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Qualitative zoning of groundwater for drinking purposes in Lenjan plain using GQI method through GIS

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Abstract

Background: A new method has been presented specifically for zoning the quality of groundwater for drinking purposes; this method is the groundwater quality index (GQI) method. The present research used the GQI method to qualitatively zoning of the Lenjan groundwater for drinking purposes.
Methods: Three phases were applied in this research. In the first phase, working on the quality data of 38 wells within the studied plain, the raster map of quality concentration parameters, including pH, TDS, Cl, SO_4, Ca, Mg, and Na parameters, was provided by interpolation using the kriging method in the ArcGIS software. In the second phase, the mentioned maps were standardized so that various bits of data can follow a common standard and scale. In the third phase, weight was applied to each standardized map, and ultimately the classification map for each parameter was drawn. The final GQI map was created by combining the mentioned classification maps.
Results: The GQI values for Lenjan plain were rated from the minimum (67.48) to the maximum (90.05). The results showed an average to acceptable level of quality for drinking water.
Conclusion: According to the final map, the central and southern parts of Lenjan plain, which have acceptable GQI rankings, are the best zones from which to use groundwater for drinking purposes.
Keywords: Drinking water, GQI, Groundwater, Lenjan, Water quality index, Water quality, Water wells
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Introduction

Due to the shortage of surface water, Iran's groundwater resources (as in many other countries with dry and semi-dry climates) have become the most important and reliable source of water. Thus, it is necessary to consider the quality of this resource for drinking purposes. In recent years, industrial development and the use of modern methods in agriculture, such as using different types of fertilizers and chemical poisons, have led to the contamination of groundwater and a decrease in the quality of this valuable resource. Decontaminating groundwater is an extremely costly and time-consuming task. Contamination is detected in a phase in which it is almost impossible to reverse the damage; therefore, the best solution is prevention. The first step of prevention is to measure the concentration of contaminants in order to find a management solution to the problem. Schoeller's quality-classification diagram is a method is widely used to estimate the contamination of groundwater used for drinking. This diagram estimates the quality of drinking water in point sources (shafts, fountains, and aqueducts) and identifies the best resource based on quality among other point sources. Many studies use this method to determine the quality of drinking water (1-4). In spite of the advantages to estimating the quality of groundwater resources with this method, it is impossible to examine an entire area so as to draw a zoning map of the condition of groundwater for drinking purposes. Another restriction of this method is the limited number of water quality parameters. For zoning and estimating groundwater quality, many water quality indexes have been developed in recent years (5-11). One of these methods is the groundwater quality index (GQI) method for drinking water that has been employed in the present study. In this method offered by Babiker et al (12), the chemical parameters affecting the quality of drinking water are normalized, indexed, and compared to the World Health Organization (WHO) standards and guidelines. After the assimilation of these parameters, a zoning map of drinking water quality is created using the geographic information system. In recent years, this method has become well-known, and numerous studies have attempted to use it (13-22). The purpose of the current study was to investigate and zoning the quality of groundwater for drinking purposes in Lenjan plain (Iran) using the GQI method.

Methods

Study area

Lenjan plain (49611N-575446N and 3522155E-3592252E) with an area of 1588 square km is located in the 39N zone (according to the UTM coordinate system), the center of Iran (Isfahan province), in the Sanandaj-Sirjan structural zone (23). This region has average annual rainfalls of 200 mm (in the northern section) to 300 mm (in the center and southern sections) and average annual temperatures of 12°C (in the northern section) to 8°C (in the central and southern sections), and it can be classified as having a cold and desert dry climate (according to De Martonne's classification). The groundwater stream in Lenjan plain stretches from southwest and northeast to the center and exits from the north (Figure 1).

