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Evaluation of water quality in Rafsanjan county aqueducts

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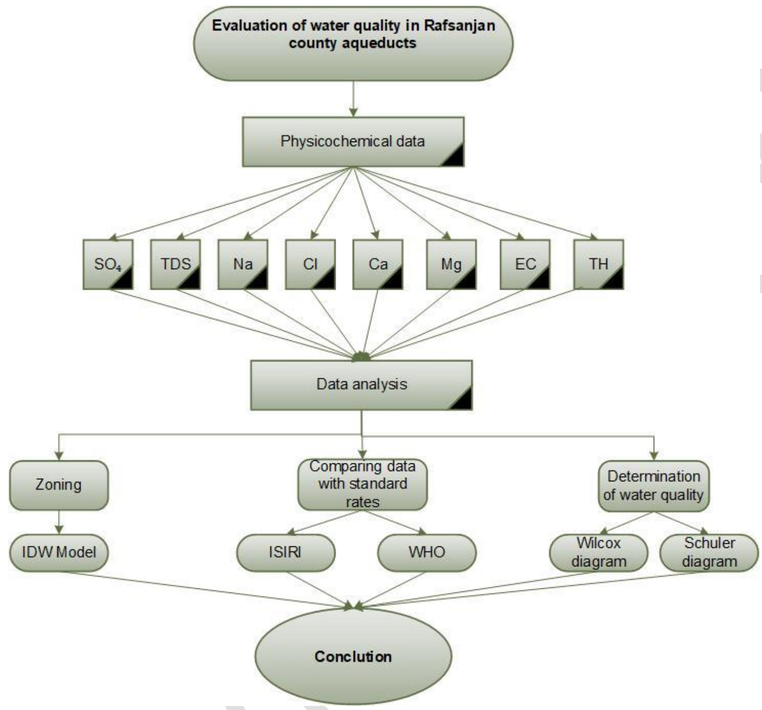
GRAPHICAL ABSTRACT



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ABSTRACT

The present study aimed to assess the water quality of six selected aqueducts using Schoeller and Wilcox diagrams and GIS, including Khanaman, Ahmadabad Daafeh, Saadatabad, Kourke, Kazemabad and Fadak in Rafsanjan in 2018. For the study, statistics and information on water quality indices such as sodium, calcium, magnesium, sulfate; bicarbonate, chlorine, electrical conductivity (EC), total hardness (TH), Arsenic, Nitrate, Ph and total dissolved solids (TDS) for 2018 were received from the Kerman Regional Water Organization (KRWO). The most suitable and unsuitable water quality for drinking and agricultural purposes was determined for the aqueducts of Khenaman and Fadak. From obtained results and Schoeller and Wilcox diagrams, Khenaman aqueduct showed good quality that is acceptable for drinking water (C2-S1). Based on the Schoeller and Wilcox diagrams, the water quality of the Fadak aqueduct ranged from "unsuitable" and "completely unsuitable" to "saline water" (C4-S4). Overall, the groundwater in the study area is generally suitable for irrigation and drinking purposes, with some exceptions that require cautious use. However, evaluating groundwater quality remains essential to ensure its safe and sustainable utilization. Utilizing GIS maps for water quality assessment can enhance the efficiency and accuracy of water quality management, and the water quality database can be easily updated for ongoing monitoring.

1. Introduction

The scarcity of freshwater resources, combined with high water demand, can result in challenges in meeting the required water supply in various regions. In recent years, water shortage has become a growing issue in developing countries. Various factors, such as physical, chemical, and biological parameters, are essential when studying the quality of both surface and groundwater (Ghamarnia *et al.*, 2023). In some areas of the world, the average yearly rainfall is under 50 mm, resulting in very limited surface water resources in these areas.

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For this reason, the most important water resources in these countries are groundwater resources (Taghavi-Jeloudar *et al.,* 2013). Annual rainfall in large parts of Iran is less than 100 mm. Therefore, the proper use of groundwater resources in arid regions is important. (Nasiri and Mafakheri, 2015). The aqueduct system is considered one of the best methods of extracting groundwater resources and is one of the innovations of the ancient Iranians based on historical documents (Naser and Azadeh, 2018). Around 800 before the Christ (BC), Iranians mastered the technology of groundwater utilization in the form of an underground channel called "Qanat or aqueduct". This technology was then spread to other countries in the Middle East, China, India, Japan, North Africa, Spain and, correspondingly, Latin America (Nasiri and Mafakheri, 2015). Aqueduct technology has been supplying water to large parts of Iran for many years by utilizing gravity without the need for aids and accessories such as electricity pump motors, etc. Unfortunately, many aqueducts have disappeared due to the expansion of the use of suction for groundwater extraction and the reduction of the groundwater table (Naser and Azadeh, 2018). Increased extraction of groundwater resources and reduced rainfall in recent years have led to a decline in the chemical quality of these resources (Hosseinifard and Aminiyan, 2015; Zahedi, 2017). In addition, population growth, urbanization and industrialization in recent years have degraded groundwater resources and reduced the quantity and quality of these groundwater resources (Suman and Narendra, 2017). Increased extraction of groundwater resources in Iran has led to increased pollution of these resources. For this reason, assessing the level of pollution plays an important role in the management and proper use of these water resources (Abbasnia *et al.,* 2019). Accordingly, the evaluation of the chemical characteristics of water resources is of great importance in the management of these water resources (Ndoye *et al.,* 2018). The impact of groundwater resources on the quality of life, public health, and sustainable development in different regions has led to various studies on the quality of these water resources.

For example, Alavi *et al.* (2016) investigated the Chemical characteristics of water sources in the Sharq Dez aquifer in Iran using the Schuller and Wilcox diagram. The research findings indicate that the quality of drinking water in this area is good. Also, Sarkar and Bhattacharya (2018) investigated the water quality of the Savitri River basin using Schuler and Wilcox diagrams. The results of the study showed that the water of this river is not suitable for agricultural and drinking purposes due to the high levels of sodium, SAR and RSC. Ebadati and Haji Hosseini (2017) investigated the quality of water in Tehran's aqueducts for drinking and agriculture, the research results show that, according to available standards, all Qanat water is useable for agricultural purposes. In another research Nouri and Montazer Faraj (2022) evaluated of water quality in Tehran city, the results showed that the quality of drinking water was in line with World Health Organization, while amount of microbes, electrical conductivity and some impurities (Cu and Pb) were higher than standard in some areas. Also, Talebi and Fatemi (2020) Investigating of the quality and quantity of groundwater in Bahadoran Basin. The research indicated that the predominant groundwater type in the Bahadoran area was sodium chloride (NaCl), known for its high volatility. Niloy and Afifa Sultana (2018) studied the quality of groundwater resources in the Savar region of Bangladesh using the CCME method. The study's findings indicated that around 62.5 percent of the specific area's water is fit for human use.

