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ORIGINAL RESEARCH PAPER

Groundwater Quality Zoning Based on Wilcox Index Using Geographic Information System in Jajarm region, north Khorasan, Iran

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ABSTRACT

The qualitative data of underground water of Jajarm city, Iran, was analyzed using geographic information system (GIS). The interpolation technique was used for the assessment of selected factors, including electrical conductivity (EC), total dissolved solid (TDS), total hardness (TH), sodium adsorption ratio (SAR), and Cl. These parameters of almost all wells in Jajarm region were applied for the spatial analysis. These parameters were measured for 14 wells in central region of Jajarm for zoning water quality class based on Wilcox index. Accordingly, four wells (Jajarm, Ghaleh Gazi, Daragh, and Kaftarac), involving 28.57% of wells, were within average order class of water quality for agricultural purposes. Their water quality was in class S1 status. Other 10 wells were in the bad order class, meaning inappropriateness of about 71.43% of the wells in Jajarm plain for agricultural purposes. Khoshab and Shah Abad wells had the worst status. By classifying the suitability of water quality for agricultural purposes based on EC, the water of these stations were classified as class C4, and based on SAR as class S4. The results indicated that the greatest decrease in water quality was in the southwestern parts of the study area, and decline in some parts of the desert, such as the southern region of Jajarm plain, was highly tangible and obvious. The decrease in water quality could be attributed to climate change, excessive use of water, and the changes and decline in rainfall..

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1. Introduction

Water quality is essential for sustainable agricultural land use (Sutharsiny et al., 2012; Ravan Nakhjavni and Fataei, 2015). The exponential increase in population size led to the depletion of groundwater. (Tushaar S., 2009; Hajjabbari and Fataei, 2016). Water quality data are critical to enforce water quality regulations and control pollutants to protect human and ecosystems health (Babaei et al., 2017; Le Roux et. al. 2007; Fataei and ajami, 2015). Monitoring the quality of water resources due to drought and industrial development is one of the major goals of environmental science (Mehrdoost et al., 2021; Kordestani et al., 2020; Tiri et.al 2011; Bahmanpour et al., 2017). To avoid problems in the agricultural area, it is necessary to assess the quality of water resources for irrigation of fields and farms (Shokuhi et.al. 2012). Water is important concern after agricultural fertilizers; if water is contaminated, it can be harmful for plants, animals, and even humans (Rahmani. Et. al.2008; Farhadi et al., 2020). The ability of water for agriculture determines the percentage of total salt in the water and can reveal the types of salt (Sánchez et.al. 2007).

Groundwater is indispensable for life and sustainability of the ecosystem. It is essential in almost every field of human activity (Nag and Suchetana, 2016). Indiscriminate use of groundwater in many parts of the world has led to a sharp drop in the level of groundwater (Karimipour et al., 2021).

Wilcox diagram classification was introduced by Wilcox in 1948 and later completed by Toren (Wilcox, 1995). Today, this index is considered as a common method of water classification for agricultural purposes (Shokuhi et al., 2011). The Wilcox diagram of sodium adsorption ratio (SAR) and salinity (Cl) represents electrical conductivity (EC), which finally classifies the water quality into four categories based on agricultural purposes (Shokuhi, et al, 2012).

Based on the Wilcox index, the water samples are categorized into excellent to good classes (Sundaray et.al. 2009; Jalilzadeh Yengejeh et al., 2014)

Balakrishnan et al. (2011) investigated groundwater quality in the state of Karnataka, India, using geographic information system (GIS). Their obtained results were helpful in the management of groundwater pollution in the study area. Rajkumar et al. (2012) conducted a case study in Karnataka, India, using GIS to present the raster maps. Zare and Fataei (2015) studied the statistics of 56 piezo-metric wells in Ardabil region, Iran, during the watery years 1971 to 2014 to briefly examine the trend of groundwater changes using the interpolation model. They found that the interpolation model was an effective model for displaying information related to piezo-metric wells in the entire area of Ardabil plain.