Data collection and preparation

To examine the quality of groundwater in the studied plain, the qualitative statistics (from 2015) of 38 wells were used (Figure 2) and included the parameters Na, Mg, Ca, TDS, SO_4, Cl, and pH. This study used the GQI method to classify water for drinking purposes. Sampling was done based on the guidelines of the US Environmental Protection Agency (EPA) (24). The samples were taken and stored in acid-washed polyethylene bottles. The collected samples were filtered using a 0.45 μm acetate cellulose filter on site and kept at a temperature below 4°C. Testing was conducted less than 24 hours after sampling at the Central Laboratory of Isfahan Province Water and Wastewater Company and based on the methods of the American Public Health Association. Field parameters such as pH were measured in the field using portable meters. Ca^{2+} and Mg^{2+} were determined using the standard EDTA titration method, and sodium was analyzed by flame photometry. The bicarbonate ion concentration was determined by acid titration, while the chloride concentration was determined by $AgNO_3$ titration and the sulfate concentration was analyzed using the turbidity meter.

This study performed groundwater quality zoning for drinking purpose using the GQI method through three phases as described below.

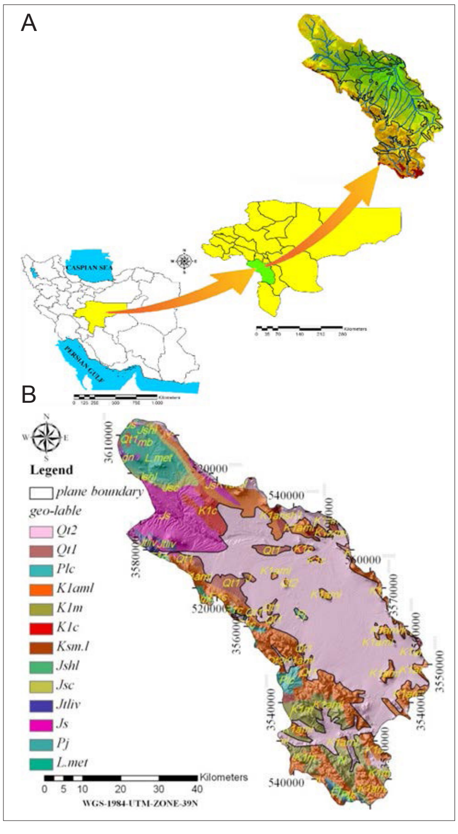

Figure 1. Location (A) and geology map of the studied area (B).

First phase

The concentration raster maps of the quality parameters were drawn using the kriging interpolation method in ArcGIS. Kriging is a method of interpolation based on a weighted moving average that uses known values to determine unknown values. This method is the best linear unbiased estimator (25).

In kriging, the estimated value, Z, at any point X_0 is given as follows:

$$Z^*(X_0) = \sum_{i-1}^{n} \lambda_i Z(X_i) \tag{1}$$

Where λ_i is the weight for the known value Z at location X_i. The kriging weights of ordinary kriging fulfill the unbiasedness condition.

$$\sum_{i-1}^{n} \lambda_i = 1 \tag{2}$$

First, an experimental semivariogram has to be calculated using the following equation:

$$\gamma^*(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(X_i) - Z(X_i + h)]^2 \tag{3}$$

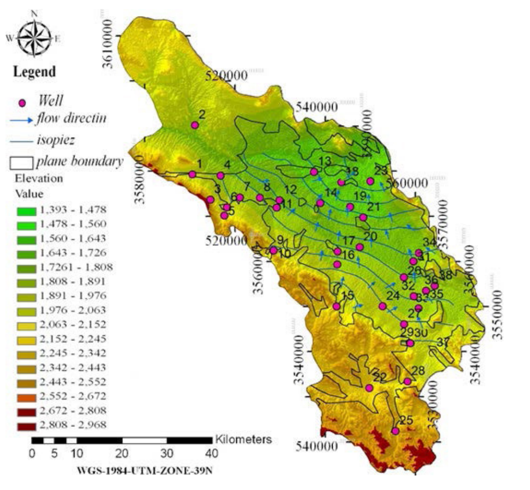

Figure 2. Location of sampling wells and groundwater flow direction of the studied area

where $\gamma^*(h)$ is the estimated value of the semivariance for lag class h; N(h) is the number of experimental pairs separated by a vector h of that lag class; and $Z(X_i)$ and $Z(X_i + h)$ are values of variable z at X_i and $X_i + h$, respectively. When the experimental semivariograms are calculated, suitable theoretical models are fitted to them, and the best model is selected based on the lowest RSS value and used in the kriging procedure.

