Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.20458

67 (2017) 74–83
March

Use of geographic information system and water quality index to assess groundwater quality for drinking purpose in Birjand City, Iran

Rasoul Khosravi[a], Hadi Eslami[a], S. Ali Almodaresi[b,*], Mohsen Heidari[c], Reza Ali Fallahzadeh[a], Mahmoud Taghavi[d], Maryam Khodadadi[e], Roya Peirovi[f]

[a]*Faculty of Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran, emails: khosravi.r89@gmail.com (R. Khosravi), hadieslami1986@yahoo.com (H. Eslami), fallahzadeh4@yahoo.com (R.A. Fallahzadeh)*
[b]*Engineering College, GIS&RS Department. Yazd Branch, Islamic Azad University, Hesabi Blv, Safaeie, Yazd, Iran, Tel./Fax: +98 35 3821 48 15; email: almodaresi@iauyazd.ac.ir*
[c]*Social Determinants in Health Promotion Research Center, Hormozgan University of Medical Sciences, Bandar Abbas, Iran, email: moheidari84@gmail.com*
[d]*Department of Environmental Health Engineering, Zabol University of Medical Sciences, Zabol, Iran, email: taghavi66@yahoo.com*
[e]*Social Determinants of Health Research Center, Department of Environmental Health Engineering, Faculty of Health, Birjand University of Medical Sciences, Birjand, Iran*
[f]*Department of Environmental Health Engineering, Faculty of Health, Gonabad University of Medical Sciences, Gonabad, Iran, email: rrppmm20@yahoo.com*

Received 29 June 2016; Accepted 26 December 2016

ABSTRACT

This study aimed at utilizing geographic information system (GIS) and water quality index (WQI) for evaluation of the quality of groundwater in Birjand City, Iran. This study evaluated the physical and chemical parameters of 19 wells located in South Khorasan Province, within the boundary of Birjand City (with an area of 5,400 km^2). First, using ArcGIS 10.22 software, the zoning maps were plotted for pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), bicarbonate, ammonium, sulfate, nitrate, calcium, magnesium, sodium, and potassium. Then, WQI was employed to evaluate water quality. According to the results, in over 90% of the studied area, EC, TDS, and TH values were above the allowable limit. Considering the zoning map and the results of spatial analysis of the parameters, the more we moved from the south of the studied region to the north, the parameters values increased, representing the worsened quality of water. Based on the results of WQI classification, only 10.5% of the studied wells were placed in the first group (excellent water), while the majority of sampling points (36.84%) were placed in the third group (poor water). The zoning and spatial analysis of water quality showed that water quality was suitable for drinking purposes only in 1,958 km^2 (36.28%) of the entire studied region. Moreover, in 3,437.53 km^2 (63.69%) of the studied area, water quality was unsuitable for drinking. Therefore, the application of WQI and spatial analysis through GIS was effective for monitoring groundwater quality in the studied region, and it can be considered as a promising tool for understanding the spatial patterns and changes.

Keywords: Physicochemical parameters; Geographic information system; Water quality index; Spatial analysis; Birjand

1. Introduction

Groundwater plays an important role in provision of water for drinking purposes in dry and semi-dry urban and rural regions especially in Iran [1]. It is estimated that around one third of the world's population use groundwater for drinking purposes [2]. The quality of groundwater normally depends on the geochemical compounds of minerals and other hydrodynamic factors present in any region [3,4]. However, due to the passage through different layers of earth, groundwater is

---

* Corresponding author.

generally filtered and is usually colorless and free of turbidity and other microbial contaminants and organic compounds. Instead, they are rich in minerals that makes it necessary to treat water only in some special cases [5]. However, it seems that the quality of groundwater is constantly worsening, which is mainly due to uncontrolled exploitation of these resources and penetration of dissolved chemicals resulting from urban and industrial activities along with agricultural wastewaters [6–8]. Low-quality drinking water can affect human health and result in the incidence of many acute and chronic diseases in many parts of the world. The mentioned health problems are considered as main important causes of mortality in many communities [9,10]. According to a report by the World Health Organization (WHO), about 80% of human diseases are somehow related to water; moreover, when a groundwater resource is contaminated, its water quality does not easily recover through stopping the entrance of contaminants [11–13]. Moreover, concurrent with the growth of population, there has been an increase in people's demand for water for different uses including household, industrial, agricultural, and recreational activities; thus, it has become necessary to better manage, monitor, and evaluate the quality of water resources [10]. The quality of water resources can be evaluated through the comparison of the values of a parameter with its standard values; however, it is considered as a traditional and simple method that cannot present a comprehensive and thorough picture of the overall status of water quality in a specific region. To overcome this problem, several water quality indices have been developed for converting the values of different parameters into a comprehensive and thorough index [14]. Water quality index (WQI) is a very promising tool for evaluation of and monitoring the extent of spatial and temporal changes in water quality parameters through a numerical scale and using mathematical calculations; it can provide policy-makers and managers with very useful information regarding water resources quality [15–17]. Indeed, WQI reflects the composite influence of several water quality parameters. It has attracted a great deal of attention for groundwater monitoring because it can present comprehensive, thorough, and understandable data about water quality status [18,19].

Geostatistical techniques, geographic information system (GIS), and ArcGIS software (as an important and useful type of GIS software) can be used as suitable tools to represent temporal and spatial variations in parameters of groundwater quality, determine the quality of groundwater between distant sampling points, and depict the overall status of groundwater quality in a region under the coverage of a water resource [20].

Given the importance of monitoring groundwater quality and application of suitable instruments and methods for water quality measurement, this study was conducted with the aim of utilizing GIS and WQI for the evaluation of groundwater quality for drinking purposes in Birjand City.

2. Methods

2.1. Location of the studied region

The studied region is located in South Khorasan Province within the boundary of Birjand City with an area of 5,400 km^2 covering a geographical position from 58°4″0′ to 59°40″0′ E and from 32°40″0′ to 33°40″0′ N (Fig. 1).