The present study aimed to evaluate the water quality of 14 wells in Jajarm region, Iran, based on the Wilcox index, which were zoned using the trend interpolation technique. It is best to keep the Kriging model as simple as possible and only remove a trend if it significantly improves the prediction errors (John et al., 2009).

2. Materials and Methods

2.1. Study area

Jajarm is the center of Jajarm city in North Khorasan province in Iran, whose coordinates are 36° 57′ 00″ N, 56° 22′ 48″ E and 36° 57′ 00″ N, 56° 22′ 48″ E. The Jajarm region with an area of about 7650 square kilometers is located in the south of Birjand province, east of Golestan and Shahrod provinces, west of Esfaraen, north of Khorasan Razavi, and northeast of Sabzavar province. The central desert of Iran is located in the south, Aladaq in the north and Golestan in the east (Gitashenasi Province Atlas of Iran). Therefore, the north is mountainous with mild to cold weather, while the south is semi-desert and semi-arid region with mild winter and hot summer (Figure 1). The base map showing the location of survey points was prepared using ArcGIS®.

Jajarm is one of the most attractive cities in North Khorasan province, with unique biodiversity and vegetation.

Miandasht protected area in Jajarm region is the best habitat for valuable species of Persian cheetah. Water shortage and deteriorating water quality endanger the life of regional plants and animals. The quality of water resources and groundwater in this region is deteriorating due to excessive use of groundwater and climate change.

Well drilling is one of the old activities in this region, which sometimes takes the life of well diggers. Today, drilling wells in this region is prohibited and the well water quality is getting worse day by day.

For this study, the water quality dataset was taken from the local water organization of North Khorasan Province. This agency analyzes water sample collected monthly using standard methods for selected factors. The latitude and longitude of sampling locations were assessed by GPS. However, the parameters selected in our study to evaluate surface water quality were total dissolved solid (TDS), sodium adsorption ratio (SAR), total hardness (TH)and Cl of 14 sampling stations, each one presenting one well in Jajarm region. The water quality data available for the analysis in this study belonged to the observation period of 1997-2018. Changes in EC for 10 years (2008 to 2018) were also studied, whereby the data of this parameter were compared with 14 wells located in Jajarm region (Tables 1, 2, 3 and 4). The data were rearranged by Microsoft Excel 2016 software. The concentration of different ions obtained from the chemical analysis of groundwater samples was converted into milliequivalent/liter (meq/L) and used to derive the SAR.

The assessment of these parameters helped to evaluate the irrigation as well as domestic suitability of groundwater in the area under study. Moreover, these values were plotted on Wilcox water quality indexes to determine the suitability of groundwater for agricultural and drinking purposes.

These parameters of almost all wells and springs in Jajarm region were used for spatial analysis. In the second phase of the analysis, these parameters were measured for 14 wells in the central area of Jajarm for zoning the water quality class based on the Wilcox index.

The EC, SAR, TH, and also the DEM (digital elevation model), geological and vegetation maps of Iran were clipped and extracted by mask technique according to the surface of the study area (Jajarm region) and the trends of changes in the above parameters were prepared using the spatial interpolation technique of ArcGIS version 10.3.

2.2. Calculation of the Wilcox Index

The SAR is an important parameter in the calculation of water quality for agricultural and drinking purposes. A low SAR in water is recommended for agricultural purposes. However, sodium (Na) itself cannot be relied upon to classify the suitability of water quality for agriculture, and so its effects must be considered along with the total water salinity.

The relation between Na and calcium (Ca)+ magnesium (Mg) ions is expressed by the SAR as equation (1):

Equation 1.

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Where, ion concentrations are expressed in equivalents per million (ppm). The two indices used to show the suitability of water for irrigation are the SAR and the specific conductance.

SAR is related to sodium hazard; the specific conductance is related to salinity hazard. These two indices are combined to create 16 classifications as shown in Figure 2.

