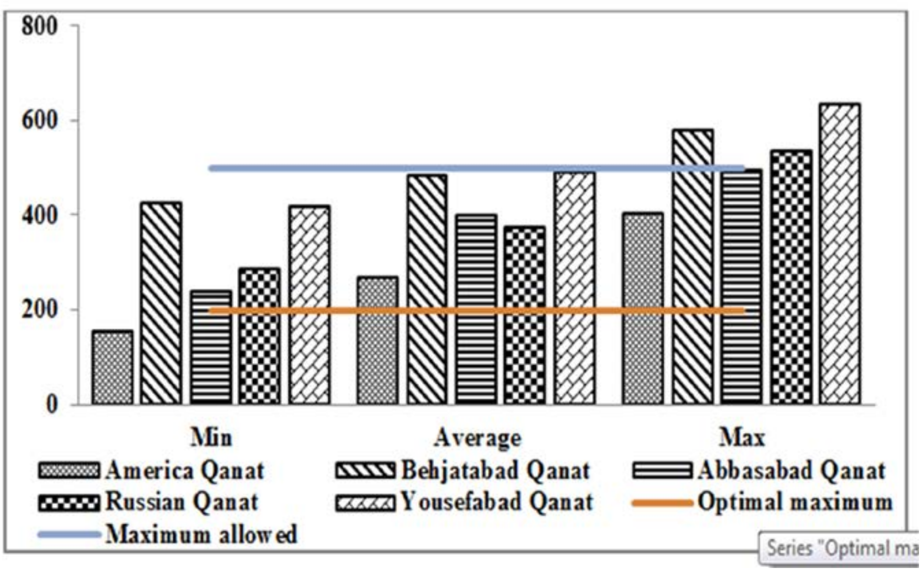

Fig. 5: Total hardness and its comparisons with the WHO and the National Standard of Iran

for this parameter. Based on the one-sample T-test, there was a significant difference between the average hardness and the maximum desired and permissible level of the Iranian national standard at the 95% level (P=0.000).

The results show that the average concentration of phosphate in the studied aqueducts is higher than the maximum value of the national standard of Iran, while the World Health Organization has not reported a value for this parameter (Fig. 6). From a statistical point of view, there is a significant difference between the mean of this parameter and the maximum allowed at the 95% level (P= 0.000). However, the amount of sulfate in the aqueducts under study was lower than the three maximum desirable and permissible levels of the national standard and the World Health Organization and was within the desirable and permissible range (Fig. 7). The results from the statistical test were also similar to phosphate and there was a significant difference with the average with an error percentage of 5% (P=0.000).

One of the important indicators to show the quality of groundwater and agricultural water is the amount of nitrate in it, which enters the surface and groundwater water through the decomposition of human and animal waste, industrial products and agricultural effluents (Mohseni and Raheli

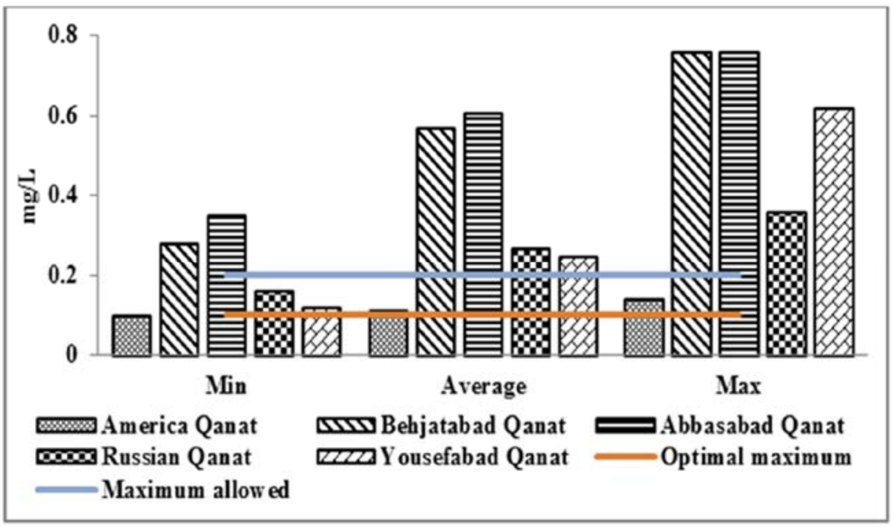

Fig. 6: Phosphate level of and its comparison with the WHO and the National Standard of Iran