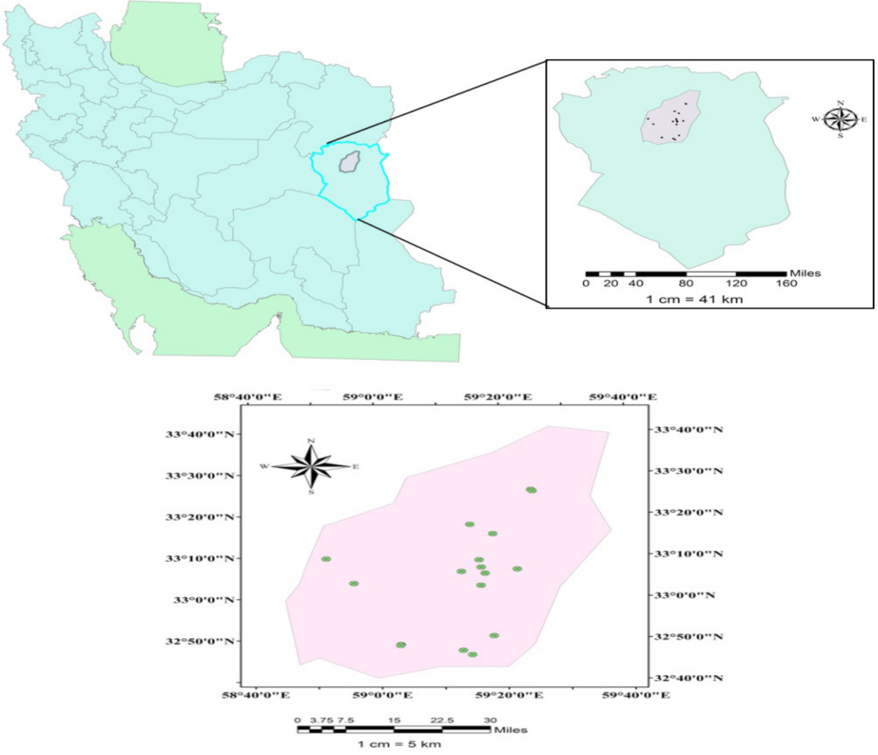

Fig. 1. The geographical position of the studied region.

2.2. Data input

In this study, the samples were collected from 19 wells located in the study region; they were collected twice during spring and autumn 2015, and mean values were reported. The parameters investigated in this study were the followings: pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), bicarbonate (HCO_3^-), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+).The data on a 1-year trend of the mentioned parameters were collected and then analyzed using standard methods [21].

2.3. Analysis using GIS and remote sensing

In this study, ArcGIS 10.22 software was used for the preparation of zoning maps. Interpolation models were used to analyze the data in GIS Software. In this study, inverse distance weighting (IDW) was used for the preparation of zoning maps of the desired parameters [22,23]. IDW is an algorithm that is used for interpolation of data in a spatial form; it predicts the distances between sampling points based on the weighted mean of each parameter and the distance between the points [24]. Moreover, to study the status of vegetation in the studied area we used Landsat Archive image (L4-5 TM sensor). ENVI 4.7 software was used to combine bands and extract maps.

The WHO's standards for drinking water were used to determine water quality in terms of the investigated parameters.

2.4. Determination of WQI

WQI was calculated through the measurement of several key factors to determine the effect of human and natural activities on the quality of groundwater resources [25]. There were three stages for calculation of WQI [26]. At the first stage, 12 parameters were chosen (pH, EC, TDS, TH, HCO_3^-, Cl^-, SO_4^2, NO^-_3, Ca^{2+}, Mg^{2+}, Na^+, and K^+); then considering the impact of each parameter on the quality of groundwater for drinking purposes and its influence on human health a weight (w_i), ranging from 1 to 5, was attributed to each parameter. The largest weight, i.e., 5, was attributed to nitrate and TDS; 4 to EC and SO_4^{2-}; 3 to bicarbonate and ammonium; 2 to calcium, sodium, and potassium; and 1 to magnesium [27]. At the second stage, the relative weight (W_i) for each parameter was calculated using Eq. (1):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} wI} \tag{1}$$

where W_i is the relative weight of each parameter; w_i is the weight attributed to each parameter; and n is the number of parameters investigated

At the third stage, the relative quality (q_i) of each parameter was calculated using Eq. (2); accordingly, the value measured for each parameter in the sample was divided by the standard value of that parameter [25]:

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

where q_i is the relative quality of each parameter; C_i is the measured concentration of each parameter in the sample (mg/L); and S_i is the WHO's standard for each parameter (mg/L).

Finally, in order to calculate WQI, the critical index or sub-index (SI_i) for each parameter was calculated using Eq. (3), where the sum of SI_i calculated for each parameter represented the WQI value (Eq. (4)) [19,25]:

$$\mathrm{SI}_i = q_i * W_i \tag{3}$$

$$\mathrm{WQI} = \sum \mathrm{SI}_i \tag{4}$$

where SI_i is the sub-index of the *i*th parameter; q_i is the relative quality of each parameter; W_i is the relative weight of each parameter; and WQI: water quality index.

3. Results and discussion

Table 1 presents the results of the statistical analysis of the investigated parameters including maximum, minimum, and the mean values. Figs. 2–4 present the zoning maps depicted for each of the investigated parameters using IDW model.

Table 1
Statistics of physicochemical parameters (n = 18)

Parameters	Maximum	Minimum	Mean	Standard Deviation
Temperature (°C)	26.7	23.4	24.573	0.915
pH	8.32	7.25	7.83	0.25
EC (μS/cm)	7,450	1,000	2,619.31	1,589.86
TDS (mg/L)	4,980	586.75	1,658.36	1,072.93
HCO_3^- (mg/L)	443.29	105.40	289.25	106.58
Cl^- (mg/L)	1,668.43	75.29	415.90	407.91
SO_4^{2-} (mg/L)	1,487.33	123.86	508.13	362.11
NO_3^- (mg/L)	54.69	6.98	25.891	12.339
Ca^{2+} (mg/L)	511.18	29.46	118.29	118.39
Mg^{2+} (mg/L)	120.64	7.05	54.485	28.64
Na^+ (mg/ L)	1,042.16	110.32	387.16	239.11
K^+ (mg/ L)	13.05	1.74	5.786	3.63
TH (mg/ L)	1,774.41	123.63	519.95	370.64