Second phase

The correlation between the WHO standard for each parameter of drinking water and the concentration map of the same parameter is determined through normalized maps with the same scale through equation 4:

$$C(X) = \frac{x' - x}{x' + x} \quad (4)$$

where x is the allowed number according to the WHO standard (26), x' is the concentration raster map of each groundwater quality parameter, and $C(X)$ is the correlative index map of the quality parameter X the pixel values of which vary between -1 and +1. In this map, the more pixel values tend toward -1, the higher the quality of water upon quality parameter X. This shows that the quality is somehow close to the WHO standard (26). Those pixel values tending more toward +1 show decrease quality, which means that the quality is far from the WHO standard (26) for this parameter.

Third phase

Each correlation index map is ranked between 1 and 10 in order to set the rank map for each quality parameter. Ranked maps show the critical zones of the aquifer in relation to each quality parameter. To rank each pixel on the rank map, equation 5 is used:

$$r(X) = 0.5 \times (C(X))^2 + 4.5 \times C(X) + 5 \quad (5)$$

On this map, the pixels approaching closer to 1 indicate that the groundwater quality to quality parameter X is proper and that, based upon this parameter, the quality is close to the WHO standard (26). When values tend more toward 10, a decrease in water quality exists, and its quality is far from the WHO standard (26) concerning the related parameter.

At the end of the phase 3, the weight of each parameter is extracted by averaging the minimum and maximum numbers on the rank map of the same parameter. Then, using equation 6, quality zoning will be done through the GQI method.

$$GQI = 100 - (\frac{(r(X1)w(1) + r(X2)w(2) + ... + r(Xm)w(m)}{n} \quad (6)$$

In equation 6, $r(X1)$ to $r(Xm)$ indicates the rank map of quality parameter 1 to m, and w to $w(m)$ shows the weight of quality parameter 1 to m; n is the number of quality parameters used.

On the final map, a higher quality of groundwater for drinking purposes is reached when the pixel value tends more toward 100. When tending to 0, it then indicates a worse quality of groundwater for drinking purposes. Water quality classification using the GQI method is shown in Table 1.

Table 1. Water quality classification using GQI method

Quality	GQI
Good	91-100
Acceptable	71-90
Medial	51-70
Poor	26-50
Very unpleasant	0-25

Results

Table 2 shows the values of the quality parameters of Lenjan plain and the value allowed for each parameter (except pH that has no unit, all other parameters are reported in mg/L) according to the WHO standards (26). As seen in this table, the only parameter which has a maximum value in groundwater lower than the WHO standard (26) is Mg; the maximum values of all other parameters, especially Na, TDS, SO_4, and Cl, are higher than the WHO standards (26). This shows the existence of points in which these parameters are in bad condition. Figure 3 shows the interpolated maps of drinking water parameters. As can be seen, most parameters reveal high levels of anomalies in the northern parts of the plain. These anomalies can be attributed to the metamorphic conglomerate as well as the sediment structures upstream from the groundwater streams, since the salts existing in these structures have entered the groundwater streams because of erosion, thus increasing groundwater salinity. Furthermore, it may have occurred due to placing in the urban zone.

After drawing the interpolated raster maps of the quality values using equation 4 in the spatial analysis section of ArcGIS, correlation index maps of quality parameters were created. As indicated in Table 3 and Figure 4, on all maps except for the index map for Mg, the northern section and at the output of the studied plain, the pixel values tending toward +1, which shows an inappropriate quality because of its distance from the WHO standard (26).

As indicated in Table 4 and Figure 4, on the rank maps of the quality parameters which were drawn using equation 5 in the spatial analysis section of ArcGIS, the maximum variation range belonged to the quality parameter Cl (minimum rank: 1.32; maximum rank: 8.87) and the minimum variation range belonged to the quality parameter pH (minimum rank: 4.96; maximum rank: 5.16). The high anomaly of Cl on these maps is related to the great range of metamorphosed structures, particularly the green schist containing Cl and sediments containing Cl in the northwestern section and, consequently, a decrease in Cl.