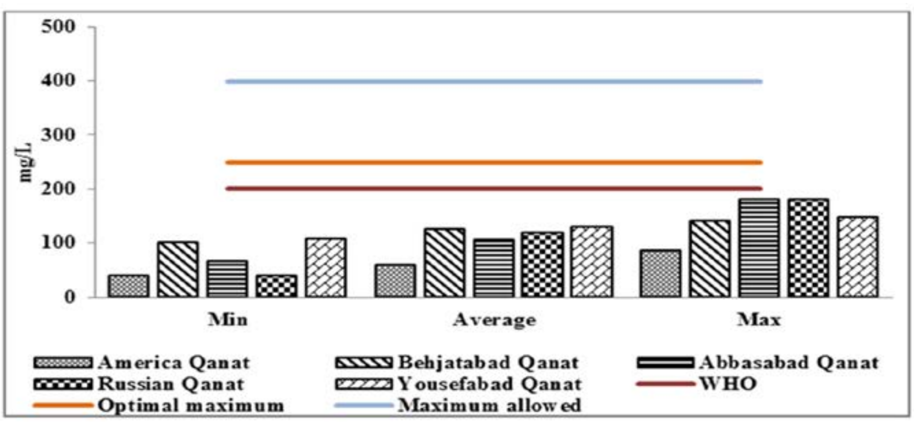

Fig. 7: Sulfate level and its comparison with the WHO and the National Standard of Iran

Namin., 2017). As shown in Fig. 8, the nitrate levels in the studied aqueducts are below the maximum permitted by the national standard of Iran and the World Health Organization. The average nitrate level in the aqueducts was significantly above the optimal maximum value and the World Health Organization's recommended limit at the 95% confidence level (P=0.000). Abbas-Abad and Russia aqueducts have a turbidity higher than the optimal maximum but lower than the maximum allowed and the water of other aqueducts has an optimal turbidity and less than 1 NTU. The mean turbidity (Fig. 9) of these channels, according to the single sample T test, has a significant difference from the desired and allowed maximum (P=0.000).

The investigation of concentration of calcium revealed that this cation was below the maximum amount specified in the national standard of Iran

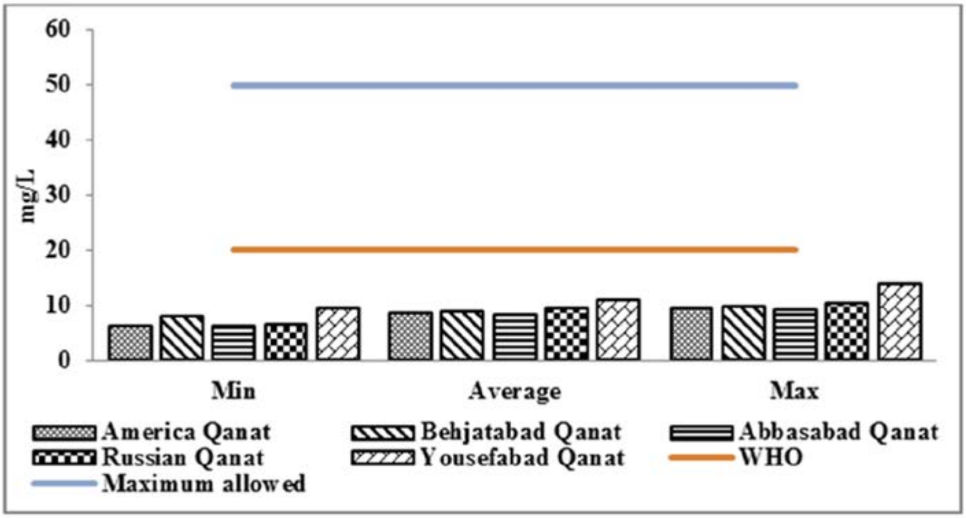

Fig. 8: NO3 level and its comparison with the WHO and the National Standard of Iran