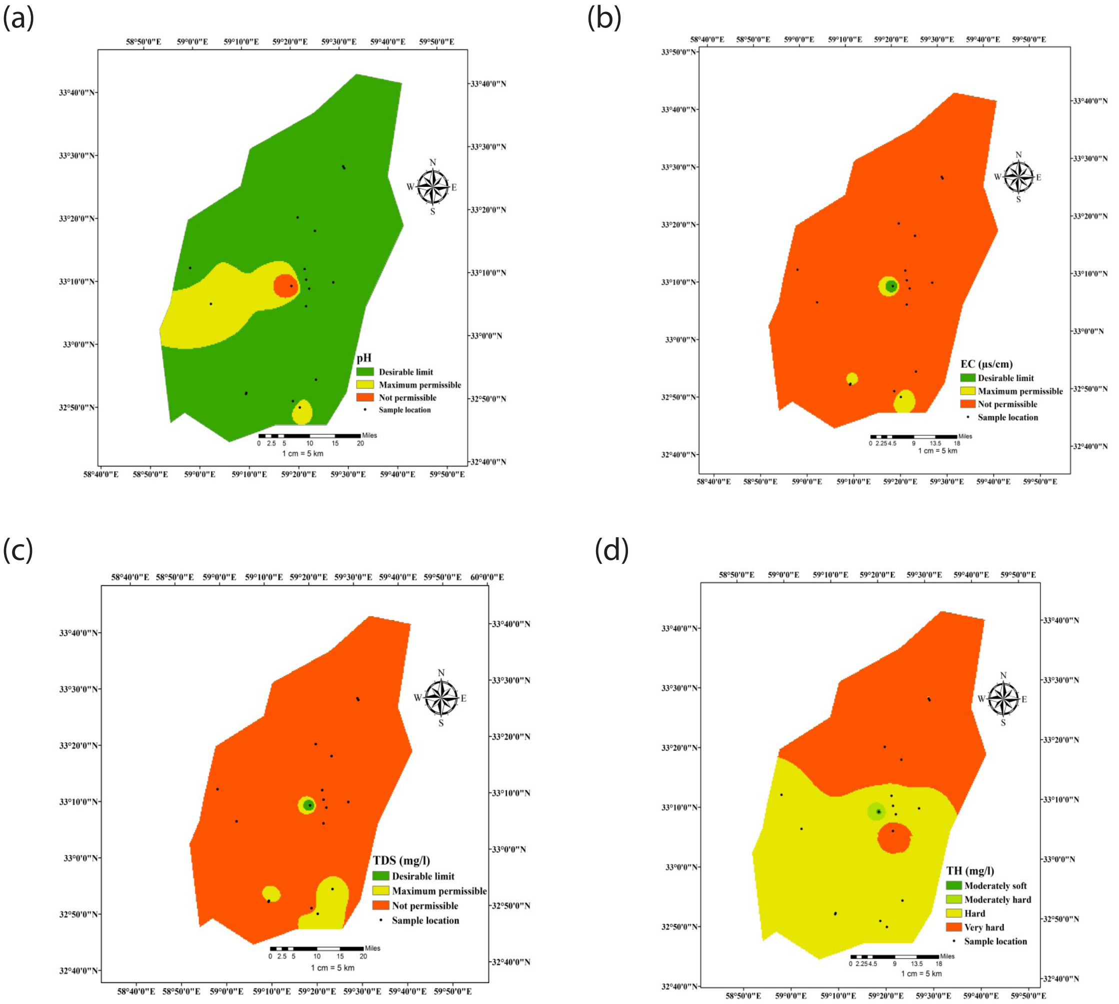

Fig. 2. Zoning the status of groundwater quality in the studied region in terms of pH (a), EC (b), TDS (c), and TH (d).

3.1. pH

The pH value represents the ability of water to react with acidic and alkaline compounds present in the water resource, controlled through the equilibrium between carbon dioxide, carbonate, and bicarbonate [13,24]. Typically, pH does not directly influence human health, but it is a very important parameter in determination of quality of water resource that can influence the extent of solubility of many salts and determine the level of contaminants in water resources [28]. The WHO's standard for pH is between 6.5 and 8.5. In this study, the mean pH was 7.83, which laid within the standard range, suggesting that bicarbonate ion was abundant and the region's wells had an alkaline nature (Table 1) [29]. As shown in Fig. 2(a) and based on the results of zoning and spatial analysis of pH values, in the majority of points and distance between them pH parameter laid within the normal range.

3.2. Electrical conductivity (EC)

EC represents the capacity of transmission of electrical current due to the presence of ions that exist in water resources. Indeed, EC shows the presence of water-soluble salts [25,30]. EC values can be categorized in three groups as follows: the first group: a value lower than 1,500 µs/cm (low soluble salts), second group: an EC value between 1,500 and 3,000 µs/cm (medium levels of soluble salts), and third group: an EC value above 3,000 µs/cm, which suggests that the level of soluble salts in the water resource is high [31]. Although the maximum standard level of EC for drinking water at a temperature of 25°C is 1,500 µs/cm [28], in this study, the level of EC laid between 1,000 and 7,450 µs/cm. Based on the EC classification, 21% of the studied water resources laid within the range of the first group (low salt enrichment); 52.6% were placed in the second group (medium salt enrichment); and 26.4% were placed in the third group (high salt enrichment). The zoning map and spatial analysis of EC values also indicate that over 90% of the studied area had unfavorable EC values (Fig. 2(b)).

3.3. Total dissolved solids (TDS)

TDS value indeed represents the weight of residual compounds following water sample evaporation and drying [32]. TDS value is one of the most important parameters in