Findings indicate a strong link between water quality and numerous diseases. In developing countries, unsanitary drinking water accounts for 80% of all illnesses. As a result, recent years have seen numerous studies focusing on the impact of water quality on public health (Essumang *et al.,* 2011). Further, groundwater contamination in the long run leads to destructive ecological effects on soil fertility, inconsistency between stakeholders, and the emergence of social crises. Groundwater has a significant contribution in supplying drinking and agricultural water in arid regions of the world such as Iran. These resources are used as storage through wells, springs, and aqueducts (Sharifinia *et al.,* 2013). Therefore, this study was designed to assess the water quality change of the aqueducts of Rafsanjan County using Schoeller and Wilcox diagrams, and GIS.

2. Materials and methods

2.1. Location of the study area

The study area is a part of Rafsanjan County in terms of political divisions, located between 55° 30' to 56°41'east longitude and 29°54'to 30°44'north latitude. Fig. 1 illustrates the positions of the aqueducts within the study region.

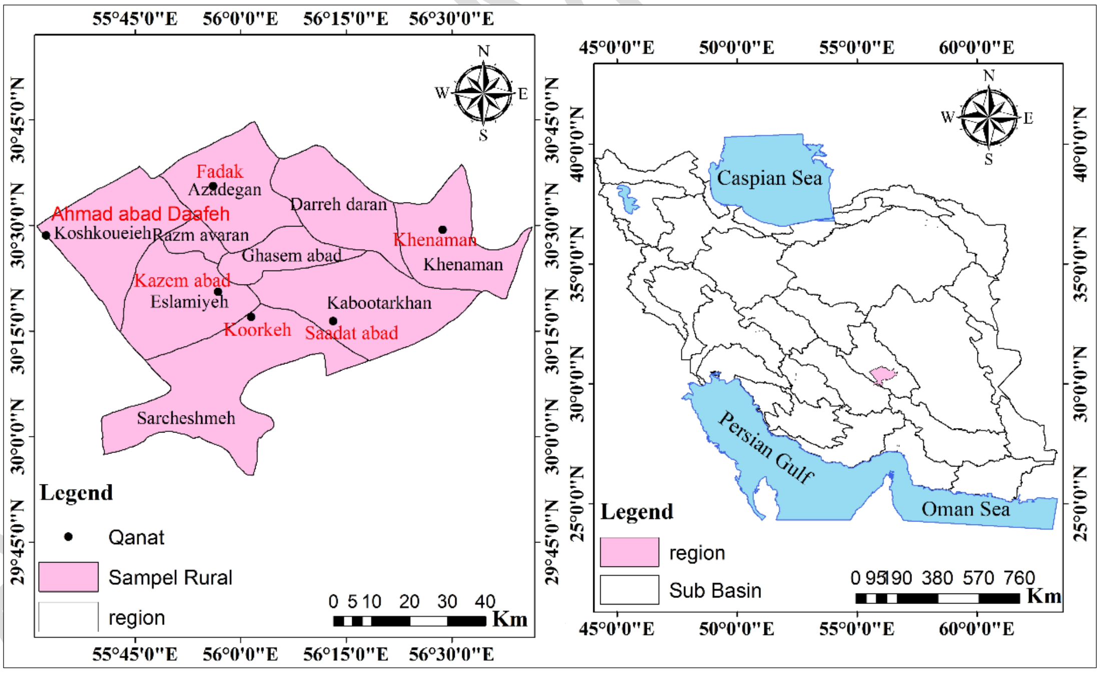


Fig. 1. Location of the study area and sampling aqueducts.

2.2. Geological and climatic features

The Rafsanjan county has a desert climate with relatively hot summers and cold winters. There are also many mountainous areas around the district. Precipitation in Rafsanjan comes mainly from precipitation systems that enter the country from the southwest and west in the fall and winter, and is influenced by southeastern air systems, the monsoon, in the spring and summer.

Precipitation takes the form of rain and snow in winter and rain in summer. In addition, Rafsanjan is influenced by the Siberian cold front penetrating from the northeast during the cold season, without precipitation. The average annual precipitation in Rafsanjan is less than 100 mm, and the average annual temperature in this city is 19.54 °C. Fig. 2 shows the precipitation trend and temperature in Rafsanjan county for 2018 (Meteorological Organization of Kerman Province, 2018).

2.3. Method

In the present descriptive study, annual statistics and qualitative parameters data such as electrical conductivity, sulfate, TDS, sodium, calcium, magnesium, bicarbonate, chlorine, Arsenic, Nitrate and Ph of six selected aqueducts including Ahmadabad Daafeh, Fadak, Kazemabad, Kourke, Saadatabad and Khanaman were used for spatial analysis of water quality characteristics of studied aqueducts in Rafsanjan county, which were sampled during the statistical period by the Kerman Regional Water Organization (KRWO), along with their chemical analysis. The World Health Organization (WHO) and Institute of Standards and Industrial Research of Iran (ISIRI) were used for comparing the results of this study (WHO, 2011, WHO, 1993, Shahvi and Torabian, 2017). In the next stage, zoning water quality of the aqueducts was classified according to different parameters based on Inverse Distance Weighted (IDW) method using Arc GIS 10.3 software. Then, zoning maps of each of the parameters were prepared. Further, Schoeller and Wilcox methods were used in Chemistry software as recommended and frequently used methods for examining the quality of drinking and agricultural water.

