Use of Water Quality Index and Spatial Analysis to Assess Groundwater Quality for Drinking Purpose in Ardakan, Iran

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ABSTRACT

Introduction: Due to water scarcity and increased water consumption during the past years, the importance of water in terms of transmission of diseases, as well as Iran's climate, groundwater aquifers are known as the most important resources of drinking water supply. Using the Water Quality Index (WQI) is considered as strong managerial tool for decision making in water resource management. Therefore, the aim of this study was to evaluate the quality of groundwater in Ardakan for drinking purpose using WQI. Spatial analysis was conducted with the geographic information system (GIS).

Materials and Methods: This is a descriptive, cross-sectional study to investigate the quality of groundwater in Ardakan for drinking purpose. Information on total dissolved solids (TDS), total hardness, pH, electrical conductivity (EC), bicarbonate (HCO_3^-), chlorine (CL^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), calcium (Ca^{2+}) and magnesium (Mg^{2+}) of 24 wells was obtained from Ardakan Health Center. The characteristics of the stations were determined using the Global Positioning System (GPS) and transmitted to the map prepared in the GIS environment. The calculated values of the WQI were zoned in the GIS environment by Inverse Distance Weighted (IDW) method.

Results: Based on the WQI, well no.5 has the best quality water (17.61), which has the lowest WQI, and the highest value of WQI was obtained for well no. 20 (156.86).

Conclusion: The results of the study showed that none of wells have drinkable water, 13 wells had good quality water, and 11 wells had poor quality and should be treated for drinking.

Introduction

Safe water is one of the essential requirements of living organism, especially humans. Water quality is one of the most important factors that should be considered when assessing the appropriate development of an area [1, 2]. Increased population and consequently excess consumption of water resources have led to changes in water

quality conditions [3, 4]. The study of water quality indexes in developing countries has increased in importance in recent years given the water scarcity problem [4]. Traditional irrigation and the lack of drip irrigation, energy production by water, the development of industries that require abundant water in the vicinity of the sources of freshwater and inefficient management of optimal consumption, has reduced the amount of water resources [5]. Contaminants from industrial, domestic, and agricultural wastewater discharge as well as leachate from waste and surface runoff have caused further contamination of available water resources and have reduced their amounts [6-8]. Surface water resources are more exposed to pollution than groundwater resources, but given the situation in Iran, which is one of the countries facing shortage of freshwater resources and air precipitation, underground aquifers are considered the most important resources of drinking water supply, and therefore conserving the quality of these resources is crucial [9, 10]. Precise information on water quality should be available for making decisions and policies related to the conservation, management and sustainable use of lakes and water resources [11]. Therefore, constant and continuous interpretation of the situation is very important. A simple and statistical method for assessing the quality of water is the utilization of WQI [3]. The WQI is used to assess the suitability of surface water and groundwater for drinking and agricultural purposes [12]. The WQI was first introduced by Brown *et al* [1]. This index has been used by the American Health Foundation in 2000 [13]. The WQI is determined based on total dissolved solids (TDS), total hardness (TH), electrical conductivity (EC), bicarbonate (HCO_3^-), chlorine (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), calcium (Ca^{2+}), and magnesium (Mg^{2+}) [13]. This index divides the water status into five categories: excellent, good, poor, very poor, and non-drinkable, and determines the rate of treatment needed. The GIS is a new technology used for analyzing and interpreting the distribution of pollutants in environmental studies

[14, 15]. The IDW is one of the ArcGIS's applied techniques for spatial distribution of pollutants, which, based on the distance between points and the concentration of pollutants at each point, simulates pollutant concentrations in other parts of the studied area [16]. So far, various GIS software has been used to analyze, interpolate and map different types of pollutants [17- 19]. In this study, Ardakan groundwater was qualitatively classified for drinking according to the WQI and was zoned by the GIS. The novelty of our study is the zoning of the WQI, which includes a range of chemical parameters in the area under purpose. This study will help achieve a rational strategy for managing resource development and conserving water resources and utilizing them appropriately, and awareness of quality will help managers and authorities better understand and better manage water resources.