Table 2. Value and statistics of the qualitative parameters and the allowed value of each parameter according to WHO standards in wells of the studied area

Parameter	SO_4^{2-}	Cl^-	Na^+	Mg^{2+}	Ca^{2+}	PH	TDS
w1	86.88	39.05	25.30	28.80	56	8.10	417
w2	490.10	262.70	209.30	68.40	102	8.10	1414
w3	101.30	145.55	73.60	19.20	76	8.20	537
w4	317.30	17.75	172.50	28.80	12	8.70	714
w5	336.50	49.70	207	22.80	26	8.60	917
w6	53.28	28.40	23	19.20	44	8.10	338
w7	216.50	56.80	69	30	74	8	619
w8	43.68	21.30	20.70	14.40	42	8.30	296
w9	125.30	17.75	27.60	20.40	34	8.50	279
w10	82.08	10.65	29.90	3.60	44	8.50	234
w11	393.60	106.50	218.50	15.60	46	8.50	863
w12	576	106.50	253	39.60	54	8.40	1163
w13	1018	2201	736	96	880	8	5649
w14	523.20	411.80	271.40	50.40	164	8.10	1547
w15	58.08	42.60	23	13.20	44	8.40	302
w16	134.90	46.15	36.80	21.60	80	7.80	466
w17	595.70	71	204.70	37.20	110	8	1118
w18	1219	1775	591.10	228	640	8	5152
w19	744.50	177.50	138	76.80	192	7.90	1407
w20	96	74.55	59.80	16.80	52	8.10	426
w21	197.30	156.20	87.40	30	94	8	789
w22	43.68	28.40	11.50	14.40	40	8.40	248
w23	1032	795.20	577.30	86.40	248	8.20	2884
w24	341.30	56.80	78.20	48	72	8.30	725
w25	29.28	10.65	4.60	14.40	32	8.40	194
w26	715.70	113.60	269.10	42	102	8.30	1435
w27	379.70	35.50	158.70	25.20	54	8.50	794
w28	62.88	24.85	13.8	20.40	34	8.40	261
w29	192.50	35.50	64.40	20.40	60	8.30	456
w30	202.10	28.40	52.90	25.20	50	8.30	414
w31	562.10	241.40	207	88.80	104	8.10	1428
w32	437.30	71	209.30	28.80	48	8.40	897
w33	197.30	42.60	69	30	70	8.30	566
w34	355.70	383.40	230	73.20	94	8.40	1414
w35	216.50	88.75	66.70	34.80	66	8.20	555
w36	523.20	106.50	186.30	40.80	92	8.30	1038
w37	96.48	67.45	32.20	33.60	40	8.50	413
w38	187.70	60.35	59.8	36	70	8.60	575
WHO standard	250	250	200	300	300	8	1000
Arithmetic average	341.68	210.80	151.80	40.61	109	8.27	1024.80
Standard deviation	300.04	452.10	167.40	38.71	164.54	0.21	1174.40
Maximum	1219.20	2201	736	228	880	8.70	5649
Minimum	29.28	10.65	4.60	3.60	12	7.80	194
Median	216.48	63.90	75.90	29.40	63	8.30	666.50
Skew	1.29	3.64	2.05	3.36	3.87	-0.14	3.01

In the last phase of the GQI method, the weight of each parameter is calculated in order to merge the layers. The weight of each parameter on the rank map of the same parameter was calculated by averaging the maximum and minimum numbers. These are indicated in Table 4. According to this table, the highest weight belongs to the quality parameter TDS with a value of 5.29, and the lowest belongs to the quality parameter Mg with a value of 2.76.