2.3.1. Schoeller and Wilcox methods

The Schoeller diagram is a graphical method for classifying drinking water quality which is suitable for Iran climate. SO_4^{2-}, Cl^-, Na^+, TH and TDS are elements that affect the quality of water resources, which are measured in the Schuler diagram. The range of changes of these elements in this diagram is shown in Table 1. In this diagram, the investigated types of water are divided into good, acceptable, average, inappropriate, completely inappropriate, and undrinkable groups. A separate axis is considered for each of the cations and anions and water hardness in Schoeller diagram, which can determine the amount of water quality for drinking water (Huang *et al*., 2017; Alavi *et al.,* 2016; Afzali *et al.,* 2014). Accordingly, the water quality was classified based on Schoeller method.

The Wilcox method is widely regarded as the most suitable approach for classifying water quality in agricultural and hydrological research. The values of EC and SAR parameters in water sources are used to constructing Wilcox method. The range of changes of these parameters in this method is shown in Table 2. In this method, letters C and S represent salinity and sodium, respectively, and numbers 1 to 4 indicate its intensity. According to the Wilcox classification, drinking water falls into the C1-S1 class and is completely ineffective for agriculture. Semi-saline water falls into classes C1-S2, C2-S1 and C2-S2, which are almost suitable for agriculture. Saline water falls into the C3-S3, C1-S3, C3-S2, and S1-C3-classes, which can be used for agriculture. Very saline water falls into C4-S1, C4-S2, C4-S3, C4-S4, C1-S4, C2-S4, C3-S4 classes, which are harmful to agriculture (Alavi *et al.,* 2016; Choramin *et al.,* 2015; Afzali *et al.,* 2014). Table 2 indicates the classification of water quality for agricultural use by Wilcox method.

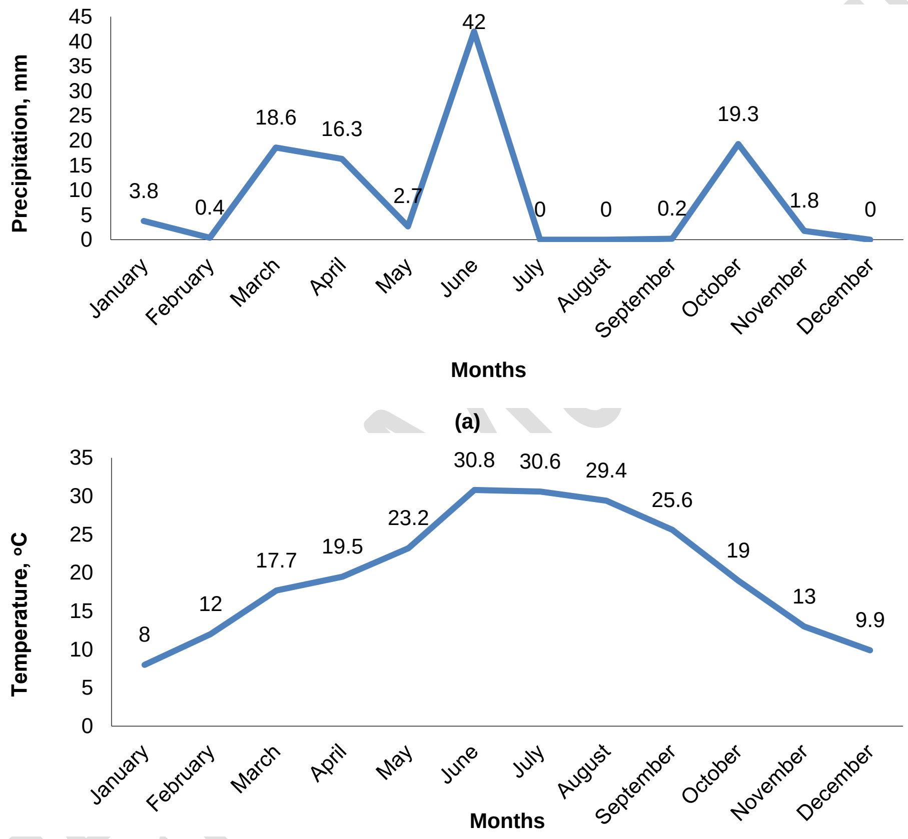


Fig. 2. (a) Monthly graphs of rainfall and (b) temperature at Rafsanjan station (2018).

Table 1. Classification of water quality for drinking purposes based on Schoeller method.

Classification of water quality for drinking	Water quality	SO_4^{2-}, mg/L	Cl^-, mg/L	Na^+, mg/L	TH, mg/L	TDS, mg/L
1	Good	<144	<177.5	<115	<250	<500
2	Acceptable	144-288	177.5-350	115-230	250-500	500-1000
3	Average	288-576	350-710	230-460	500-1000	1000-2000
4	Inappropriate	576-1152	710-1420	460-920	1000-2000	2000-4000
5	Completely inappropriate	1152-2340	1420-2840	920-1840	2000-4000	4000-8000
6	Non potable	>2340	>2840	>1840	>4000	>8000

Table 2. Water quality classification for agricultural use based on Wilcox method.

Class	Water quality
C_1-S_1	Sweet—completely ineffective for agriculture
C_1-S_2, C_2-S_1, C_2-S_2	Brackish—approximate perfect for agriculture
C_1-S_3, C_2-S_3, C_3-S_1, C_3-S_2, C_3-S_3	Passion—usable for agriculture
C_4-S_1, C_4-S_2, C_4-S_3, C_4-S_4, C_1-S_4, C_2-S_4, C_3-S_4	Very passion—harmful to agriculture