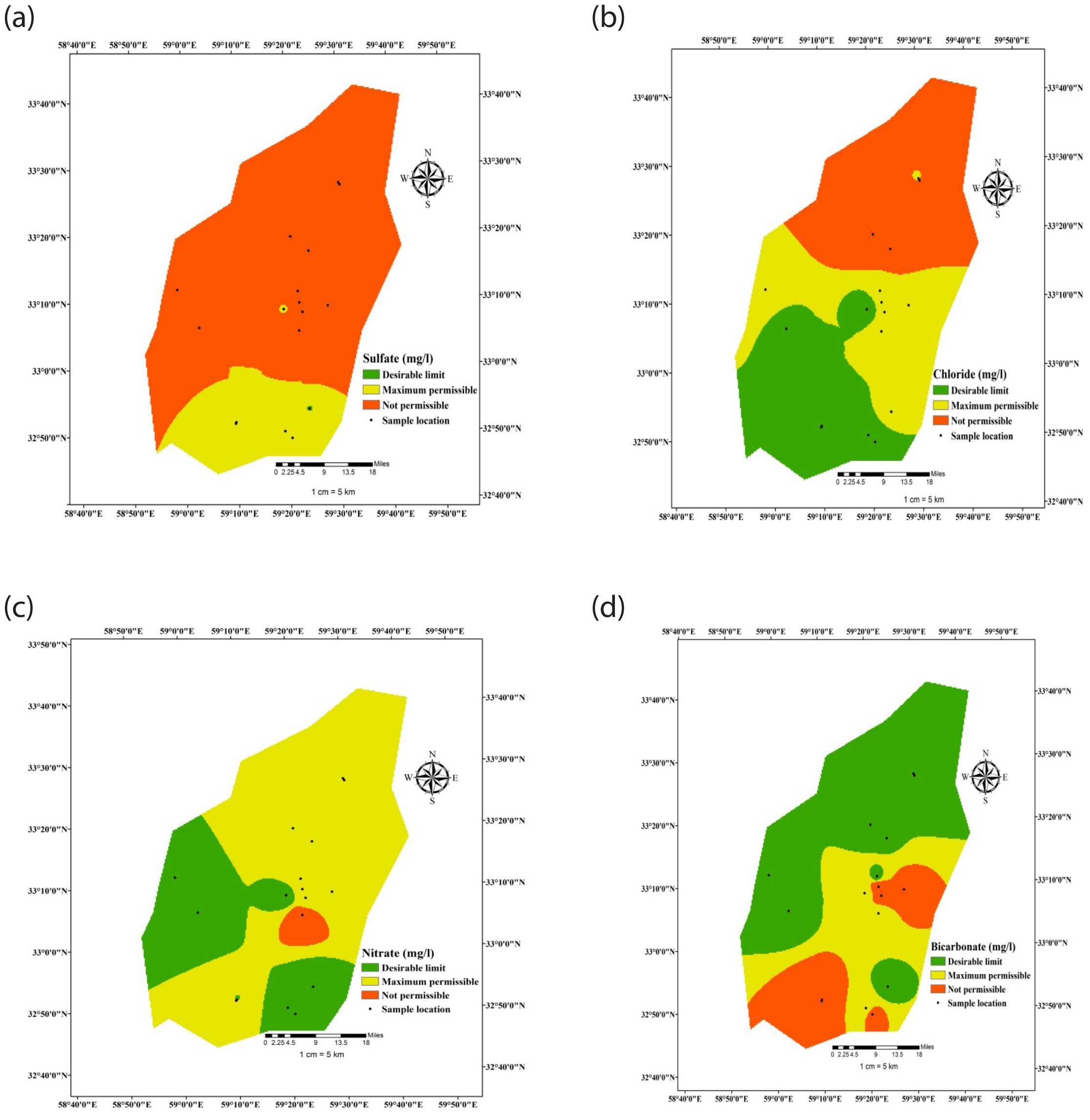

Fig. 3. Zoning the status of groundwater quality in the studied region in terms of SO_4^{2-} (a), Cl^- (b), NO_3^- (c), and HCO_3^- (d).

determination of the level of water consumption and withdrawal in a region. High levels of TDS are not suitable for agricultural purposes nor for drinking purposes [33]. Studies have revealed that high concentration of TDS in groundwater alone cannot be harmful for human, but consumption of this type of water can be detrimental to the health of people suffering from cardiovascular and kidney disorders [34]. According to TDS classification of groundwater, water with a TDS lower than 1,000 mg/L is classified as freshwater, between 1,000 and 10,000 mg/L as brackish, and over 10,000 mg/L as salty waters [20]. Fig. 2(c) presents the zoning map and spatial analysis of TDS values; in this figure, orange color, which covers over 90% of the studied area, represents TDS values above 1,000 mg/L, suggesting that TDS values do not lie within the allowable limit for drinking purposes and the studied water type is brackish. The high TDS concentration could be a result of the entrance of soil salts into the groundwater resources due to uncontrolled exploitation of the resources. Further, human activities and penetration of household wastewaters to the water resources can increase TDS values [20].

3.4. Total hardness (TH)

Water hardness is mainly caused due to the presence of calcium and magnesium cations together with carbonate, bicarbonate, chloride, and sulfate anions [35]. Water with a hardness of above 200 mg/L can form scale in the distribution network. In addition, water with a hardness of above 300 mg/L is considered as a very hard water [36]. Although high levels of water hardness have no known adverse effects on human health, some recent evidences have suggested its relationship with cardiovascular disorders. It can also result in scale formation in the distribution network, system fouling, and increased boiling point; moreover, it makes it