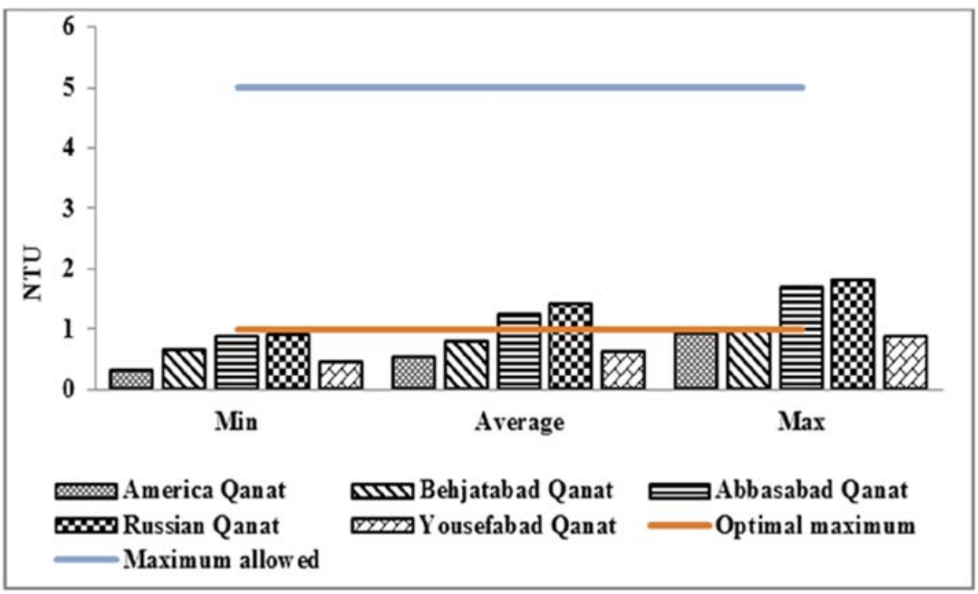

Fig. 9: Turbidity level and its comparison with the WHO and the National Standard of Iran

in all the aqueducts, but the average amount in the aqueducts, with the exception of the Russian aqueduct, was above the permissible limit of the World Health Organization (Fig. 10). Also, the average amount of calcium based on the statistical test had a significant difference at the 95% level with the World Health Organization and the optimal maximum of the national standard of Iran (P=0.000). The average amount of magnesium measured for different aqueducts in this research showed that only the America aqueduct has a value lower than the optimal maximum in some seasons of the year, and the average of the other aqueducts has values higher than the optimal maximum. Also, based on the statistical T test, the average value of magnesium has no significant difference at the 95% level (P=0.865) (Fig. 11), but there is a significant difference with the permissible limit of the World Health Organization (P=0.000).

Chloride is one of the main anions in water that

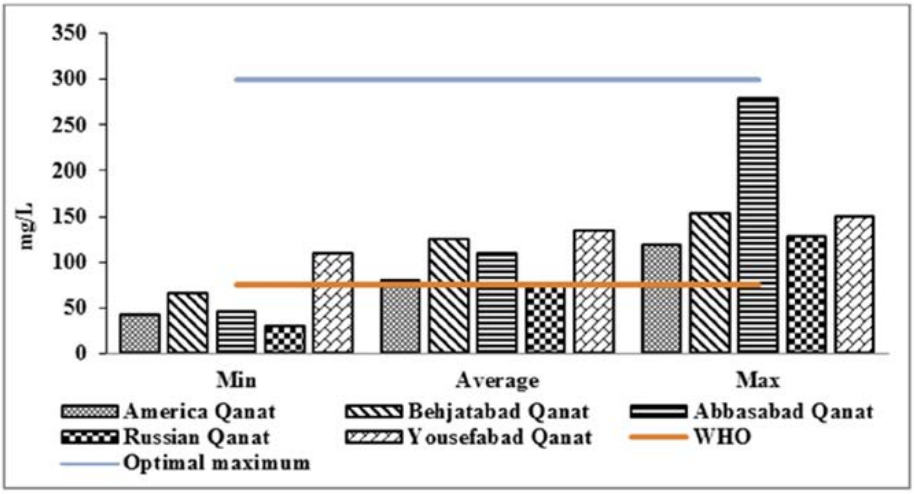

Fig. 10: Calcium level and its comparison with the WHO and the National Standard of Iran