3. Results and discussion

3.1. Physical and chemical properties of water resources

Results from Table 2 indicate that, the TDS, sodium, chlorine, calcium sulfate, magnesium and EC in Ahmadabad Daafeh aqueduct were less than the amounts of the standard set by Institute of Standards and Industrial Research of Iran (ISIRI). In addition, bicarbonate, TDS, sulfate, and EC were higher than the World Health Organization (WHO) standard in Ahmadabad Daafeh aqueduct. In Fadak aqueduct, all of the parameters except magnesium, bicarbonate, and calcium were higher than the standard limit of Institute of Standards and Industrial Research of Iran (ISIRI). Further, the values of all parameters except bicarbonate, magnesium, and calcium were higher than those of the standard limit of World Health Organization (WHO) in Fadak aqueduct. The amount of sodium in the aqueduct of Kazem Abad was higher than the standard limit of Institute of Standards and Industrial Research of Iran (ISIRI). Furthermore, all of the values except magnesium and calcium were higher than the standard limit of the World Health Organization (WHO) in Kazemabad aqueduct. The amounts of sodium, chlorine, and EC were higher than the standard limit of Institute of Standards and Industrial Research of Iran (ISIRI). In Korkeh aqueduct. Additionally, TDS, sodium, chlorine, sulfate, and EC exceeded the World Health Organization (WHO) standard in Kourkeh aqueduct. The amount of sodium and bicarbonate was higher than the standard limit of Institute of Standards and Industrial Research of Iran (ISIRI) in Saadatabad aqueduct. In addition, bicarbonate, TDS, sodium, chlorine, calcium, and EC were higher than the World Health Organization (WHO) standard in Saadatabad aqueducts. All values were lower than the World Health Organization (WHO) standard in Khanaman aqueduct. However, the amount of bicarbonate in the Khanaman aqueduct was slightly higher than that of the World Health Organization (WHO) standard. The qualitative parameters surveyed in the studied aqueduct and comparison of the values with the Institute of Standards and Industrial Research of Iran (ISIRI) and the World Health Organization (WHO) are given in Table 3.

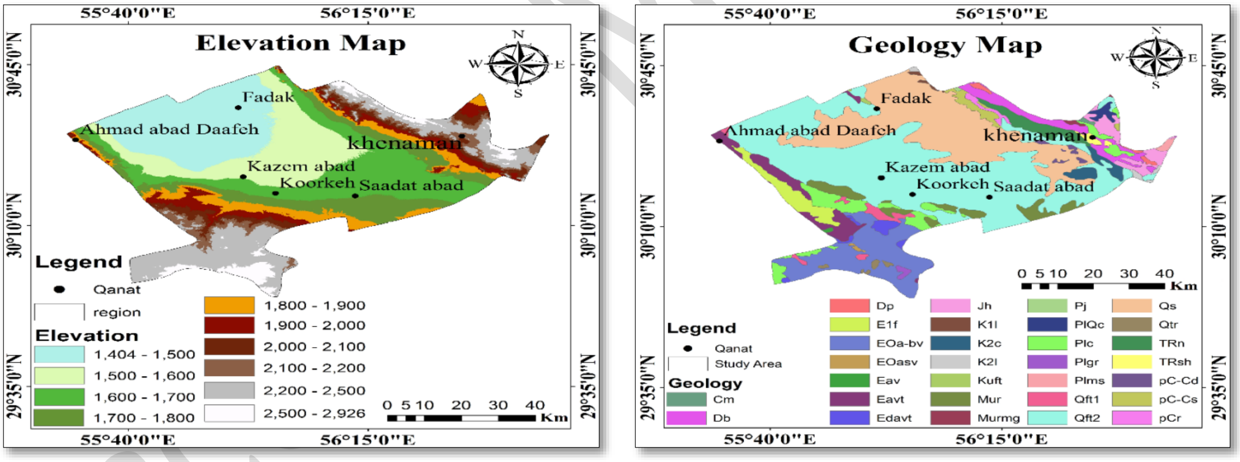
3.2. Elevation points and geology of the studied aqueduct

Based on the results, the area formation is mainly formed by terraced reservoirs and new low-height foothill alluvial fans. Among the studied aqueducts, Fadak, Kazemabad, Kourke and Saadatabad are located in this formation. Furthermore, the type of aqueducts of the Khanaman and Ahmad Abad Daafeh aqueducts were camel dolomite (TRSH), volcanic tuff and andesite (EAVT), respectively. The types of geological formations of the entire study area and their description are given in Table 3.

The altitude of the study area is from 1404 to 2926 meters above the sea level. Khanaman aqueduct is located at 2100 to 2200 m high, Ahmadabad Daafeh aqueduct at 1800 to 1900 m high, Saadatabad and Kourke aqueduct at 1600 to 1700 m high, Kazemabad aqueduct at 1500 to 1600 m high, and Fadak aqueduct at 1404 to 1500 m high. The altitude and geology of the studied aqueducts are illustrated in Fig. 3.

Table 3. Qualitative parameters examined in the studied aqueducts and comparing the values with standard limit of ISIRI and WHO.

Sample aqueducts		HCO_3^-, mg/L	TDS, mg/L	Na^+, mg/L	Cl^- mg/L	SO_4^{2-} mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Ec, µ mho/cm
Ahmadabad Daafeh		213.5	702	147.2	92.3	273.6	60	29.16	1080
Fadak		100	2795	754.4	923	1065.6	200	72.9	4300
Kazemabad		158.6	1105	358.8	355	211.2	46	16	1700
Koorkeh		122	1391	333.5	454.4	273.6	60	33	2140
Saadatabad		244	1053	220.8	284	196.8	80	30.375	1620
Khanaman		158.6	319	25.3	35.5	43.2	44	14.58	490
Institute of standards and industrial research of Iran	Favorable Limit	150	100	200	250	250	75	30	1500
	Admittable Limit	150	1500	200	400	400	250	150	2000
World health organization		150	600	200	200	200	75	50	600



(a) (b)

Fig. 3. (a) Elevation points, and (b) geological formations of the studied aqueduct.

3.3. Evaluation of magnesium, calcium, electrical conductivity, and TDS

As shown in Fig. 4, the aqueducts of Fadak and Khanaman have the highest and lowest values for magnesium, calcium, TDS and electrical conductivity, respectively. Furthermore, the results show that magnesium, calcium, TDS and electrical conductivity values are lower the further one moves from the north of the area to the northeast, south and southeast. The lower altitude of the northern part of the region compared to its east and south, as well as the presence of sand and clay layers in the northern part of the region have resulted in the quality of underground water resources being lower in the northern parts than in the other parts. Fig. 4 shows the zone map of the investigated aqueducts based on the qualitative parameters of calcium, magnesium, total dissolved solids and electrical conductivity.

3.4. Evaluation of quality parameters of sulfate, chlorine, sodium, and bicarbonate

The results in Fig. 5 show that the Fadak and Khanaman aqueducts have the highest and lowest amounts of chlorine, sulfate and sodium respectively. The spatial distribution map also shows that the amounts of chlorine, sulfate and sodium decrease from the north side of the study area to the west, east, south and south-east. The Saadatabad and Fadak aqueducts have the highest and lowest bicarbonate content respectively. According to the spatial distribution map of the bicarbonate element, the lowest amount of bicarbonate is found in the north of the study area, while the amount increases towards the west and southeast.

