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Assessment of groundwater quality using GIS at north-east of Iran

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ABSTRACT

The groundwater quality is equally as important as that of quantity. Mapping of spatial variability of groundwater quality is of vital importance and it is particularly significant where groundwater is primary source of potable water. Geostatistics was used to determine the spatial distribution of groundwater quality parameters in the study area using geographic information system and geostatistical techniques. Ordinary kriging interpolation techniques were applied to generate water quality maps. For this purpose, water samples were collected from 65 tube wells and analyzed for some physicochemical parameters such as electrical conductivity (EC), pH, total dissolved solid (TDS), total hardness (TH), sodium (Na^+), chloride (Cl^-), nitrate (NO_3^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), bicarbonate (HCO_3^-), and sulfate (SO_4^{2-}) using standard methods in the laboratory. The results of analysis showed the following concentration ranges: pH (7.0–8.6), EC (724–12,755 μS/cm), TH (60–1,350 mg/L), TDS (456–8,000 mg/L), Cl^- (53–3,443.5 mg/L), NO_3^- (≤1 mg/L), HCO_3^- (11.26–400 mg/L), SO_4^{2-} (98–1,440 mg/L), Ca^{2+} (6–460 mg/L), Mg^{2+} (7.2–192 mg/L), Na^+ (92–2,047 mg/L,) and K^+(3.6–21.8 mg/L). Also, water quality index (WQI) was used to assess the suitability of groundwater from the study area for drinking purpose. From the WQI assessment the map showed that 70.06% (430.33 km^2) of the groundwater of the study area were found to be in the excellent water class, 8.21% (50.44 km^2) good, 7.02% (43.25 km^2) moderate, 5.29% (32.47 km^2) poor, 3.63% (22.28 km^2) very poor and the remaining 5.79% (35.59 km^2) was classified under very poor water class based on the computed WQI classification results.

Keywords: Analysis; GIS; Groundwater; Water quality index

1. Introduction

Distribution of freshwater resources is uneven throughout the world and the freshwater availability is becoming scarce annually, owing to population growth and diverse human activities. In the absence of fresh surface water resources, groundwater is exploited to meet the demand exerted by various sectors. Spatial variation in the quality of groundwater in response to local geologic set-up and anthropogenic factors warrants the evaluation of the quality of groundwater for any purposes including that for human consumption. Assessment of the water quality for drinking purpose involves the determination of the chemical composition of groundwater and the remedial measures for the restoration of the quality of water in case of its deterioration demand the identification of possible sources for the contamination of groundwater. This paper presents findings on the chemical composition of the groundwater and investigates the possible geogenic and anthropogenic sources for chemical solutes. Many researchers across the globe [1–5] have carried out studies with spatial technologies and interpreted the quality of groundwater. Groundwater quality is determined for drinking purpose in Raipur city, India using water quality index (WQI) and geographic information system (GIS). The results indicated that 76% area is falling under excellent, very good, and good category and 24% area is falling under poor, very poor, and unfit category as per the WQI classification. The predicted accuracy of the obtained result was about 97.05% reflecting capability of adopted techniques [6]. Mapping the spatial distributions

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of major elements and their interpolation with the geology and land use/land cover maps in GIS environment [7,8] has contributed for the better understanding of the chemical processes of water and the methods of their acquisition. GIS has been used in the map classification of groundwater quality, based on correlating total dissolved solids (TDS) values with some aquifer characteristics [9] or land use and land cover [10]. Other studies have used GIS as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents [11,12]. In such studies, GIS is utilized to locate groundwater quality zones suitable for different usages such as irrigation and domestic [12]. A similar approach was adopted by Skubon [13] where GIS was used to prepare layers of maps to locate promising well sites based on water quality and availability. In the study conducted by Hu et al. [14], spatial variability of groundwater quality and risk of NO_3 pollution in groundwater in the central North China Plain were determined using the ordinary kriging (OK) method. Zimmerman et al. [15] evaluated and compared the accuracy of OK, universal kriging (UK), and inverse distance weighted methods based on an analysis of synthetic data from a computational experiment. Geostatistical methods, kriging and cokriging, were applied to estimate the sodium adsorption ratio in a 3,375 ha of agricultural field. Zhu et al. [16] produced a radon distribution map using the kriging and GIS techniques in Belgium. The spatial distribution of nitrate concentration in the aquifer of central Italy (about 110 km^2) was investigated and cokriging and OK techniques were compared in another study by D'Agostino et al. [17].