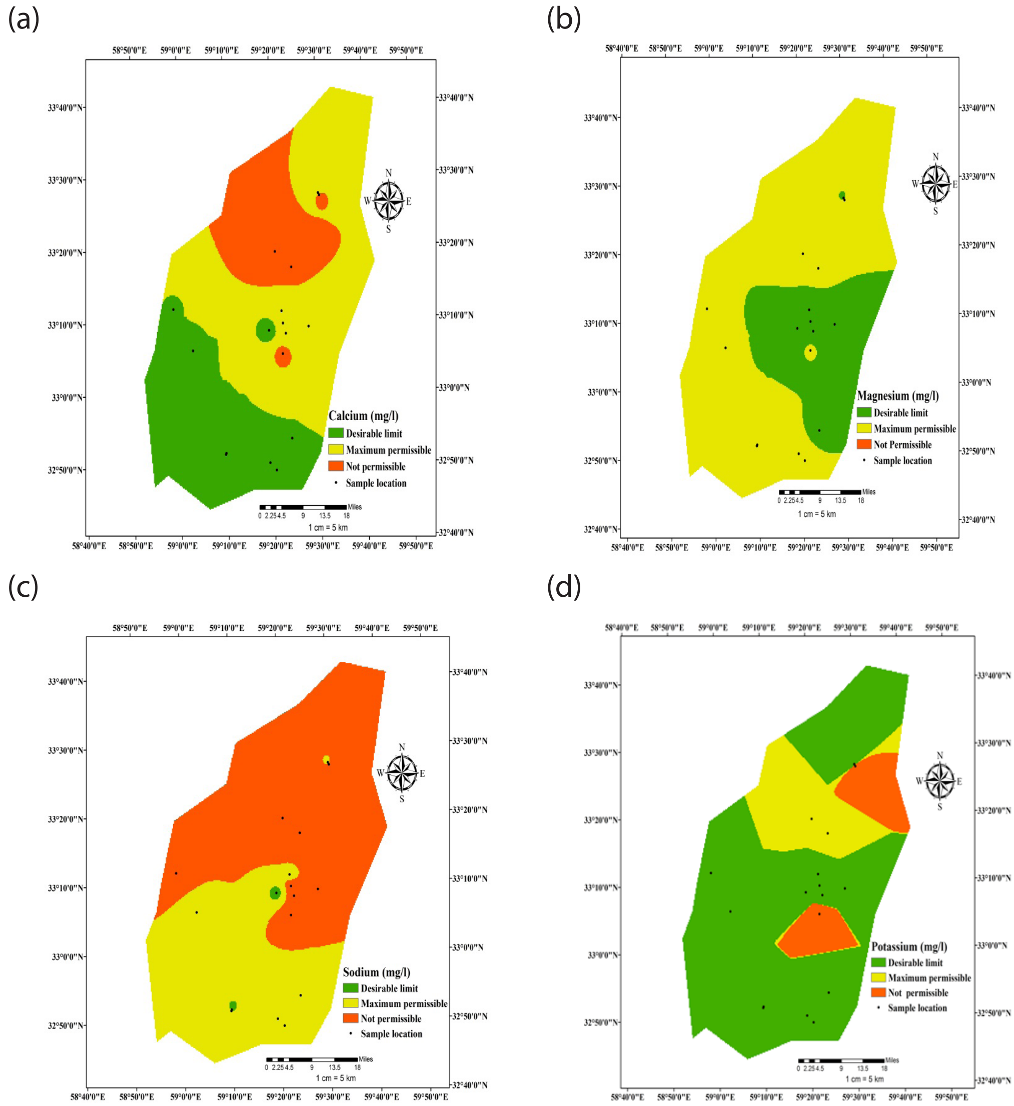

Fig. 4. Zoning the status of groundwater quality in the studied region in terms of Ca^{2+} (a), Mg^{2+} (b), Na^{+} (c), and K^{+} (d).

difficult to use the water for washing clothes for household uses [20,36]. In this study, the TH values ranged from 123.43 to 1,774.41 mg/L with a mean value of 519.93 mg/L, suggesting that TH of groundwater in the studied region was very high. Fig. 2(d) presents the zoning map and spatial analysis of TH values; in this figure, orange color, which covers over 90% of the studied area, represents TH values above 300 mg/L. The high level of hardness in the studied region is attributed to the material and texture of pathway of groundwater, as it passes through calcareous layers and collects carbonate as well as bicarbonate ions, which later accumulate in water resources.

3.5. The main studied anions

3.5.1. Sulfate (SO_4^{2-})

The high concentration of sulfate in drinking water brings about a laxative effect in the body system [25]. According to the WHO's standard, the maximum desirable level of sulfate is 250 mg/L, and the maximum allowable concentration of sulfate in water is 400 mg/L. In this study, the concentration of sulfate ranged from 123.86 to 1,487.33 mg/L; moreover, in 52.6% of the sampling points, its concentration did not lie within the allowable range. Fig. 3(a) presents the zoning map and spatial analysis of sulfate values; in this figure, orange color represents an area of the studied region where sulfate values were above 400 mg/L, i.e., they were not in an allowable range, suggesting that in the majority of the studied region sulfate values were above the allowable limit. Presence of large amounts of sulfate can be due to the existence of reduced form of sulfur in sedimentary rocks that form metallic sulfides and change into sulfate in response to contact with water and air humidity [37].

3.5.2. Chloride (Cl^{-})

Chloride ion is often naturally available in the form of chlorine and has a very low mobility in water. The presence of chloride ion in groundwater resources can be due to different factors including weathering, leakage of soil sediments, minerals, as well as urban and industrial wastewaters into water resources [25]. According to the WHO's standard, the maximum desirable level of chloride is 250 mg/L. In this study, the concentration of chloride ranged from 75.29 to 1,668.43 mg/L. The maximum allowable limit for chloride is 600 mg/L, where in 15.7% of samples, it exceeded the allowable limit. Fig. 3(b) presents the zoning map and spatial analysis of Cl^- values; in this figure, orange color represents an area of the studied region where Cl^- values were above 600 mg/L. It was observed mainly in northern regions. The more we move toward south, the Cl^- values decrease more. The high level of chloride can be attributed to the material of rocks and the soil of the region or entrance of urban and industrial wastewaters. The high concentration of chloride can give a salty taste to water and cause the water to become corrosive, not to mention that it is not very suitable for cardiovascular and kidney patients [24].

3.5.3. Nitrate (NO_3^-)

Nitrate is one of the elements that is highly water soluble; it can enter water resources easily through soil [29]. Its presence in groundwater is mainly attributed to the impact of agricultural and human wastewaters [38]. The most important problems caused by these compounds are methemoglobinemia, blue baby syndrome, hypertension, diabetes, thyroid disease, stomach cancer, abortion, and altered immune function [39–41]. According to the WHO's standard, the maximum allowable concentration of nitrate is 45 mg/L (as NO_3^-). In this study, its level ranged from 6.98 to 54.69; in addition, in only one point of the sampling its level exceeded the allowable limit, which is shown in zoning map and spatial analysis of nitrate values presented in Fig. 3(c).

3.5.4. Bicarbonate (HCO_3^-)

The concentration of carbonates in natural water mainly depends on the level of soluble carbon dioxide, temperature, pH, cations, and some soluble salts. The concentration of carbonates in groundwater is usually higher than that in surface waters [25]. According to the WHO's standard, the maximum allowable concentration of bicarbonates is 500 mg/L. In this study, the level of bicarbonate ranged from 105.43 to 443.29 mg/L, and it laid within the standard range. The zoning map and spatial analysis of the values of bicarbonate also indicate that in the majority of the studied area, bicarbonate values laid within the standard and allowable range (Fig. 3(d)).

3.6. The main studied cations

3.6.1. Calcium and magnesium (Ca^{2+} and Mg^{2+})

The presence of calcium and magnesium cations in groundwater is mainly attributed to mineral carbonates including calcite and dolomite [33]. These items can directly result in water hardness; they mainly exist in form of bicarbonate and to a little extent sulfate and chloride [25,42]. According to the WHO's standard, the maximum desirable level of calcium is 75 mg/L, and its maximum allowable limit is 200 mg/L. In this study, it ranged from 29.46 to 511.18 mg/L, where in four sampling points (21%), its value was above the standard level. Fig. 4(a) presents the zoning map; in this figure, orange color represents the area with values out of the allowable range. The water with a calcium level above the allowable limit can cause stomach problems, kidney problems, bladder stone, and urinary tract obstruction in human beings [24]. Further, the use of such a water for household purposes can result in encrustation and scaling of the pipes [25]. According to the WHO's standard, the maximum desirable level of magnesium is 50 mg/L, and its maximum allowable level is 150 mg/L. In this study, it ranged from 7.05 to 120.64, and in all the sampling points, its value was below the maximum allowable level. Fig. 4(b) presents the zoning map of magnesium levels.