To calculate this index, the EC was scaled on the x-axis named (C) and the SAR on the y-axis of the diagram. According to the classification of the suitability of water quality for agriculture in four categories (low, medium, high, and very high), very high including (C1S1), high including (S1C2, S2C2, and S2C1), medium including (C1S3, C2S3, C3S1, C3S2, and C3S3), and low including (C4S1, C4S4, C3S4, C2S4, C1S4, C4S2, C4S3) as shown in Figure 2 and Table 4.

Physicochemical analysis was carried out to determine the TDS, TH, and Cl values compared to the standard guidelines recommended by the World Health Organization (WHO, 2012) and the Iranian Standards Institution (ISI, 1994) (Tables 2-5).

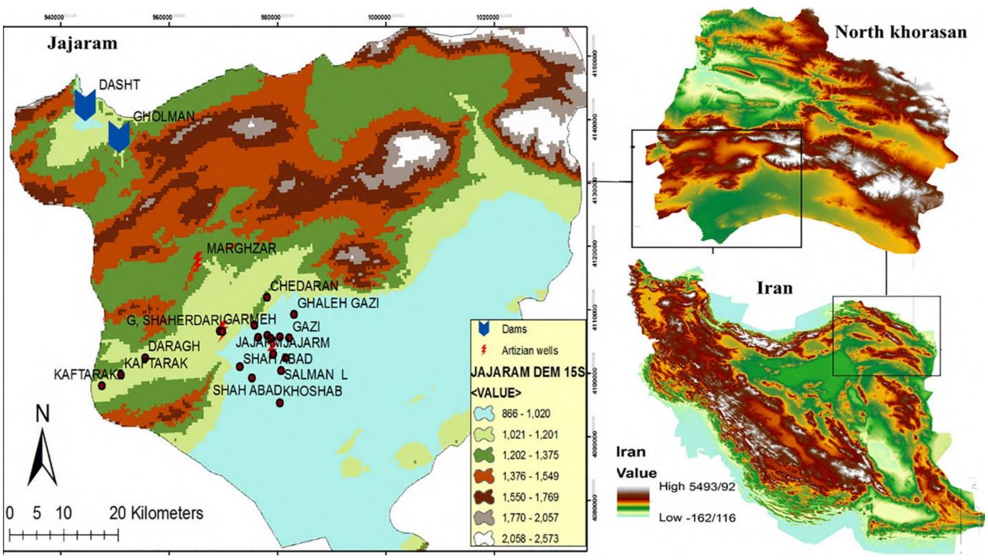

Figure 1. Dem (Digital Elevation Map) layout of Jajarm region in North Khorasan province and location of 14 wells around Jajarm city, Iran

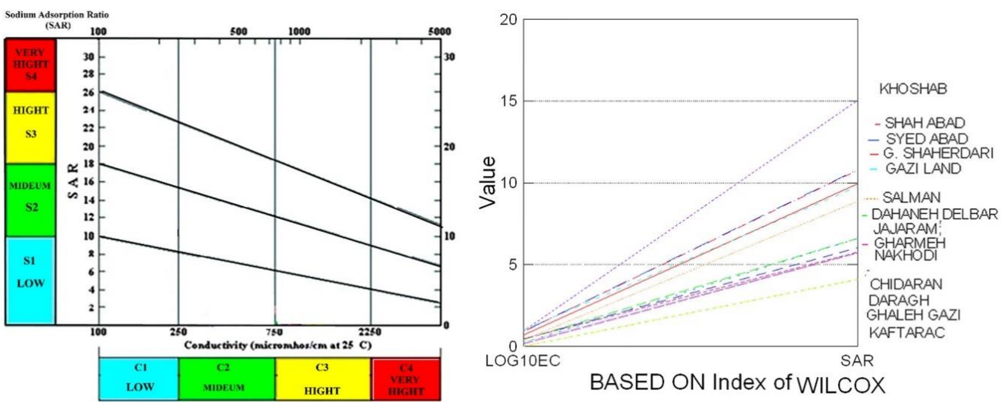

Figure 2. Classification of water quality based on the Wilcox Diagram EC was scaled on the horizontal axis and the SAR on the vertical axis of the diagram (Table 4