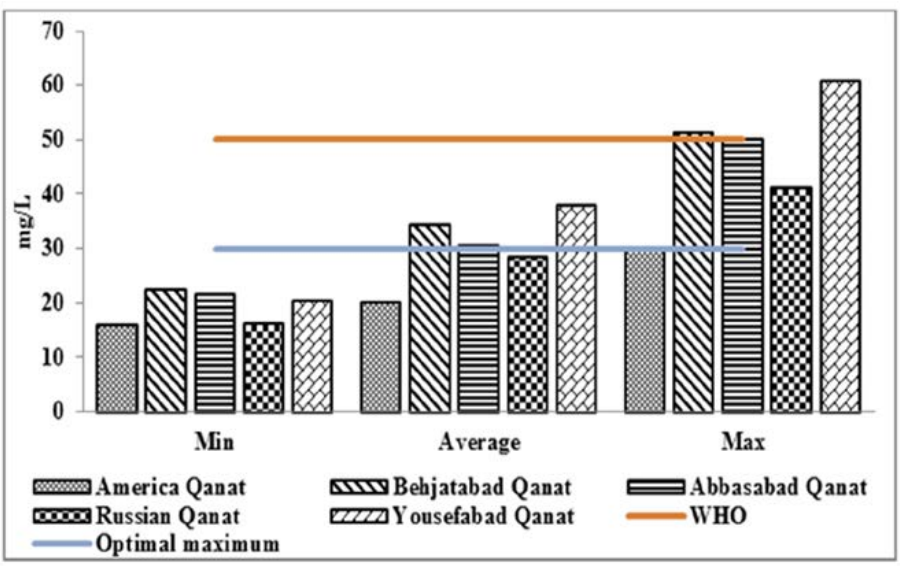

Fig. 11: Magnesium level and its comparison with WHO and National Standard of Iran

can cause permanent hardness. According to Fig. 12, the amount of chlorine in the different aqueducts is less than the maximum desired and allowed by the national standard, which is in accordance with the results of (Golzar Khojasteh *et al*., 2019), but the maximum values of the American and Yusuf-Abad aqueducts are more than the permissible amount of the World Health Organization. The average behavior of this parameter in the statistical test showed that there is a significant difference from the optimal and permissible maximum of the national standard of Iran and the World Health Organization (P=0.000). In the classification of water based on sodium absorption ratio, if SAR is less than 10 and is within one or two, the water is fresh and drinkable. If it is around 6, it is satisfactory for arable soils and crops (Jafari Aval *et al*., 2017) which according to Fig. 13 studied aqueducts are desirable for irrigation of agricultural lands and gardens and green spaces.

In addition to the parameters measured, Total Coliforms (TC), Fecal Coliforms (FC), COD and BOD were also measured. The allowable amount

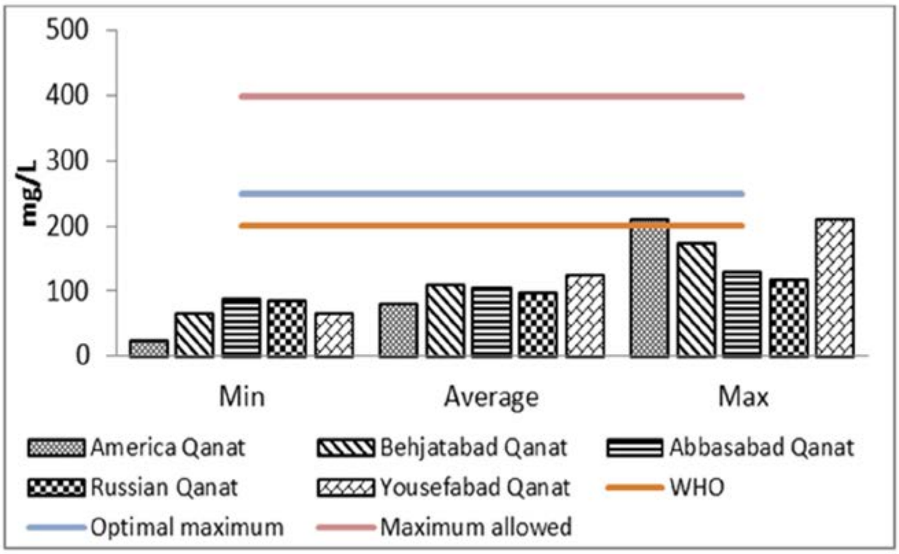

Fig. 12: Chlorine level and its comparison with the WHO and the National Standard of Iran