3.6.2. Sodium and potassium (Na^+ and K^+)

According to the WHO's standard, the maximum allowable concentration of sodium in drinking water is 200 mg/L. In this study, the concentration of sodium ranged from 110.32 to 1,042.16 mg/L, and in 15 points of the sampling site (78.9%), it was above the allowable level. Fig. 4(c) presents the sodium's zoning map; in this figure, the orange color represents the area where sodium concentration was not in the allowable range. In this study, sodium ion was the predominant cation; in addition, the higher value of sodium, as compared with calcium, is due to the process of cation exchange in soil. The high level of sodium in groundwater can be the result of weathering of silicate rocks or solubility of the salts present in soil due to evaporation, human activities, and agricultural activities [25]. According to the WHO's standard, the maximum allowable concentration of potassium is 12 mg/L. In this study, it was 1.74–13.05 mg/L. According to the results, in four points of the sampling (21%), potassium values were above the allowable level. Fig. 4(d) presents the potassium's zoning map; in this figure, orange color represents the area where potassium concentration was not in allowable range.

3.7. Estimation and mapping of water quality index

WQI is known as a very important parameter for determining water quality for drinking purposes [33]. WQI is a technique that measures the effect of several parameters on the quality of water resource together and expresses them as one parameter [25]. Table 2 presents weight, relative weight, and the WHO's standard for every parameter required for calculation of WQI. Moreover, WQI classification is presented in Table 3. The results of WQI classification indicated that out of the 19 sampling points (the sampling wells), 10.5% (two sampling wells) were located in the first category (excellent water), 31.57% (six sampling wells) in the second category (good water), 36.84% (eight sampling wells) in the third category (poor water), 15.7% (three sampling wells) in the fourth group (very poor water), and 5% (1 sampling well) in the fifth category (water unsuitable for drinking purposes) (Table 4). Zoning and spatial analysis of water quality (Fig. 5) showed that the more we moved from south to north, water quality worsened further, and only in 1,958 km^2 (36.28%) of the entire studied area, water quality was good for drinking purposes; on the other hand, in 3,437.53 km^2 (63.69%) of the studied area, water quality was not suitable and was poor

Table 2
Weight, relative weight, and the WHO's standard for physical–chemical parameters in the studied region

parameters	WHO standards	Weight (w_i)	Relative weight (W_i)
pH	6.5–8.5	4	0.114
EC (μS/cm)	500	4	0.114
TDS (mg/l)	500	5	0.142
HCO_3^- (mg/l)	500	3	0.086
Cl^- (mg/l)	250	3	0.086
SO_4^{2-} (mg/l)	250	4	0.114
NO_3^- (mg/l)	45	5	0.142
Ca^{2+} (mg/l)	75	2	0.057
Mg^{2+} (mg/l)	50	1	0.029
Na^+ (mg/l)	200	2	0.057
K^+ (mg/l)	12	2	0.057
Sum		$\sum w_i = 35$	$\sum w_i = 0.998$

Table 3
Water quality classification ranges and types of water based on water quality index (WQI) values [30,43]

WQI range	Type of water
<50	Excellent water
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking purposes

for drinking purposes (Table 5). The low quality of water in northern regions of the studied area could be attributed to the process of weathering of rocks and dissolution of salts from the bedrock into the water resources. It can be also attributed to the material of the bedrock or mother rock in this region, which is of clay or shale. Therefore, penetration of rainfall into groundwater in these regions is low, and thus, the quality of groundwater has declined. Furthermore, the low water quality in this region can be the result of discharging industrial and urban wastewaters as well as agricultural wastewater in this area.

3.8. Land-cover pattern and groundwater quality

Fig. 6 presents region vegetation cover. As shown in the figure, there is vegetation cover around wells located in a region south band. This vegetation cover does not include agricultural lands, but natural vegetation cover. In north of wells located in the center of the region, a mass vegetation cover can be seen that indicates agricultural vegetation. In the rest of the region, the plant cover is scarce and scattered. A comparison between vegetation and WQI index is shown in Fig. 5. Based on the figure, it is clear that, in areas with natural vegetation, WQI is in the green status, and in areas where vegetation is related to agriculture, WQI is in the red; in other areas with low vegetation and in the absence of the agricultural activities, WQI is in the yellow status.

Table 4
WQI classification for individual samples

Sample number	WQI values	Water quality classification type
1	85.91	Good water
2	51.58	Good water
3	122.94	Poor water
4	48.80	Excellent water
5	70.54	Good water
6	73.81	Good water
7	203.97	Very poor water
8	121.66	Poor water
9	124.53	Poor water
10	121.96	Poor water
11	113.74	Poor water
12	76.44	Good water
13	83.82	Good water
14	158.91	Poor water
15	45.18	Excellent water
16	102.71	Poor water
17	206.03	Very poor water
18	366.93	Water unsuitable for drinking
19	205.54	Very poor water

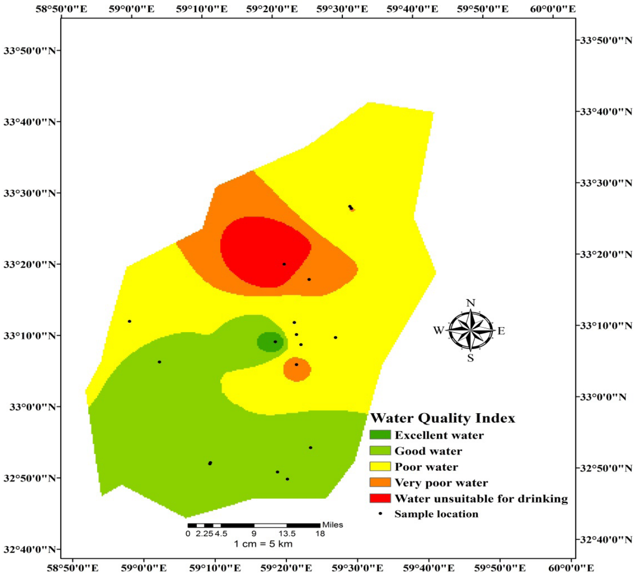

Fig. 5. Zoning the status of the water quality in the studied region in terms of WQI.