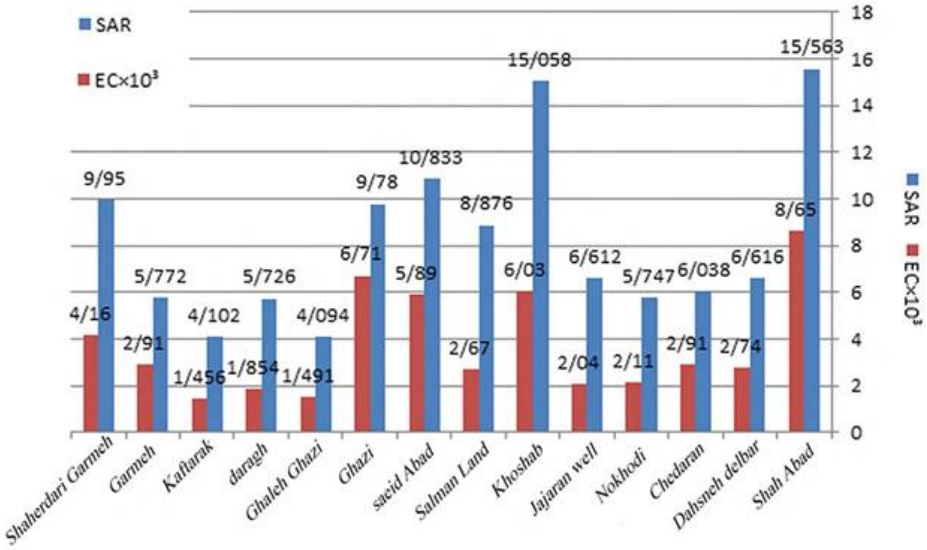

Figure 3. SAR and EC×10-3 of water samples from 14 localities in the central region of Jajarm, Iran, in 2018

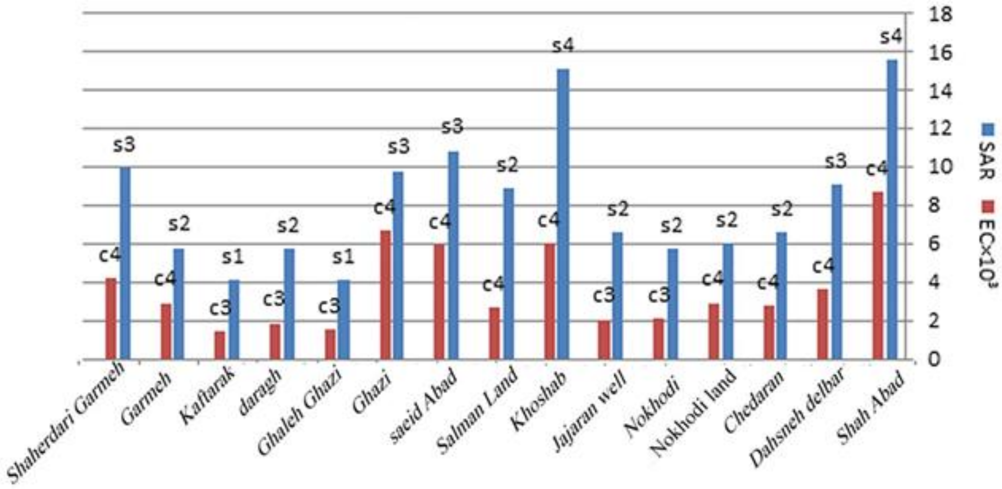

Figure 4. Ddiagram of SAR and EC×10-3 based on Wilcox water quality indexes of water samples in 14 wells in central region of Jajarm, Iran, in 2018