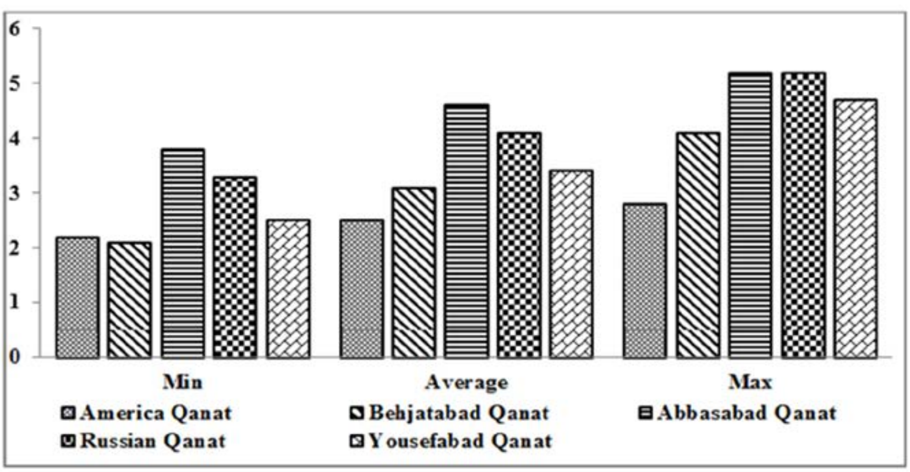

Fig. 13: SAR level of the studied aqueducts

of fecal coliforms for irrigation of green spaces with wastewater is about 100 MPN/100 ml, and the allowable amount of fecal coliforms and total coliforms for the return of wastewater to seepage pits and surface water is about 400 and 1000 units per 100 mL. (Environmental Aspects of Wastewater Reuse, 2015). According to the Figs. 14 and 15, the average of fecal coliforms and total coliforms of the water of the aqueducts were higher than the authorized limit, indicating that the water of these aqueducts is polluted and even for agricultural purposes, it needs purification.

The permissible values of BOD and COD parameters for return to absorption wells and surface water are 30 and 60 mg/liter, respectively, and for irrigation of green spaces with sewage, the BOD value is 31 mg/liter (Varse *et al*., 2014), that according to the results of these two parameters in the water of the investigated aqueducts, both parameters are below the permissible limit (Figs. 16 and 17).

The classification of water from an agricultural perspective is based on two parameters of electrical conductivity and sodium absorption ratio (Pourkhabaz *et al*., 2017). The points resulting from the intersection of these two parameters in the Wilcox diagram represent the category of the desired water sample.

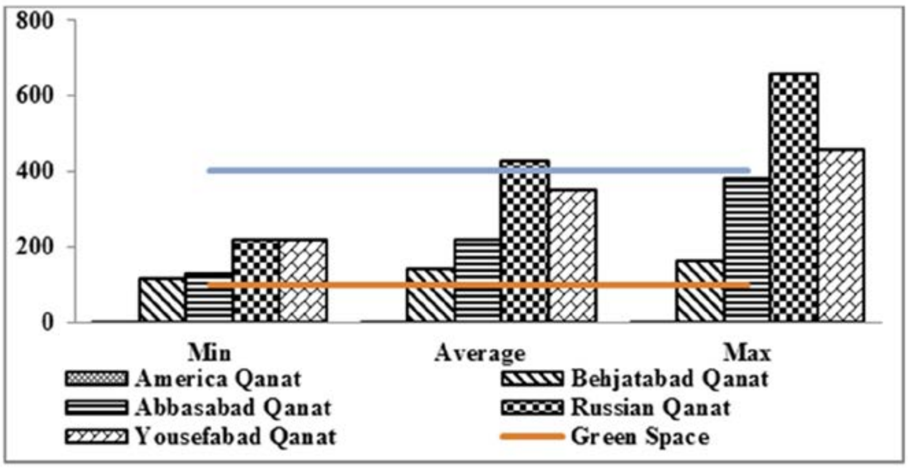

Fig.14: Measured fecal coliforms of the studied aqueducts (Qanats)