Materials and Methods

Study Region

This descriptive-cross sectional study was conducted to evaluate the quality of 24 wells in Ardakan with the aim of monitoring Ardakan groundwater quality and its impact on drinking purpose. Ardakan has a warm and dry climate with an average precipitation of 60 mm [20]. The city is located in the center of Iran, on the four-way of north-south and east-west, at 60-km distance from Yazd, with coordinates 32.3082 N, 54.0086 E and 1033 m above sea level [13]. The city neighbors Jandagh Desert, Tabas Plain and Naein from north and northeast, the Central Desert of Iran and Yazd County from east and southeast, and Meybod, the Gav Khuni Moorland, and individual desert mountains from the south and west [13]. This data were seasonally (one sample per season) sampled during 2017. Figure 1 shows the geographical location of the studied area. The area was divided into two different geographic zones 39 (left side) and 40 (right side), and each zone was studied separately.
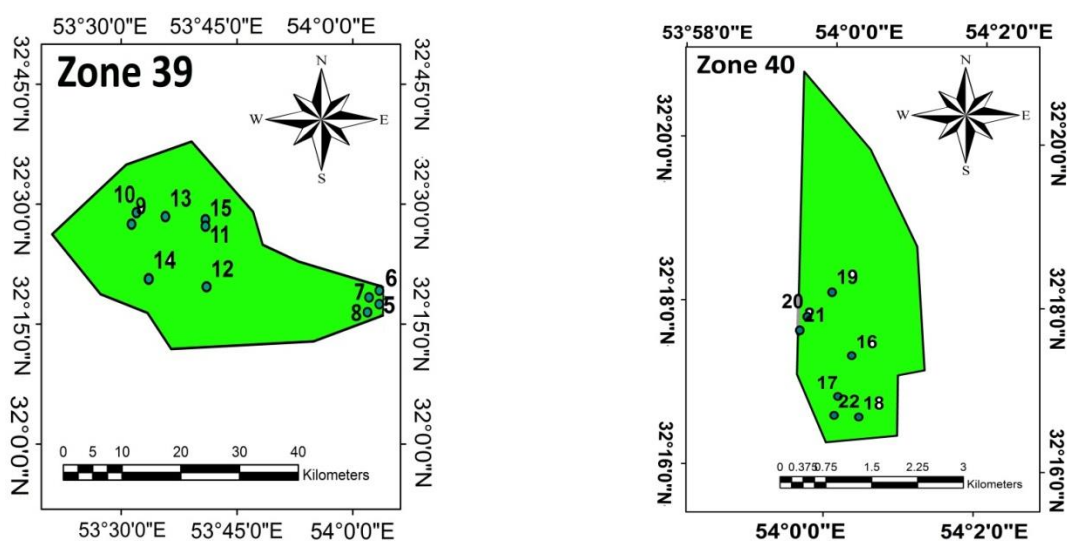
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Figure 1: Geographical location of the studied area

To determine the groundwater WQI, the parameters TDS, total hardness, pH, EC, HCO_3^-, CL^-, SO_4^{2-}, NO_3^-, Ca^{2+} and Mg^{2+} were investigated. Specifications of the stations were identified and recorded using the GPS and transmitted to the map prepared in the ArcMap GIS 10.2.2 environment. The calculated values of the WQI were zoned in the GIS environment using the IDW method. IDW is an algorithm used to interpolate data in a spatial image.

Calculating WQI

1. First, each of the parameters was given weight from 1 to 5 based on the parameter importance as Wi.

2. Then, the relative weight W_i was calculated for each of the parameters using the equation 1.

(1) $Wi = \frac{Wi}{\sum_{i=1}^{n} Wi}$

where W_i represents the parameter weight and the number of parameters.

3. In the third stage, the relative quality was calculated using the equation 2.

(2) $qi = \frac{ci}{si} \times 100,$

Where C_i represents the concentration of the parameter in question and S_i the standard value of

that parameter according to the WHO guideline.