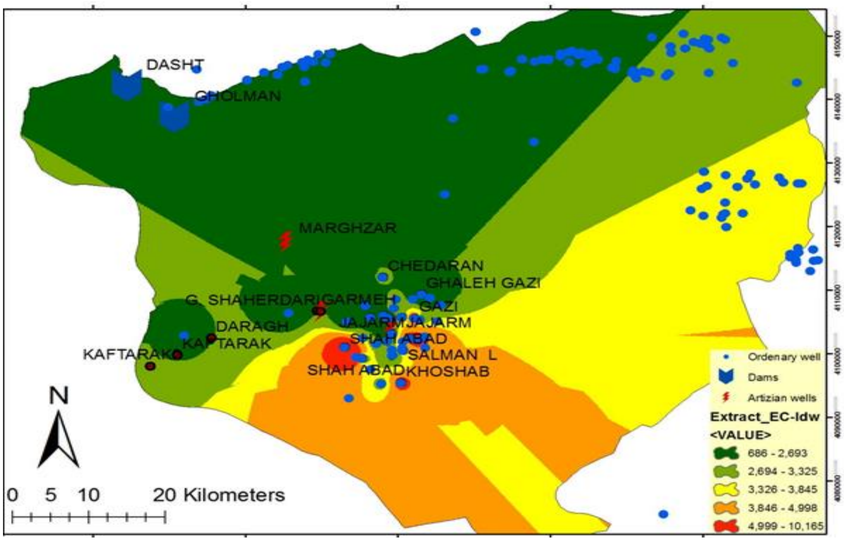

Figure 5. Spatial distribution of EC l value in Jajarm region, Iran, processed by ArcGIS® 10.3 shows that the EC value is high in the region (in red colour)

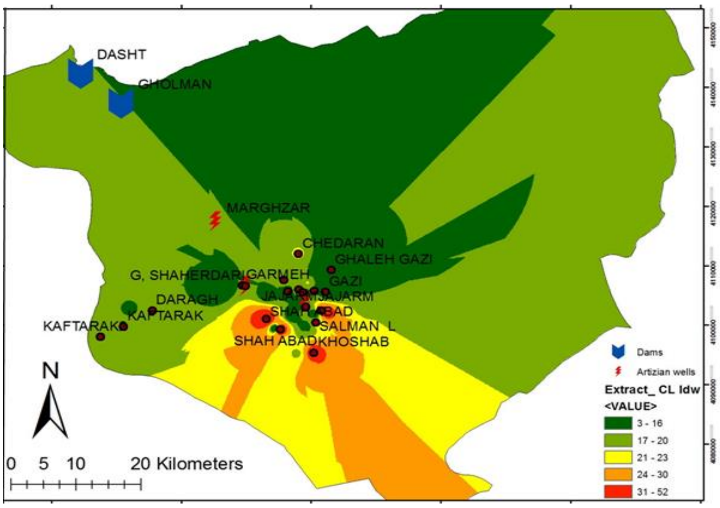

Figure 6. Spatial distribution of Cl level in Jajarm region, Iran, shows that the Cl value is high in the region (in red colour)

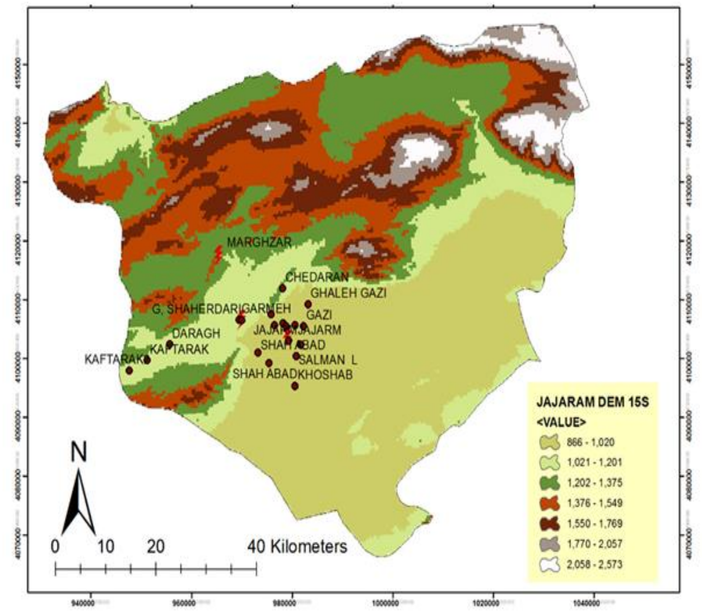

Figure 7. Digital Elevation Map (DEM) of Jajarm, Iran. The elevation ranges from 2572 meters above sea level in the northern parts to 866 meters in the southern parts