Table 4. Type of geological formations of the region (Source: geological map 1/1000000).

Type of geological formations	Description
Cm	Fossil-rich, dark grey to black limestone, with minor black shale
Db	Nodular limestone in grey and black, with layers of calcareous shale
Dp	Light red to white quartz arenite with dolomite layers and gypsum
E1f	Silty shale, sandstone, marl, sandy limestone, limestone, and conglomerate
Eav	Volcanic andesitic rock
Eavt	Andesitic volcanic tuff
Edavt	Andesitic volcanic tuff
EOa-bv	Volcanic rocks from andesite to basalt
EOasv	Eocene-Oligocene andesitic subvolcanic formations
Jh	Alternating sandstone and sandy to clay-rich shale with coal and carbonaceous shale layers
K1l	Massive, thick-bedded limestone containing orbitolina
K2c	Conglomerate and sandstone
K2l	Limestone with hyporite presence
Kuft	Flysch turbidites
Mur	Red marl, gypsum-rich marl, sandstone, and conglomerate
Murmg	Gypsum-rich marl
pC-Cd	Recrystallized dolomite and fetid limestone; violet-red micaceous sandstone and siltstone; gypsum
pC-Cs	Thick unit of dolomite and limestone, partly cherty, with thick shale layers
PCr	Dolomite and limestone, partly cherty, reddish sandy shale and sandstone, volcanic rocks, and tuffs
Pj	Dark grey, partly reef-like limestone, thick-bedded, with a thick yellow dolomite band at the top
Plc	Polymictic conglomerate and sandstone
Plgr	Granite
Plms	Marl, shale, sandstone and conglomerate
PlQc	Fluvial and Piedmont conglomerate and sandstone.
Qft1	High-level piedmont fan and valley terrace deposits
Qft2	Low-level piedmont fan and valley terrace deposits
Qs	Sand dunes and sand sheets
Qtr	Travertine
TRn	Sandstone, quartz arenite, shale, and fossiliferous limestone
TRsh	Well - bedded, dense, yellow dolomite

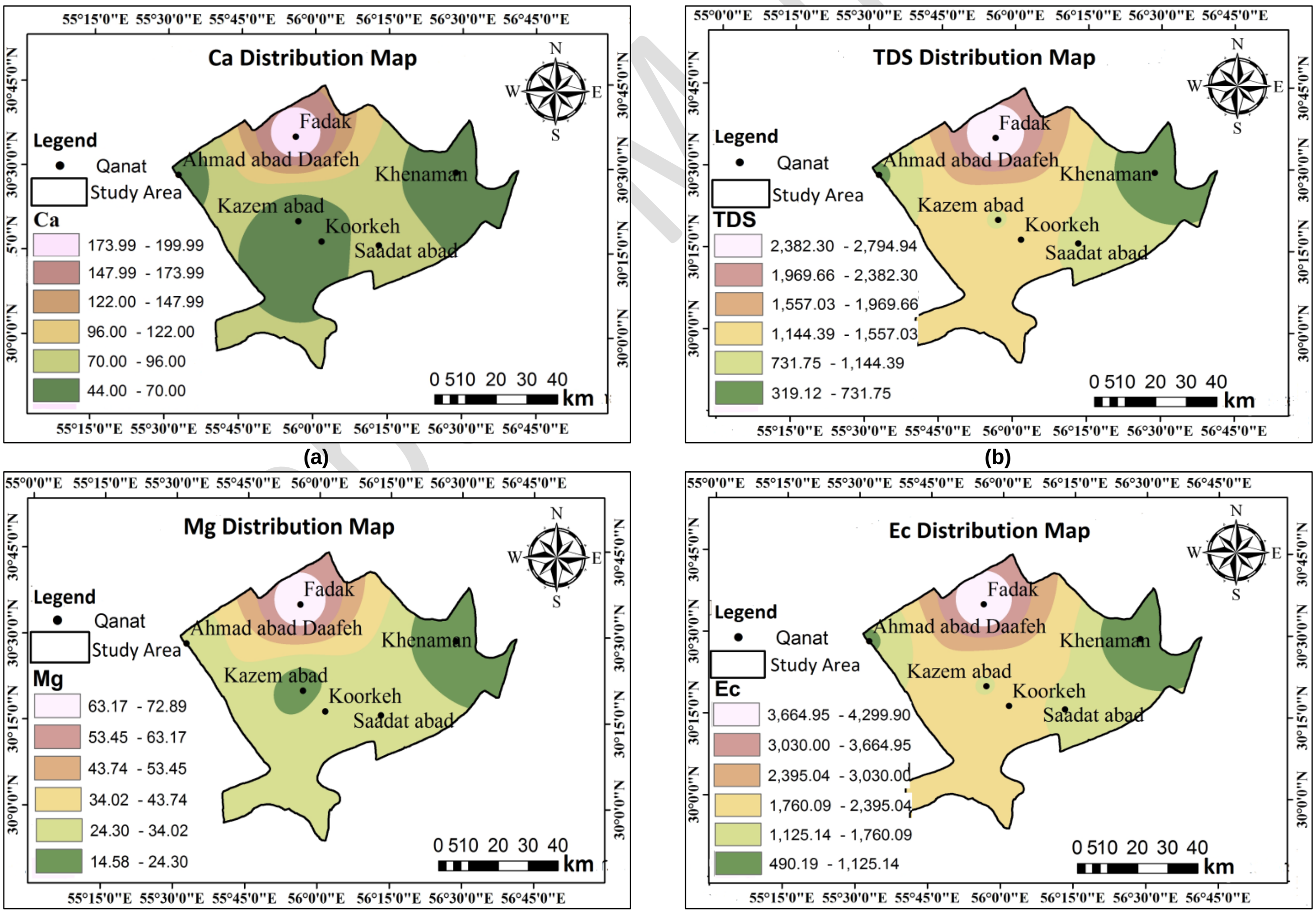


Fig. 4. Zoning the study area based on (a) calcium, (b) magnesium, (c) TDS, and (d) electrical conductivity parameters.