Discussion

Eventually the groundwater quality zonation map of Lenjan plain using the GQI method was created by merging the quality parameters rank maps. According to the map (Figure 4), the value of GQI was between a minimum of 67.48 and a maximum of 90.05. To sum up, the results of this study indicated that the quality of the drinking water in the studied area could be classified as

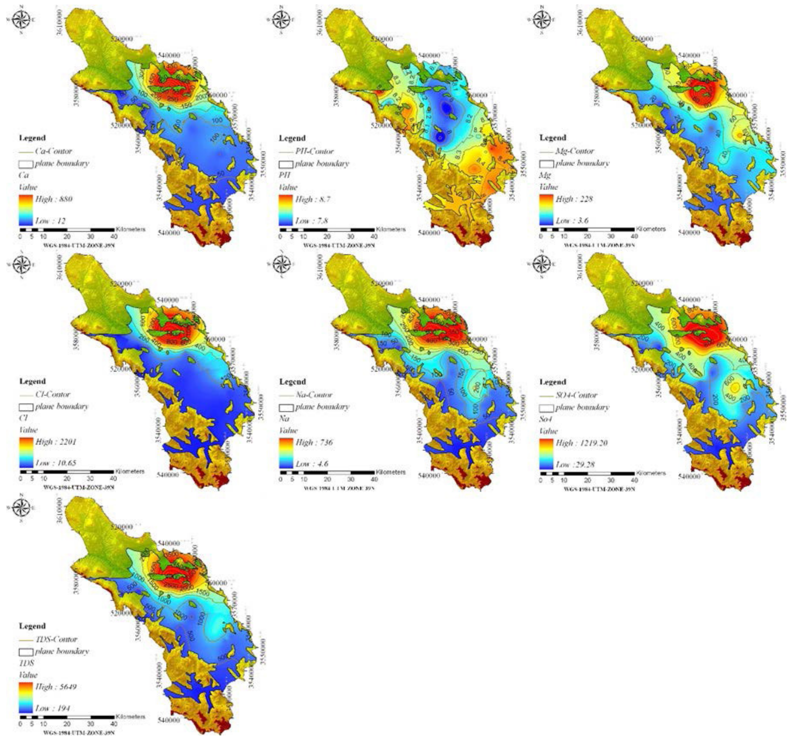

Figure 3. Interpolate drinking water parameters by kriging method.

Table 3. Statistical parameters of correlation index map

Parameter	Minimum	Maximum
C(Ca)	-0.91	0.48
C(Cl)	-0.90	0.79
C(Na)	-0.94	0.56
C(Mg)	-0.95	-0.14
C(pH)	-0.008	0.036
C(SO4)	-0.77	0.65
C(TDS)	-0.66	0.69

Table 4. Statistical parameters of rank map and weight calculations of qualitative parameters

Parameter	Minimum	Maximum	Weight (Mean)
r(Ca)	1.28	7.27	4.28
r(Cl)	1.32	8.87	5.10
r(Na)	1.18	7.70	4.44
r(Mg)	1.14	4.37	2.76
r(pH)	4.96	5.16	5.06
r(SO4)	1.81	8.18	5.00
r(TDS)	2.22	8.36	5.29

medial (in the northern parts of the plain) to acceptable. The findings of the current study are similar to those of Jokar et al (27) who used the GQI method to study Ahu-dasht plain in Khuzestan (southwestern Iran) for groundwater quality zoning. Their study showed a minimum level of 66 to a maximum of 84 for GQI in different parts of the plain; therefore, the groundwater quality was rated as average to acceptable.

Jodavi (28) studied the groundwater quality for drinking purposes in Feyz-abad plain (in northeastern Iran) using the GQI index for drinking water quality zoning. Their results showed a minimum level of 92 and a maximum of 94 for GQI.

Mir Arabi et al (29) also used the GQI method for drinking water quality zoning in the Abarkuh plain in Yazd province (central Iran). Their results showed that according to the estimated GQI, the drinking water quality was rated as average.

In another study done by Rahmani et al (30), the groundwater quality in Izeh plain (southwestern Iran) was assessed for drinking. The results showed GQI = 92; thus, it was concluded that the groundwater quality is proper. Afzali et al (20) used the GQI method to assess groundwater quality in Haraz Alluvial fan. The investigation of water samples using the GQI method showed that the water quality in the study area (in terms of the indicator) ranged from moderate to good (71.83–82.26).

Geologic and GQI maps show that the water with the lowest quality was in the northern section and at the output of the studied plain. Possible explanations for this could be related to the long distance traveled by the groundwater, low sedimentation, concentration of the geological textures and structures in these areas. These possible explanations are similar to the findings of Kheiry and Khademi (17) and Mohebbi Tafreshi et al (16).