Comparing Figs. 5 and 6, it is clear that WQI is red for a well that is located quite close to agricultural lands (sample 18) while it is shifted to orange for downstream well. This clearly shows the effects of farmlands on groundwater quality. For example, elevated concentration of nitrate in groundwater is usually related to diffused pollution caused by an overuse of nitrogen fertilizers on farmlands. Application of nitrogen fertilizers on farmlands can accelerate rock weathering, with

Table 5
Status of water quality for drinking purposes in the studied region in terms of WQI

Water quality classification type	Area (km^2)	Area (%)
Excellent water	24.53	0.45
Good water	1,933.47	35.83
Poor water	2,629.72	48.73
Very poor water	533.51	9.88
Water unsuitable for drinking	274.30	5.08

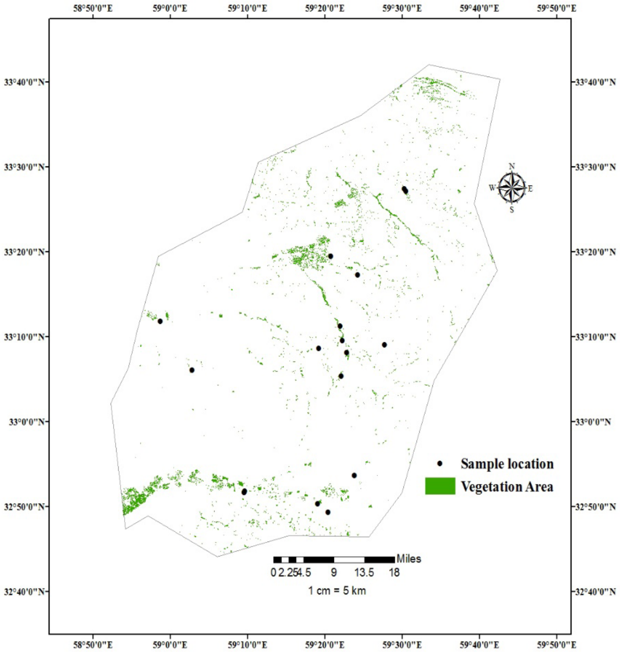

Fig. 6. Vegetation area image produced by ENVI and ArcGIS.

reflexing on groundwater chemistry, because nitrification of these fertilizers improves the alteration of minerals by the nitric acid reaction in concurrence with the alteration of minerals with carbonic acid reaction [44].

In the southern part of the studied area, natural vegetation is in a good situation; there is no farmland around; and regional water quality is better too. Vegetation cover has a very important role on regulating hydrological processes as well as changes in soil properties that control nutrient leaching and hence groundwater quality. As groundwater quality is related to the type of land use, any change in the use of land affects water quality as well. In general, a change caused by agricultural activities, instead of natural vegetation, will degrade groundwater quality, while afforestation of bare lands will remediate groundwater pollution [44].

4. Conclusion

In this study, WQI was applied in order to evaluate the quality of groundwater in some regions of Birjand City. Moreover, GIS was employed for spatial analysis of parameters. The results of zoning the area through GIS indicated that in over 90% of the studied area, the values of the parameters of EC, TDS, and TH were above the allowable limit, which are shown in orange color in the related maps. In this study, in 52.6% and 15.7% of the sampling points, the concentration of main anions, i.e., sulfate and chloride, respectively, was not within the allowable range. Considering the studied cations, the concentration of calcium, sodium, and potassium were above the standard level in 21%, 78.9%, and 21% of the sampling points, respectively. The zoning map and spatial analysis of the investigated parameters showed that the more we moved from the south to north, the value of these parameters increased, suggesting worsened quality. The results of WQI classification also indicated that only 10.5% of the studied wells (two sampling wells) laid within the range of excellent water (the first group), whereas the majority of points (36.84%) laid in the third group. The zoning and spatial analysis of water quality in the studied region indicated that only in 1,958 km^2 (36.28%) of the entire studied area water quality was good for drinking purposes, whereas in 3,437.53 km^2 of the studied area water quality was unsuitable and poor for drinking purposes. Therefore, in order to improve the quality of groundwater especially in the northern areas of the studied region, it is possible to use rainwater harvesting systems and artificial recharge methods. Finally, it can be stated that the application of WQI and spatial analysis through GIS was effective for monitoring groundwater quality in the studied region and it can be considered as a promising tool for understanding the spatial pattern and variations.

Acknowledgment

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

[1] B. Ganeshkumar, C. Jaideep, Groundwater quality assessment using water quality index (WQI) approach–case study in a coastal region of Tamil Nadu, India, Int. J. Environ. Sci. Res., 1 (2012) 50–55.

[2] H. Khosravi, K. Karimi, T. Mesbahzadeh, Investigation of spatial structure of groundwater quality using geostatistical approach in Mehran Plain, Iran, Pollution, 2 (2016) 57–65.

[3] R. Saleem, Groundwater management—emerging challenges, Water Digest, 1 (2007) 12–28.

[4] H. Biglari, A. Chavoshani, N. Javan, A. Hossein Mahvi, Geochemical study of groundwater conditions with special emphasis on fluoride concentration, Iran, Desal. Wat. Treat., 57 (2016) 22392–22399.

[5] I.S. Babiker, M.A. Mohamed, T. Hiyama, Assessing groundwater quality using GIS, Water Resour. Manage., 21 (2007) 699–715.

[6] J. Causapé, L. Auqué, M.J. Gimeno, J. Mandado, D. Quílez, R. Aragüés, Irrigation effects on the salinity of the Arba and Riguel Rivers (Spain): present diagnosis and expected evolution using geochemical models, Environ. Geol., 45 (2004) 703–715.

[7] S. Tyagi, B. Sharma, P. Singh, R. Dobhal, Water quality assessment in terms of water quality index, Am. J. Water Resour., 1 (2013) 34–38.

[8] J.P.W. Oliveira, R.N. dos Santos, J.M. Boeira, Genotoxicity and physical chemistry analysis of waters from Sinos River (RS) using *Allium cepa* and *Eichhornia crassipes* as bioindicators, Biochem. Biotechnol. Rep., 1 (2012) 15–22.

[9] M. Milovanovic, Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe, Desalination, 213 (2007) 159–173.

[10] A.A. Aly, A.M. Al-Omran, M.M. Alharby, The water quality index and hydrochemical characterization of groundwater resources in Hafar Albatin, Saudi Arabia, Arab. J. Geosci., 8 (2015) 4177–4190.

[11] M. Al-Hadithi, Application of water quality index to assess suitability of groundwater quality for drinking purposes in Ratmao–Pathri Rao watershed, Haridwar District, India, Indian J. Sci. Ind. Res., 10 (2012) 5251.

[12] C. Singaraja, S. Chidambaram, P. Anandhan, M. Prasanna, C. Thivya, R. Thilagavathi, A study on the status of fluoride ion in groundwater of coastal hard rock aquifers of south India, Arab. J. Geosci., 6 (2013) 4167–4177.

[13] S. Selvam, R. Iruthaya Jeba Dhana Mala, V. Muthukakshmi, A hydrochemical analysis and evaluation of groundwater quality index in Thoothukudi district, Tamilnadu, South India, Int. J. Adv. Eng. Appl., 2 (2013) 25–37.