Fig. 5 shows the spatial distribution of sulfate, chlorine, sodium, and bicarbonate parameters. The geological structure of the Khanaman aqueduct consists of hard and loose formations. The values of magnesium, calcium, electrical conductivity, chlorine, sulfate, sodium and TDS are low due to the hard formations and the deposition of these aqueducts in the highest part of the studied basin, where the permeability and contamination of the aquifer are lower. However, the amount of bicarbonate in these aqueducts is high due to the loose and dissolved formations, especially the calcareous formations in the geological structure of the Khanaman aqueduct.

3.5. Evaluation of arsenic, pH, and NO_3^-

The amounts of As^{3+}, NO_3^- and PH parameters in the study area's water resources are presented in Table 5. The results of Table 5 show that the range of arsenic changes varies between 5 and 30. Thus, Saadatabad aqueduct has the highest amount of As^{3+} (30 µg/L), and Kazemabad and Ahmadabad Daafeh aqueducts have the lowest amount of arsenic (5 µg/L). Also, according to the results of this table, the highest amount of nitrate is related to the Fadak aqueduct (21 mg/L), and the lowest amount is related to Kazemabad aqueduct (11 mg/L). The range of pH parameter changes in the studied aqueducts is between 7.1 and 7.8. Thus, the highest pH is related to the Saadat Abad aqueduct (7.8), and the lowest is related to the Khanaman and Kazemabad aqueducts (7.1). Based on this, according to the examined samples, the amount of arsenic in Saadatabad, Fadak, and Korke aqueducts is more than the permissible limit (10 ppb).

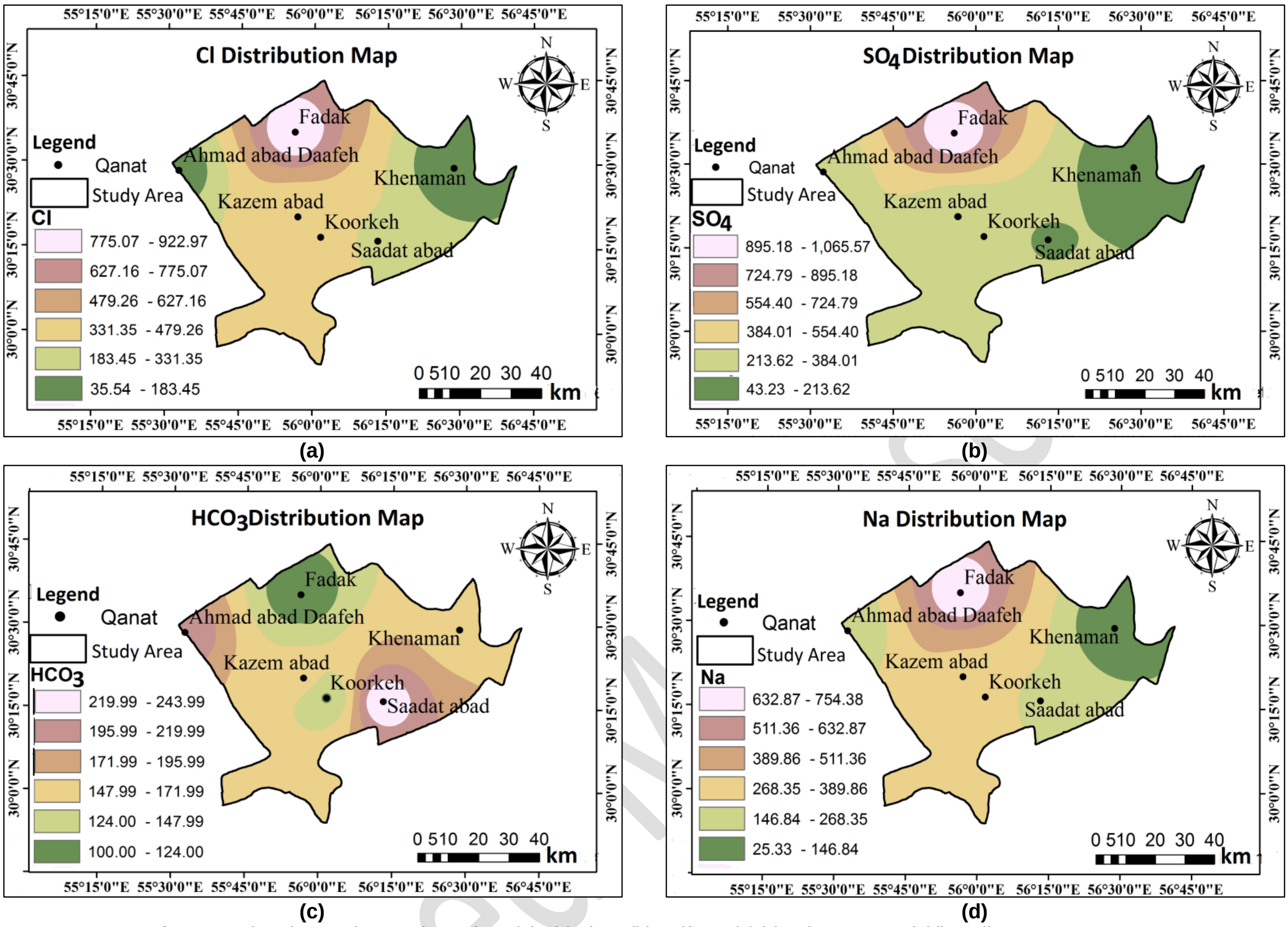


Fig. 5. Zoning the study area based on (a) chlorine, (b) sulfate, (c) bicarbonate, and (d) sodium parameters.