4. Then, the S_i was calculated using the equation 3;

(3) $SI_i = q_i \times W_i$

For each parameter, and by calculating S_i, the WQI value would be equal to the sum of S_i for all of the parameters at each point.

Ethical issues

This study was conducted with the approval of Shahid Sadoughi University of Medical Sciences and Health Services, Medical Ethics Committee Code: IR.SSU.SPH.REC.1397.072

Results

Table 1 shows the parameters used to calculate the WQI and their values. In this study, the measured parameters available to the Ardakan Health Center were used.

Figures 2 and 3 show maps zoned by the GIS. Figure 4 shows the WQI values in different stations.

Figure 3 shows the zoning of water quality in the area under purpose based on the WQI in zone 39.

Table 1: Results of the measurement of the studied parameters in the stations under purpose in 2017-2018

Well number	pH	EC (μmho/cm)	TDS	Cl⁻	HCO₃⁻	SO₄²⁻	NO₃⁻	Ca²⁺	Mg²⁺	WQI
1	7.4	2800	1764	230	320	180	0	140	80	150.63
2	7.6	3500	2205	320	300	210	0	250	130	115.36
3	7.4	2100	1323	270	95	210	0	150	80	74.41
4	7.3	2340	1474	290	130	210	0	310	150	96.1
5	7.4	1102	1102	190	130	180	0	100	90	61.17
6	7.4	2022	2022	240	115	290	0	190	95	101.09
7	7.5	2900	1827	302	280	250	0	170	130	99.28
8	7.5	2750	1732	180	275	265	0	100	160	89.65
9	7.3	2820	1776	330	110	150	0	200	120	93.03
10	7.6	2300	1449	210	300	310	0	130	90	83.08
11	7.4	1600	1008	220	100	280	0	110	70	63.49
12	7.5	1230	775	220	70	250	0	285	145	72.25
13	7.6	2700	1701	250	240	250	0	290	160	104.01
14	7.2	3200	2016	190	0	250	15	0	0	80.68
15	7.3	2200	1386	320	0	290	11.2	0	0	67.6
16	7.2	670	388	130	140	180	28	280	130	63.68
17	7.2	2200	1386	260	126	270	27.5	280	140	101.06
18	7.6	2200	1386	190	110	280	20.4	320	160	100.79
19	7.6	2200	1386	225	58	310	45	350	140	111.84
20	7.8	2400	1512	180	90	170	26.5	310	210	156.86
21	7.7	3100	1953	220	95	290	60	320	150	130.25
22	7.8	1500	945	320	125	310	35	350	160	101.04
23	7.9	1428	900	165	130	250	24	215	120	75.85
24	7.5	3100	1953	255	115	290	31.5	330	140	122.99

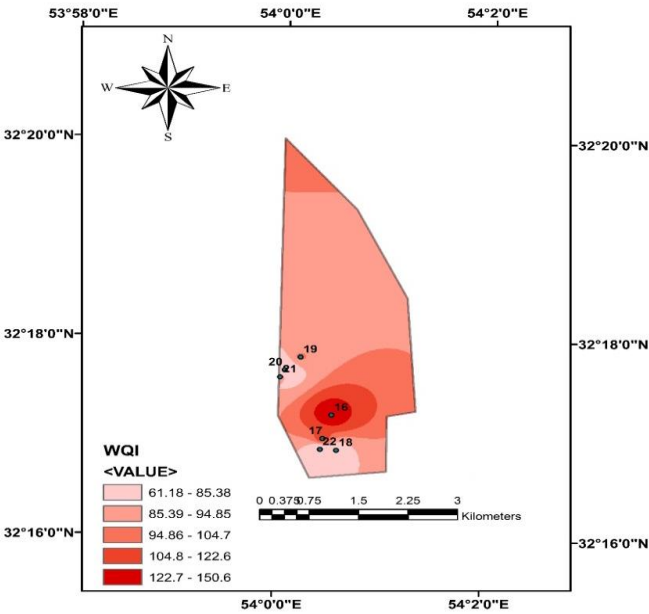*All parameters based on ppm, except EC and pH