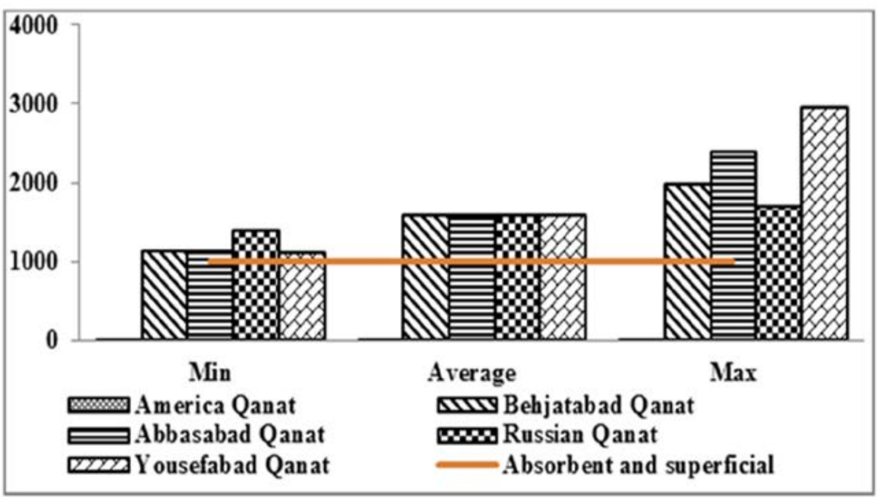

Fig. 15: Total coliforms (TC) measured of the studied aqueducts (Qanats)

The Wilcox classification method and its mapping is a very useful method to classify agricultural water in hydrological studies (SolaimaniSardo *et al*., 2013). According to the study results for the 5 aqueducts examined in the District 6 of the Municipality of Tehran showed that all samples fall into class (C3S1) and are acceptable for agriculture, but are more suitable for salt-resistant plants (Fig. 18).

According to current study conducted on the physical and chemical properties of water in the aqueducts of America, Behjat-Abad, Abbas-Abad, Russia and Yousef-Abad, it emerged that the parameters measured and compared were maximum desired and allowed by the national standard of Iran and the World Health Organization, magnesium alone has no statistically significant differences from the optimum maximum and other parameters such as turbidity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), phosphate, sulfate, nitrate, total hardness, chloride, calcium were measured in the terms of the one-sample T-test had a significant difference with the permitted values of the World Health Organization and the national standard. The concentration of most of the parameters was below the permissible limit of the compared standard, and this indicates that they have the necessary quality