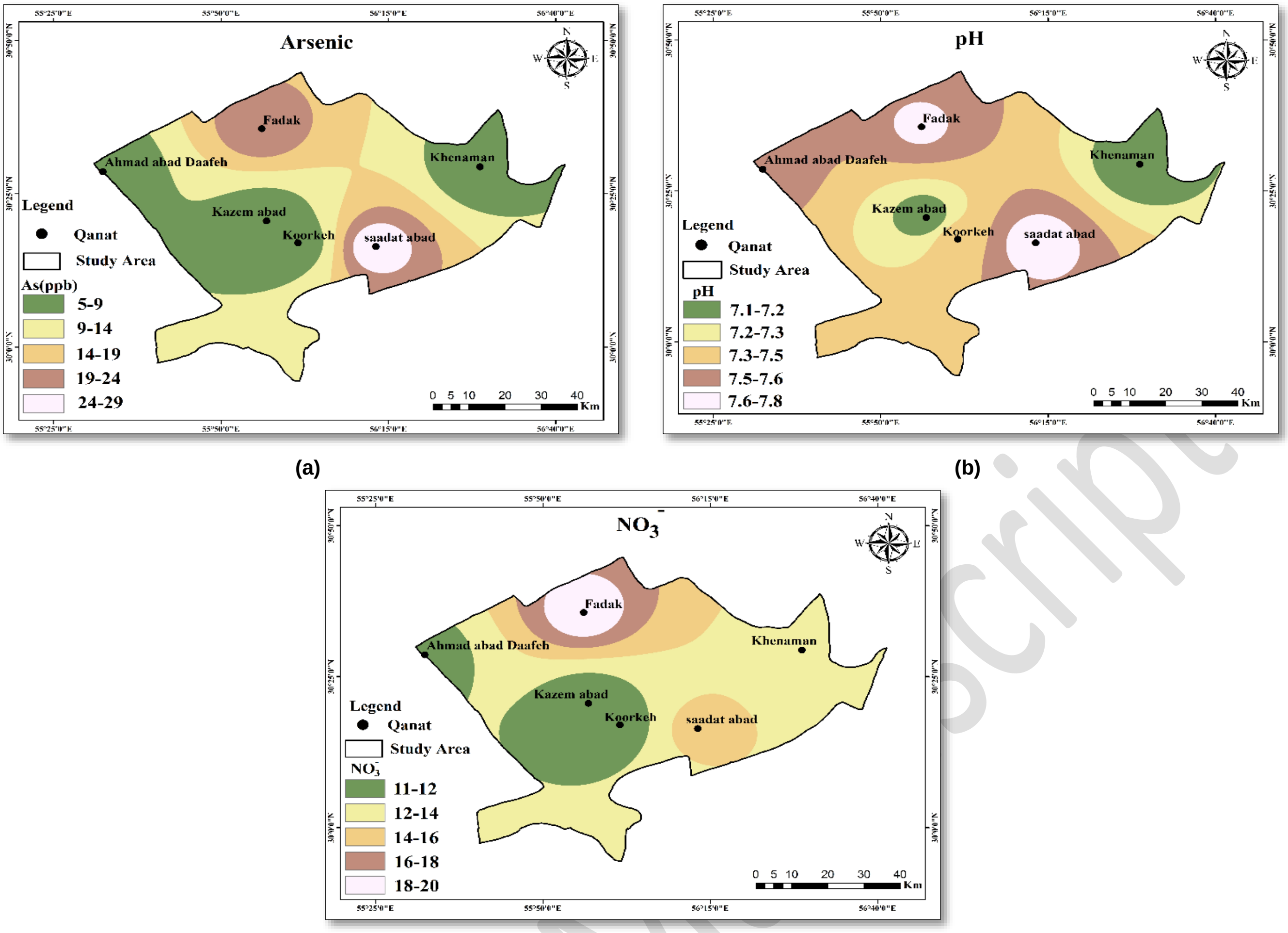
Table 5. The amount of Arsenic, Nitrate and Ph parameters in the water resources of the studied area

Sample aqueducts	PH	As, µg/L	NO_3^-, mg/L
Ahmad Abad Daafeh	7.6	5	12
Fadak	7.7	25	21
Kazem Abad	7.1	5	11
Koorkeh	7.5	6	12
Saadat Abad	7.8	30	16
Khanaman	7.1	5	14

3.6. Evaluation of the quality of the studied aqueducts for drinking water use

This study classifies the water quality of the Khanaman aqueduct as ranging from good to acceptable, according to the Schoeller diagram from 2018. Based on the trend of these aqueducts, the amount of calcium, magnesium, sodium, chlorine, and sulfate is in a good range and the amount of bicarbonate, TH and TDS is within an acceptable range, and the water quality of these aqueducts is in better condition than that of other aqueducts. The water quality of Ahmedabad Daafeh aqueduct is classified into an acceptable to moderate range. Based on this diagram, calcium, magnesium, bicarbonate, chlorine, sulfate, and TH values are in the acceptable range, and sodium and TDS are in the moderate range, and the water quality of these aqueducts is lower than that of the Khanaman aqueducts. The water quality of Saadatabad aqueduct is classified into an acceptable to moderate range. Based on the trend of diagram of these aqueducts, the amount of calcium, magnesium, sulfate, and bicarbonate is in the acceptable range, and the amount of sodium, chlorine, TDS, and TH is in the moderate range. In addition, the water quality of these aqueducts for drinking water is lower than that of Khanaman and Ahmadabad Daafeh aqueducts. Further, the quality of Kourkeh aqueduct is classified into an acceptable to inappropriate range. Based on the trend of diagram of these aqueducts, the amount of calcium, magnesium, and bicarbonate is in the acceptable range, the amount of sulfate and TH is in the moderate range, and the amount of sodium, chlorine and TDS is inappropriate range, and the water quality of these aqueducts is lower for drinking purposes than Khannaman, Ahmed Abad Daafeh, and Saadatabad. Additionally, the water quality of the Kazemabad aqueduct is classified into a good to inappropriate range. By considering the trend of diagram of these aqueducts, the amount of calcium and magnesium is in the good range, the amount of sulfate, bicarbonate and TH is in the acceptable range, the amount of chlorine and TDS is in the moderate range, and that of sodium is in the inappropriate range. The quality of Fadak's aqueduct is classified into a good to completely inappropriate range. Based on the trend of diagram of these aqueducts, the amount of bicarbonate, calcium, and TH is in a good, medium, and inappropriate range, respectively, while the amounts of sodium, chlorine, sulfate and TDS are in a completely inappropriate range. Furthermore, the water quality of these aqueducts for drinking purposes is lower compared to the quality of other aquatic water under study.

Fig. 7 shows the drinking water quality of the examined aqueducts as determined by the Schoeller diagram. In another study conducted by using the Schoeller and Wilcox methods to assess the quality of the eastern aquifer, based on the Schoeller diagram, Alavi *et al*. (2016) determined that the drinking water quality is good and acceptable. Additionally, the Wilcox diagram indicates that the water quality is slightly saline yet appropriate for agricultural purposes. In the present study, only the Khamanam aqueducts were in a good to acceptable range based on Schoeller diagram and the other aqueducts were of lower quality.