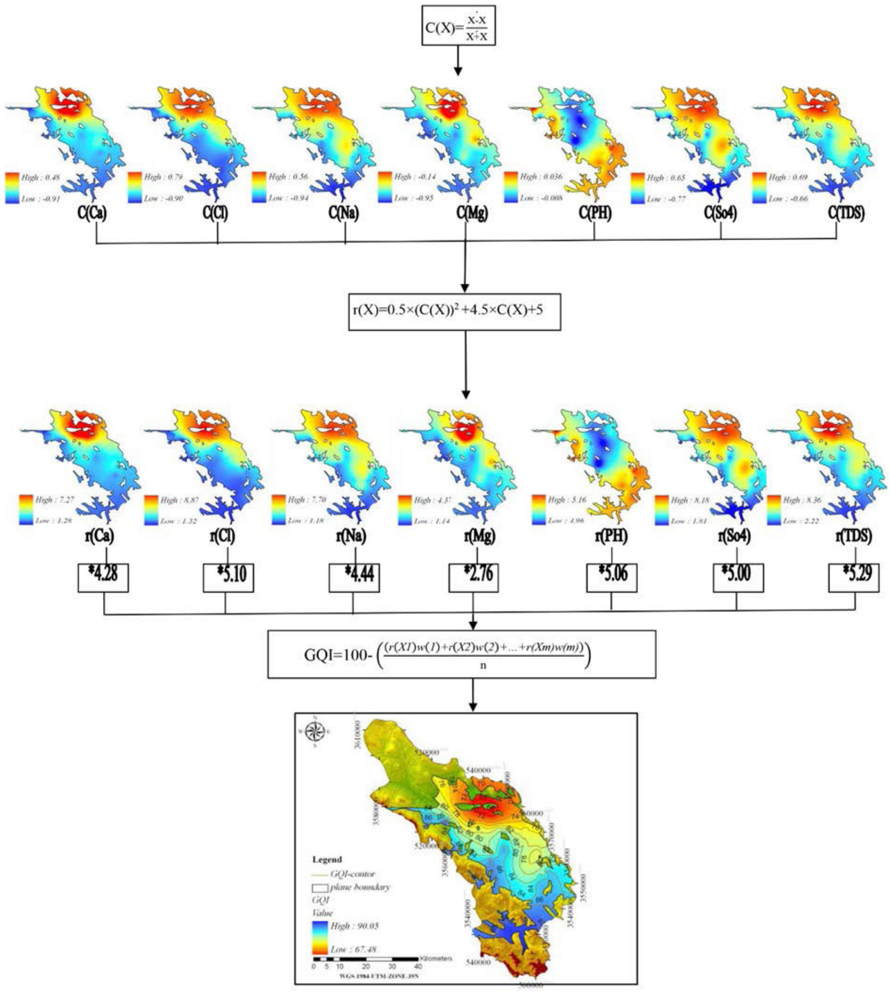

Figure 4. Various stages of GQI method.

Conclusion

According to the spatial variability of different pollutants, qualitative zoning of groundwater is the first and most crucial step in water management measures. Zoning aims at identifying the qualitative features of groundwater in order to make appropriate decisions concerning the use or disuse of water resources in the required applications. This study used the GQI method (a GIS-based method) to qualitative zoning of groundwater.

The results obtained by analyzing the effective parameters on drinking water quality showed that the quality of the groundwater samples taken from the studied area based on the GQI method could be classified as medial (in the northern parts of the plain) to acceptable (in the central and southern parts of the plain) for drinking purposes.

The model used in this work was based on using GIS, the GQI method, and drinking water parameters, and it is a good approach to qualitative zoning groundwater for drinking proposes. It extends the existing methods of this field in terms of groundwater management.

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Ethical issues

The authors confirm that this manuscript is their original work and has not been published nor is under review in any other refereed journal, and it is not being submitted for publication elsewhere.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

All authors contributed equally and participated in the collection, analysis and interpretation of the data. All authors critically reviewed, refined and approved the manuscript.

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