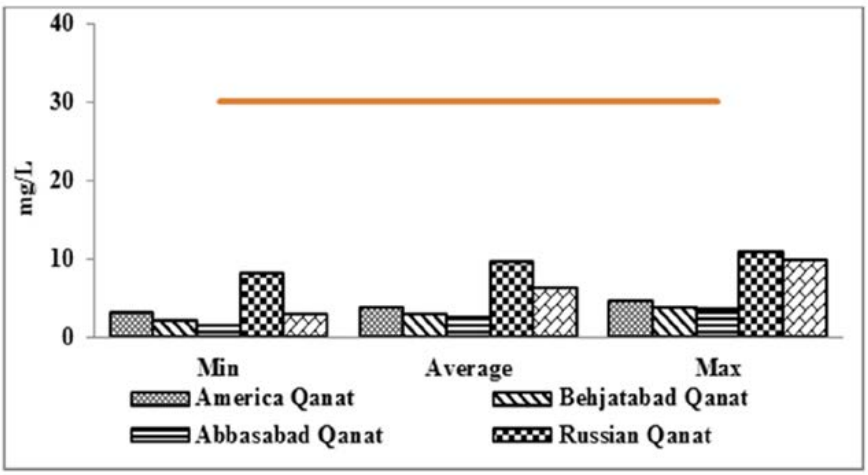

Fig. 16: The measured BOD level of the studied aqueducts

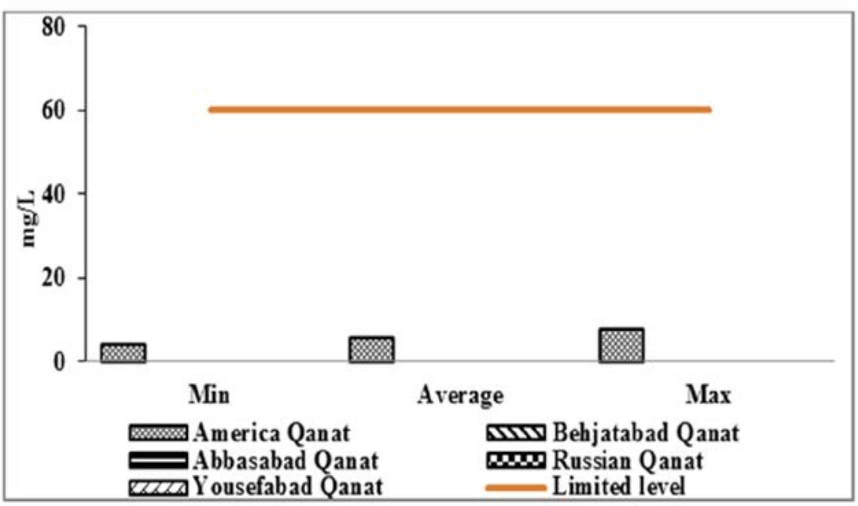

Fig. 17: COD level of the studied aqueducts

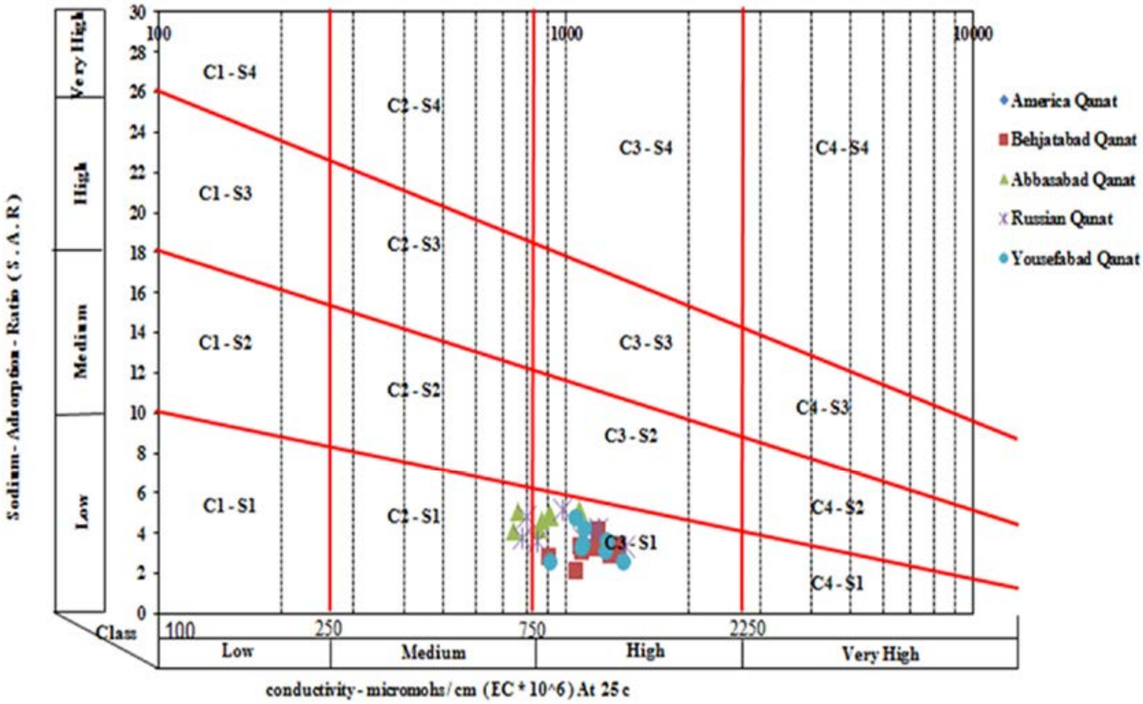

Fig. 18: Wilcox diagram of the studied aqueducts (Qanats)