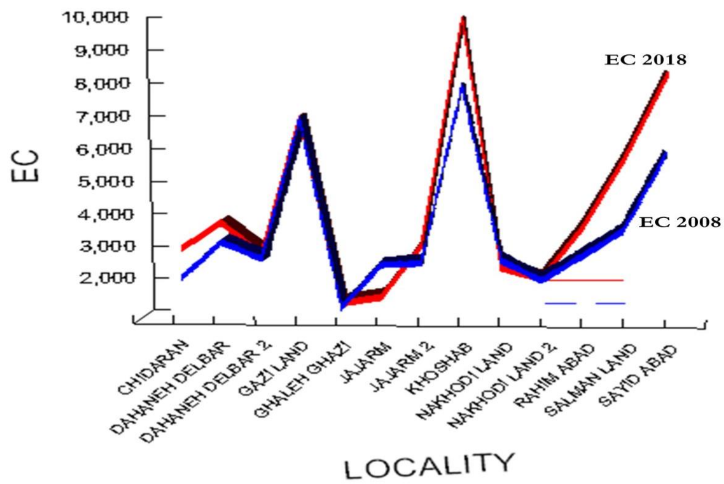

Figure 8. Comparing EC of wells in Jajarm region, Iran, for the years 2008 and 2018

Table 1. Name, locality, and the level of SAR and EC of 14 wells in the central part of Jajarm region, Iran

	locality	LATITUDE	LONGITUDE	SAR	EC
1	SHAH ABAD	56° 16' 36.171" E	36° 56' 55.969" N	15.653	8650
2	NAKHODI LAND	56° 19' 16.146" E	36° 58' 29.178" N	6.609	2390
3	DAHANEH DELBAR			6.616	2740
4	CHIDARAN	56° 23' 18.879" E	36° 52' 35.970" N	6.038	2910
5	JAJARM	56° 23' 44.620" E	36° 57' 58.649" N	6.612	2040
6	KHOSHAB	56° 23' 18.879" E	36° 52' 35.970" N	15.058	6030
7	SALMAN			8.876	2670
8	SYED ABAD	56° 26' 9.040" E	36° 55' 30.329" N	10.833	5890
9	GAZI LAND	56° 24' 15.335" E	36° 58' 13.626" N	9.78	6710
10	GHALEH GAZI	56° 24' 15.335" E	36° 58' 13.626" N	4.094	1491
11	DARAGH			5.726	1854
12	KAFTARAC			4.102	1456
13	GHARMEH	56° 23' 13.244" E	36° 59' 8.630" N	5.772	2910
14	G. SHAHERDARI			9.95	4160

Table 2. Classification of surface water for agriculture based on sodium adsorption ratio, electrical conductivity, FAO; 1985. [updated 2014]. Available from: http://www.fao.org/ DO- CReP/003/T0234e.htm

	Quality Parameters	Water Class
SAR	< 10	Top (S1)
	11-18	Good (S2)
	19-26	Average (S3)
	> 27	Bad (S4)
EC, µs/cm	100-250	Top (C1)
	251-750	Good (C2)
	751-2250	Average (C3)

Table 2. Classification of surface water for agriculture based on sodium adsorption ratio, electrical conductivity, FAO; 1985. [updated 2014]. Available from: http://www.fao.org/ DO- CReP/003/T0234e.htm

World Health Organization		Data	
Quality	Maximum Permissible	No. of WELL with contents more than the maximum permissible limit (WHO, 2011)	Sampling station/ regions with contents LESS than the maximum permissible limit
TDS(mg/l)	1000	12	Ghaleh Gazi, kaftarak
Na(mg/l)	200	0	All well
Mg (mg/l)	150	0	All well
SAR	>10	11	DAHANEH DELBAR, CHIDARAN, NAKHODI, JAJARM, , SALMAN, GAZI LAND, GHALEH GAZI, KAFTARAC, DARAGH, GHARMEH, GHARMEH SHAHERDARI