Figure 2: Water quality zoning based on the Water Quality Index in the studied area (zone 40)
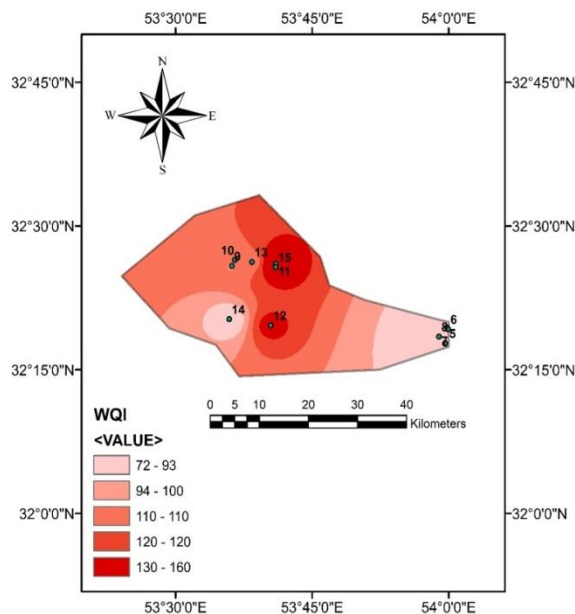
Figure 3: Water quality zoning based on the Water Quality Index in the studied area (zone 39)
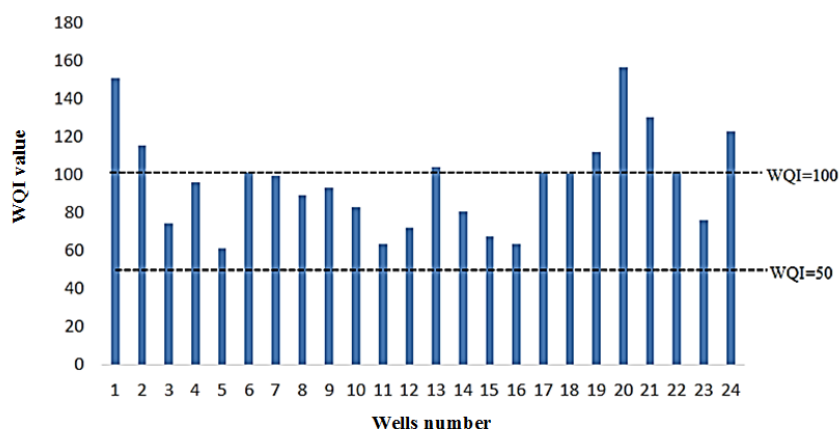

Figure 4: The values of the Water Quality Index in different sampling stations

According to Table 2 and the obtained values for WQI, the lowest WQI was obtained for well no. 5 (17.61) and its water is classified as good quality.

In this case, drinking water is not prohibited and it will be drinkable after chlorination, but the highest WQI was obtained for the well no. 20 (156.86), indicating the poor quality of its water and that it should be treated before drinking. The water of all wells is drinkable after primary treatment.

Table 2: Different levels of the Water Quality Index and the type of water quality [13]

Water Quality	WQI
Excellent	50 >
Good	50-100
Poor	100-200
Very poor	200-300
Water unsuitable for drinking purposes	300 <

Discussion

Water is the most important human need, and its conservation is of great importance. Underground water resources are more important in hot and dry areas because 50% of the need for water is met by groundwater due to low rainfall and high evaporation rate [21].