for agricultural use, only for salinity-resistant plants and green spaces, which is consistent with the results of Pourfaraj and Mokhtari (2021); Nasrabadi and Abbasi (2013); Golzar Khojasteh *et al*. (2019). The Sodium Absorption Ratio in the studied channels is favorable for irrigation of agriculture and gardens and green spaces, which is also consistent with the results of Yazdanbakhsh *et al*. (2015). The Wilcox classification for agricultural water classification showed that all samples were in class (C3S1) and acceptable for agriculture, but best suited for salt-tolerant plants. These results are consistent with the results of Salameh Nezhad *et al*. (2013); Golpayegani *et al*. (2012). To verify the biological properties, parameters such as fecal coliforms, total coliforms, BOD and COD were measured, and comparing with the environmental criteria of return water and wastewater reuse, it is found that the BOD and COD are lower. It has exceeded permitted use limits in urban green spaces and has returned to surface waters and sinks, but they are not in favorable condition in terms of fecal coliform and total coliform counts, suggesting that these underground sources are contaminated with household waste in the water. It should be noted that there are industrial effluents that can lead to an increase in sodium, nitrate and phosphorus and gradually lead to soil compaction and a decrease in soil permeability. On the one hand, a decrease in precipitation, which leads to a decrease in surface runoff, and on the other hand, an increase in population leads to an increase in the production of polluted wastewater, and all this adds to the groundwater resources and reduces the physical, chemical and biological quality of groundwater resources. Therefore, it is necessary to periodically measure the existing or added effluents to these aqueducts and evaluate the quality of the groundwater to prevent contaminating sediments from entering the agricultural land and urban greenery.

CONCLUSION

The aqueduct is one of the most amazing collective works of art in human history, created with painstaking work, management and planning to meet one of the most important needs of human societies, to meet to the needs of dry and scarce areas in drinking water and to provide drinking water for humans, animals and agriculture. Qanat of the water supply has played an important and effective role in the economic system and social life of the country since the Iron Age as one of the sources of drinking water supply and agriculture in drought-prone areas such as the Iranian plateau, and led to the prosperity of agriculture and the creation of jobs and many urban and rural activities and reassured the populations. The present research attempted to review the previous research related to the subject, by spot sampling and at different time intervals from 5 aqueducts existing in the 6th district of Tehran, to examine the regeneration and optimal use of these aqueducts from the chemical and physical dimensions Also compared the values of the tested parameters with the permissible values of the World Health Organization and Iran's national standard. Data analysis was performed using SPSS26 software and a one-sample t-test. The results showed that the parameters of alkalinity, electrical conductivity, total dissolved solids, sulphate and nitrate are below the desirable and permissible maximum standards of the Iranian national standard or the World Health Organization and do not create any restrictions on drinking consumption and agricultural use.

LIMITATIONS OF THE RESEARCH

Quantitative and qualitative studies on groundwater resources always encounter difficulties in gathering information, but the protection and optimal exploitation of these resources require continuous monitoring of groundwater and careful identification and analysis of their quantity and quality are essential. The quantity and quality of the water from these sources is affected by the returning water, on the other hand accurately measuring and monitoring the returning water is considered a difficult task and reduces the accuracy of the research results and brings uncertainty.

SUGGESTION

According to the research conducted to improve the water quality of Tehran's aqueduct (Qanat) and better use of these underground resources, the following suggestions are made: 1) Study and identification of sources of contamination of the aqueduct and their elimination; 2) Prevent the entry of domestic wastewater through injection wells and discharge domestic wastewater into the municipal sewer system; 3) Prevention of industrial wastewater ingress; 4) Improve and solve the problems of the aqueducts and preserve these traditional water works; 5) Application of advanced water purification and sewage treatment methods for drinking.

AUTHOR CONTRIBUTIONS

P. Tolouei performed the literature review, taking samples, analyzed and interpreted the data, prepared the manuscript text, and manuscript edition. F. Babaei Semiromi and R. Arjmandi and A.H. Hassani and R. Azizinejad supervised and performed the corrections and reviewed the article and controlled the results of the research.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS

BOD	Biochemical oxygen Demand
COD	Chemical Oxygen Demand
CrT	Total Chromium
EC	Electrical Conductivity
HEI	Heavy Metal Evaluation Index
HPI	Heavy Metal Exposure Index
TDS	Total Dissolved Solids
WQI	Water Quality Index

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