Table 4. Classification the water quality of 14 well of Jajarm region based on Wilcox indexes

	REGION	SAR	EC	CLASS	WATER QUALITY
1	SHAH ABAD	15.653	8650	C4-S4	BAD
2	NAKHODI LAND	6.609	2390	C4-S2	BAD
3	DAHANEH DELBAR	6.616	2740	C4-S2	BAD
4	CHIDARAN	6.038	2910	C4-S2	BAD
5	JAJARM	6.612	2040	C3-S2	AVERAGE
6	KHOSHAB	15.058	6030	C4-S4	BAD
7	SALMAN	8.876	2670	C4-S2	BAD
8	SYED ABAD	10.833	5890	C4-S3	BAD
9	GAZI LAND	9.78	6710	C4-S3	BAD
10	GHALEH GAZI	4.094	1491	C3-S1	AVERAGE
11	DARAGH	5.726	1854	C3-S2	AVERAGE
12	KAFTARAC	4.102	1456	C3-S1	AVERAGE
13	GHARMEH	5.772	2910	C4-S2	BAD
14	GHARMEH SHAHERDARI	9.95	4160	C4-S3	BAD

Table 5. Irrigation Water Quality Standards (US Regional Salinity Laboratory and FAO) adopted from: Arshad M., Shakoor A., 2017

Water Quality Classification	Salinity Hazard		SAR	RSC
	EC at 25 °C (Micromhos/cm)	TDS (mg/L)	(meq/L)	(meq/L)
Excellent	<250	<160	Upto 10	<1.25
Good	250-750	160-500	10-18	1.25-2.5
Medium	750-2250	500-1500	18-26	>2.5
Bad	2250-4000	1500-2500	>26	-
Very Bad	>4000	>2500	>26	-

Table 6. General EC classification of irrigation water, adopted from: Al-Najar Husam, 2019

Class of Water	TDS (mg/l)	Electrical conductivity (ds/m)
Class 1, excellent	< 1000	≤ 0.25
Class 2, good		0.25- 0.75
Class 3, permissible	1000-2000	0.76-2.00
Class 4, Doubtful		2.01-3.00
Class 5, Unsuitable	> 2000	≥ 3.00

Permissible: leaching is needed if used Doubtful and Unsuitable:
good drainage needed and sensitive plants will have difficulty obtaining stand.

3. Results

There was a direct relationship between increasing use of groundwater and decreasing water quality. The evaluation of the groundwater based on TDS, SAR, and TH and Cl was carried out in water samples of 14 piezometric wells representing 14 sampling stations in Jajarm region.

According to the Wilcox index, four wells (Jajarm, Ghaleh Gazi, Daragh, and Kaftarac) were in the area of average order class of water quality for agricultural use, including 28.57% of the wells located in the average order class. Although the Kaftarac and the Ghaleh Gazi stations had better conditions, their water quality status was in class S1 (Figures 3, 4, and 5).

The other 10 wells, including Shah Abad, Nakhodi Land, Dahaneh Delbar, Chidaran, Khoshab, Salman, Syed Abad, Gazi Land, Gharmeh, and Gharmeh Shaherdari, were in the bad order class (Figure 5, 6), meaning that about 71.43% of the wells in Jajarm plain were not suitable for agricultural use. Among these wells, Khoshab and Shah Abad had the worst conditions (see Tables 3 and 4; Figures 3, 4, 5, 6 and 7). By classifying the suitability of water quality for agricultural purposes based on EC, the water of these stations were classified as class C4, and based on SAR as class S4 (Figures 4, 5, and 6).

In addition, the comparison of the EC changes in the waters of these wells in 2008 with 2018 showed that this parameter had increased by 20% in some stations.

4. Discussion

Groundwater quality maps are valuable for judging water quality for various purposes. Figure 6 shows the spatial distribution trends of chloride, total hardness, and total dissolved solids in the study area, respectively. The created groundwater quality maps are shown in Tables 3 and 4.