(a) (b)

(c)

Fig. 6. Zoning the study area based on (a) arsenic, (b) pH and (c) nitrate parameters.

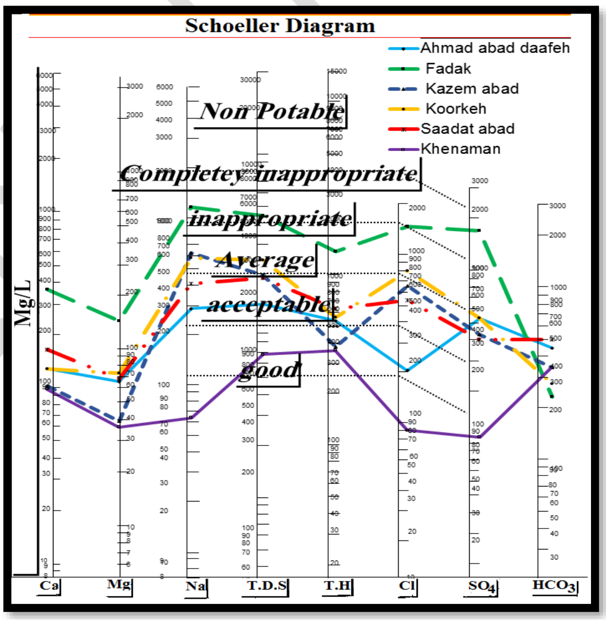


Fig. 7. Water quality of the studied aqueducts for drinking water consumption based on the Schoeller diagram.

3.7. Evaluation of the water quality of the studied aqueducts for agricultural purposes

The water quality is classified into drinking water (C1-S1), semi-saline (C1-S2, C2-S1, C2-S2) and saline (C3-S1, C3-S2, C1-S3, C3-S3), and very saline (C4-S1, C4-S2, C4-S3, C4-S4, C1-S4, C2-S4, C3-S4) ranges in the Wilcox diagram. In the current study, the Khanaman aqueduct's water quality was classified as C2-S1 for drinking water, according to the 2018 Wilcox diagram, and it was found to be more suitable for agriculture compared to other examined aqueducts. The water quality of the Ahmedabad Daafeh's aqueduct was in the semi-saline water ranges (C3-S1). The water quality of the Saadatabad and Korkeh's aqueducts fell into the semi-saline water (C3-S2), which had a more inappropriate quality than that of Ahmadabad Daafeh's aqueduct. Further, the water quality of the Kazemabad aqueduct was in the semi-saline water range (C3-S3), which had a more inappropriate quality than that of the Korkeh and Saadatabad's aqueducts or had higher salinity intensity. The water quality of Fadak's aqueduct was in the saline water (C4-S4), which was lower than that of other aqueducts and had a high salinity for agricultural purposes. Fig. 8 illustrates the assessment of water quality in the studied aqueducts for agricultural use. In a separate study, Afzali *et al*. (2014) applied the Schoeller and

Wilcox methods to evaluate the groundwater quality of the Haraz alluvial fan in the southern Caspian Sea, finding that the water quality based on the Schoeller diagram falls within the acceptable range. In addition, based on the results of the Wilcox diagram of this study, all water samples (100%) were in the class (C3-S1) indicating that they were in the semi-saline water range. In the present study, the studied aqueducts failed to have the same and suitable quality for agricultural purposes. Further, 66.67% of the aqueducts were in the saline water and the water quality of the Fadak aqueducts was in the saline water range. The findings of this research are consistent with those of Alavi *et al*. (2016), Ebadati and Haji Hosseini (2018), and Choramin *et al*. (2015) who also utilized the Schuler and Wilcox methods to evaluate groundwater quality.

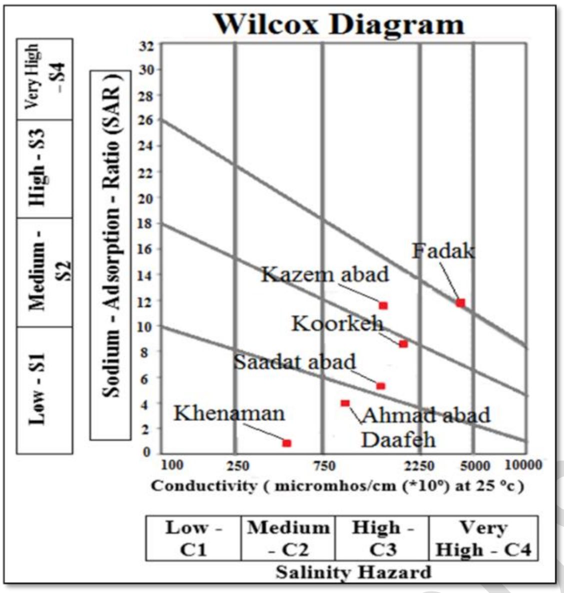


Fig. 8. Water quality survey of studied aqueducts for agricultural use based on Wilcox diagram.

4. Conclusions

The findings of this study indicated that, except for bicarbonate in the Khanaman aqueduct, the water quality parameters of the six aqueducts studied were below the WHO standards and ISIRI guidelines. According to the Schoeller and Wilcox diagrams, the Khanaman aqueduct displayed good, acceptable water quality (C2-S1), making it suitable for both drinking and agricultural purposes. These results are attributed to the aqueduct's location in the highest part of the studied catchment, as well as the presence of hard formations, which contribute to the low solubility of the geological formations in the area. Moreover, the values of water quality indices in the studied water lines in Fadak aqueduct were higher than those of WHO standards and ISIRI. Furthermore, the results from the Schoeller and Wilcox diagrams showed that the water quality of the Fadak aqueduct falls within the unsuitable, completely unsuitable, or saline range (C4-S4), indicating a high risk of salinity. Among the aqueducts studied, the Khanaman and Fadak aqueducts had the best and worst water quality, respectively. In conclusion, the Schoeller and Wilcox diagrams and GIS can be regarded as effective tools for assessing the quality of aqueduct water.

Author Contributions

Mohsen Pourkhosravani: Conceptualization, investigation, analysis, methodology, review and editing.

Fatemeh Jamshidi: Data collection, writing original draft, analysis.

Conflict of Interest

The authors declare no conflict of interest

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Data Availability Statement

Data will be available on request.

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