The higher quality of groundwater and the presence of various minerals in it have caused humans to consume more amounts of it compared to other water resources. The quality of groundwater has changed dramatically due to the release of pollutants in the environment and the excess consumption of these resources [22]. According to the results of our study and the WQI values obtained, none of the wells under purpose were of good quality. Well no. 5 with the WQI of 17.61 had good quality and it's chlorination is sufficient for drinking purpose, but the water quality of well no. 20 with the WQI of 156.86, i.e., the highest WQI, should be treated for drinking purpose. According to Table 1 and the values of the parameters for different wells and the WHO guidelines, the increased WQI in well no. 20 is due to high amounts of the EC, TDS, Ca^{2+} and Mg^{2+} parameters. In order to correct and reduce the amount of WQI and increase water quality, the values of parameters that are higher than the standard limits should be eliminated in water treatment. Thirteen cases of the studied wells had desirable conditions and should be only chlorinated for drinking purpose and did not require advanced treatment. In a similar study by Barmaki et al. to evaluate the WQI of groundwater of Lenjanat aquifer using the GIS the WQI by describing the spatial variation of groundwater quality, it was observed that the water quality of the basin was relatively good (the WQI of over 70), and underground water along Zayandeh Rud had a lower quality than other areas [1]. In another study to investigate the quality of Dez Dam Lake using the WQI, the laboratory results and the qualitative indices obtained showed that the Dez reservoir water was desirable for a variety of general purposes, and only needed advanced treatment for drinking [23]. In one study,

the evaluation of quality of Darreh Roud water in Moghan area for irrigation using the sustainable conservation approach and the CCME-WQI model by selecting 30 parameters with different physico-chemical and biological characteristics and with respect to various nutrients and heavy metals, showed the suitability of the water quality in wet and dry periods for irrigation purpose was assigned to class B (good and good-moderate quality) [24]. Khalaji et al. evaluated the quality of Lake Zayandeh Rud Dam water using the WQI. To this end, they sampled 5 stations, which were selected from different parts of the river, at 45-day intervals during the spring and summer of 2013. The results showed the water quality was generally good (between 50-100) in spite of the decrease in its amount in spring and summer.

This water has usability for human consumption, including drinking. That study showed that conserving the water quality of Lake Zayandeh Rud Dam requires an accurate and comprehensive management [5]. The assessment of the quality of groundwater resources of Ardabil aquifer for drinking and agricultural purposes by Rahimi et al., showed that WQI of this aquifer was good-excellent, but the water has corrosive properties that causes its use for agricultural purpose challenging because of creating certain problems with the metal fittings of drip irrigation systems [25]. Nasr et al. used a Fuzzy WQI (FWQI) to evaluate the amount of drinking water resources in Yazd province; and their results showed that 8 underground water samples were assigned to the excellent class with a confidence level of 5.33-76.67%, 41 samples to the good class with a confidence level of 5.96-8.5%, 8 to the medium class with a confidence level of 5.93-14.5%, one sample to the fair or relatively good class with a confidence level of 36.5%, and 13 samples to the poor quality class with a confidence level of 54.8-81.5% [26].

Ehrampoush et al. concluded that the NSFWQI of the Shirin Darreh Lake in the cold months was better than that in the warm months for the urban drinking water supply [4]. Samarghandi et al. conducted a cross-sectional, descriptive study on

7 stations during the 12 months of 2010, and reported that the lake water had a better quality in the cold months than in the warm months, and with respect to drinking purpose, stations 1 and 2 were more suitable than other stations and could be used for drinking after routine treatment [9]. Khosravi *et al*. used the GIS and WQI to assess the quality of groundwater in Birjand. In more than 90% of the area under study, EC, TDS and TH were higher than the permissible limits [15]. Overall, the results of this study showed that although the water in all of the studied sites was potentially drinkable, none had excellent quality water, and all required chlorination and occasionally treatment before being used for drinking.

Conclusion

In this study, the quality of water in the wells supplying drinking water of Ardakan was studied. The results showed that in none of the studied wells, water quality was excellent with respect to the WQI, 13 wells had good quality water and 11 wells had poor quality water. The water of all wells would be drinkable after primary treatment and the overall conditions of the wells were desirable. In wells with good quality water, chlorination would be sufficient to make their water drinkable. however, recommended that the water of the wells that have poor quality water be treated before drinking, and decrease the value of the parameters that lead to increased WQI to those mentioned in the respective guidelines. It is also recommended that special attention be directed to the implementation or lack of implementation of urban development projects in the areas near the wells and the groundwater in the studied area to prevent the deterioration of the quality of groundwater resources.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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