Depending on the degree of water quality, the source of potential degradation of water quality was identified for different sampling stations. According to Figures 5, 6, 7, and 8, the water quality in all the wells of Jajarm region did not meet the standards of drinking water (Tables 1, 2, 3, 4, 5, 6).

The decline in water quality can be attributed to various reasons, including climate change, excessive use of water, and the variation and decline in rainfall.

Examining the long-term water quality data available for the observation period of 1997-2018 for all the sampled stations, it is clear that the greatest EC ratio always corresponds to the dry session (July to October). The lowest EC ratio is related to the rainy season, in the last months of the dry season, September and October for all the stations were in the bad class order.

Some of the reasons for the decline in water quality in the whole region are excessive use of water for washing, drinking and agriculture, domestic waste, and industrial activities which is in accordance with the research results of Shahmorad Moghanlou and Fataei (2015) .In addition to these factors, the increase in EC and SAR was caused by the physiographic characteristics of the land in Jajarm. As per Figures 1 and 6, the digital elevation map revealed that the northwest of Jajarm is mountainous and highland, with an elevation of 2000 m (Figures 4 and 8). From the northwest to the southeast, the land becomes lowland and decreases near the border of the central desert of Iran to a height of about 866 to 1020 meters.. The Khoshab and the Shah Abad wells with high levels of EC and SAR are located in this area. As shown in Figure 5, the variation trends of EC, TDS, and TH in the water samples are consistent with each other, which become more critical from the northeast to the southwest for all the wells located in Jajarm region, while the SAR trend is slightly different, which may be due to the variation in Ca and Mg levels (Equation 1).

The trend of variation for the observation period of 1997-2018 showed that the decreasing trend of water quality began from northwest to northeast and from northwest to southeast. Poor water quality belonged to the wells located in a densely populated area near the city center, while the worst water quality was related to the wells located in the southeast of the region. This region is located on the border of the central desert of Iran. The results of the classification showed that the greatest decline in water quality was in the areas close to the southwestern parts of the study region, and this rate of change and decline in some parts of the desert such as in the southern region of Jajarm plain was very tangible and clear.

Moreover, the city of Jajarm and most of the villages are supplied with piped potable water from dams and river reservoirs located in the highlands of the northeast. Dependence on groundwater is currently very high, and after piping water that comes from dams located in the highlands, it is the main supply of water for drinking and agricultural purposes for a large number of village residents. Due to the inadequacy and concern over the quality of water for agricultural and horticultural purposes, which are unique economic sources for a large part of the rural population, groundwater will continue to be significant in the near future. Hardness of water is an important feature that helps prevent foam soap and increases the boiling point of water. The main cause of the hardness of the natural water is calcium and magnesium ions (Khoramabadi et. al. 2014). However, as revealed in this study, most of the groundwater samples were found to have chloride, hardness, and TDS values higher than desirable limits. Therefore, one of the main reasons for the decline in groundwater quality is the extrapolation of groundwater over time.

changes in EC values in the central part of Jajarm region between 2008 and 2018 showed that this parameter had increased up to 20% in some stations. As shown in Figure 8, more changes have occurred in the Khoshab and the Sayed Abad stations, indicating that the pressure on groundwater over the last decade has been increasing continuously with population and water demand.

5. Conclusions

The obtained results highlight the necessity for awareness of the public of the region. To raise this goal, environmental education in the field of water conservation and optimal use, public awareness of the current quality crisis, as well as their participation and cooperation with the actions of the local managers are very important. Since groundwater will play a major role in water supply plans in the future, there is a need for programs to protect groundwater quality.

The bad and the average qualities of water indicate a serious problem of water management in this region, and since climate changes and drought have occurred in recent years, more attention is needed to this issue. Public awareness on the current status and the future trends of water availability, environmental education, and sustainable development are essential action plans for water management (Valiallahi J, Khefaf Rody, 2021). The results of this study will help to monitor and manage the reduction of groundwater quality in the study area.

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