[14] M.R. Mohebbi, R. Saeedi, A. Montazeri, K.A. Vaghefi, S. Labbafi, S. Oktaie, M. Abtahic, A. Mohagheghianc, Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI), Ecol. Indic., 30 (2013) 28–34.

[15] H. Boyacioglu, Development of a water quality index based on a European classification scheme, Water SA, 33 (2007) 101–106.

[16] Y. Icaga, Fuzzy evaluation of water quality classification, Ecol. Indic., 7 (2007) 710–718.

[17] W. Ocampo-Duque, M. Schuhmacher, J.L. Domingo, A neural-fuzzy approach to classify the ecological status in surface waters, Environ. Pollut., 148 (2007) 634–641.

[18] A.K. Tiwari, A.K. Singh, Hydrogeochemical investigation and groundwater quality assessment of Pratapgarh district, Uttar Pradesh, J. Geol. Soc. India, 83 (2014) 329–343.

[19] P. Singh, A. Tiwari, P.K. Singh, Assessment of groundwater quality of Ranchi township area, Jharkhand, India by using water quality index method, Int. J. ChemTech. Res., 7 (2015) 73–79.

[20] S. Selvam, G. Manimaran, P. Sivasubramanian, N. Balasubramanian, T. Seshunarayana, GIS-based evaluation of water quality index of groundwater resources around Tuticorin coastal city, South India, Environ. Earth Sci., 71 (2014) 2847–2867.

[21] APHA, AWWA, WEF, Standard Methods for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, D.C., USA, 2005.

[22] S. Asadi, P. Vuppala, M.A. Reddy, Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India, Int. J. Environ. Res. Public Health, 4 (2007) 45–52.

[23] R. Shabbir, S.S. Ahmad, Use of geographic information system and water quality index to assess groundwater quality in Rawalpindi and Islamabad, Arab. J. Sci. Eng., 40 (2015) 2033–2047.

[24] N. Magesh, N. Chandrasekar, Evaluation of spatial variations in groundwater quality by WQI and GIS technique: a case study of Virudunagar District, Tamil Nadu, India, Arab. J. Geosci., 6 (2013) 1883–1898.

[25] A. Logeshkumaran, N. Magesh, P.S. Godson, N. Chandrasekar, Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India, Appl. Water Sci., 5 (2015) 335–343.

[26] M. Saeedi, O. Abessi, F. Sharifi, H. Meraji, Development of groundwater quality index, Environ. Monit. Assess., 163 (2010) 327–335.

[27] M. Vasanthavigar, K. Srinivasamoorthy, K. Vijayaragavan, R.R. Ganthi, S. Chidambaram, P. Anandhan, R. Manivannan, S. Vasudevan, Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India, Environ. Monit. Assess., 171 (2010) 595–609.

[28] WHO, Guidelines for Drinking-water Quality, World Health Organization, Geneva, 2011, pp. 303–304.

[29] S. Varol, A. Davraz, Evaluation of the groundwater quality with WQI (Water Quality Index) and multivariate analysis: a case study of the Tefenni plain (Burdur/Turkey), Environ. Earth Sci., 73 (2015) 1725–1744.

[30] M. Ketata-Rokbani, M. Gueddari, R. Bouhlila, Use of geographical information system and water quality index to assess groundwater quality in El Khairat deep aquifer (Enfidha, Tunisian Sahel), Iran J. Energy Environ., 2 (2011) 133–144.

[31] S.S. Prasanth, N. Magesh, K. Jitheshlal, N. Chandrasekar, K. Gangadhar, Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India, Appl. Water Sci., 2 (2012) 165–175.

[32] M.M. Bahar, M.S. Reza, Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of Southwest Bangladesh, Environ. Earth Sci., 61 (2010) 1065–1073.

[33] N. Magesh, S. Krishnakumar, N. Chandrasekar, J.P. Soundranayagam, Groundwater quality assessment using WQI and GIS techniques, Dindigul district, Tamil Nadu, India, Arab. J. Geosci., 6 (2013) 4179–4189.

[34] L. Pei-Yue, Q. Hui, W. Jian-Hua, Groundwater quality assessment based on improved water quality index in Pengyang County, Ningxia, Northwest China, E-J. Chem., 7 (2010) S209–S216.

[35] P. Ravikumar, R. Somashekar, M. Angami, Hydrochemistry and evaluation of groundwater suitability for irrigation and drinking purposes in the Markandeya River basin, Belgaum District, Karnataka State, India, Environ. Monit. Assess., 173 (2011) 459–487.

[36] K. Ramesh, L. Elango, Groundwater quality assessment in Tondiar basin, Indian J. Environ. Prot., 26 (2006) 497–504.

[37] K. Fytianos, C. Christophoridis, Nitrate, arsenic and chloride pollution of drinking water in Northern Greece. Elaboration by applying GIS, Environ. Monit. Assess., 93 (2004) 55–67.

[38] Z. Pang, L. Yuan, T. Huang, Y. Kong, J. Liu, Y. Li, Impacts of human activities on the occurrence of groundwater nitrate in an alluvial plain: a multiple isotopic tracers approach, J. Earth Sci., 24 (2013) 111–124.

[39] S.K. Kumar, N. Chandrasekar, P. Seralathan, P.S. Godson, N. Magesh, Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island, India, Environ. Monit. Assess., 184 (2012) 4127–4138.

[40] L. Fewtrell, Drinking-water nitrate, methemoglobinemia, and global burden of disease: a discussion, Environ. Health Perspect., 112 (2004) 1371–1374.

[41] M. Pirsaheb, M. Fazlzadehdavil, S. Hazrati, K. Sharafi, T. Khodadadi, Y. Safari, A survey on nitrogen and phosphor compound variation processes in wastewater stabilization ponds, Polish J. Environ. Stud., 23 (2014) 831–834.

[42] M. Al-Ahmadi, A. El-Fiky, Hydrogeochemical evaluation of shallow alluvial aquifer of Wadi Marwani, western Saudi Arabia, J. King Saud Univ. Sci., 21 (2009) 179–190.

[43] P. Sahu, P. Sikdar, Hydrochemical framework of the aquifer in and around East Kolkata Wetlands, West Bengal, India, Environ. Geol., 55 (2008) 823–835.

[44] R.F. Valle Junior, S.G.P. Varandas, L.F. Sanches Fernandes, F.A.L. Pacheco, Groundwater quality in rural watersheds with environmental land use conflicts, Sci. Total Environ., 493 (2014) 812–827.