The WQI is an important parameter for determining the drinking water quality for the end users. WQI is developed for groundwater quality assessment of Greater Noida subbasin, Uttar Pradesh, India. The results showed that the WQI ranged from 53.69 to 267.85. The WQI indicated the very poor quality water in the area dominated by industrial and construction activities [18].

Bardaskan city is located in the Khorasan Razavi province at the margin of the north part of Namak Desert (salt desert). Annual raining average in this area is about 150 mm. Bardaskan's temperature in the hottest summer day is nearly 45°C and in the coldest winter night is −5°C. There is not any permanent river in the Bardaskan but there are several seasonal rivers. The main water resource for drinking and agricultural purposes is groundwater. Therefore, investigation and monitoring of the groundwater quality and quantity is vital in such areas. Besides this, the coupling of groundwater analysis with GIS increases the speed and ease in which results can be attained and conclusions can be drawn, enabling the ability to analyze larger datasets with more complicated models across larger spatial extents. This study pertains to determine spatial distribution of groundwater quality parameters such as hardness, pH, TDS, Ca, Mg, Na, NO_3, Cl, HCO_3, and SO_4. Also, to generate groundwater quality zone map for the study area and create WQI.

2. Methods

2.1. Study area

Bardaskan is a city of Khorasan Razavi province in the east of Iran (Fig. 1). The study area lies between 56°14′ to 58°15′ longitude and 34°42′ to 35°28′ latitude and 985 m above mean sea level. The average annual precipitation is less than 150 mm and its climate is essentially arid. Maximum temperature and annual rainfall (2012–2017) of the study area is shown in Fig. 2. The aquifer is recharged by direct infiltration of precipitation, the main source of groundwater recharge. Groundwater in the study area occurs under water table conditions ranging in depths from about 84–210 m.

2.2. Groundwater sample collection and analysis

Groundwater samples from 65 bore wells of the unconfined aquifer were collected in duplicate in new precleaned polypropylene bottles (1 L capacity) in the month of October 2014 (postmonsoon season). The study area is about 614.22 km^2. Location of sampling sites in study area is presented in Fig. 3.

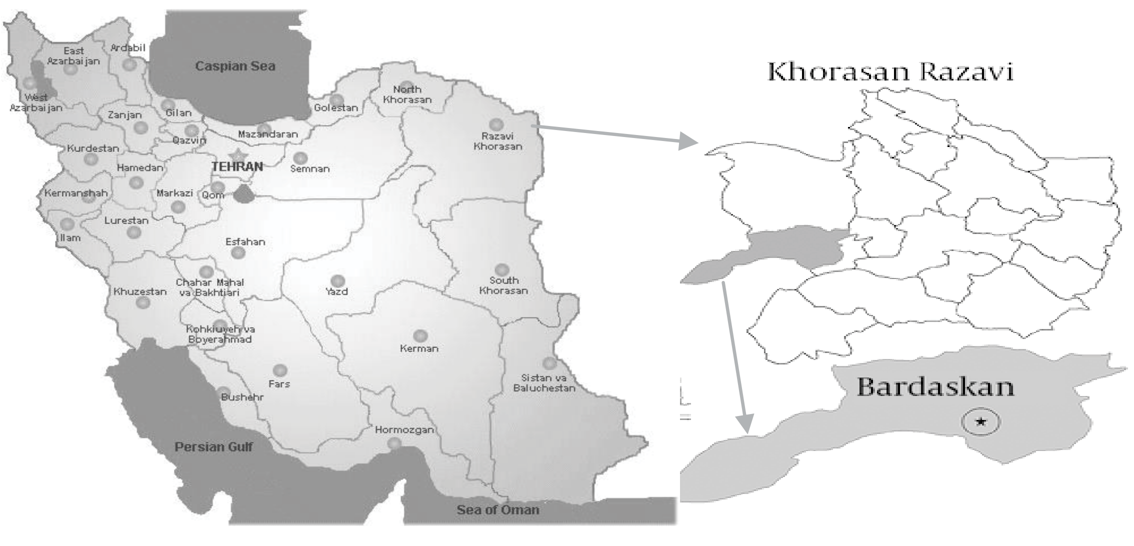

Fig. 1. Location of groundwater quality study.

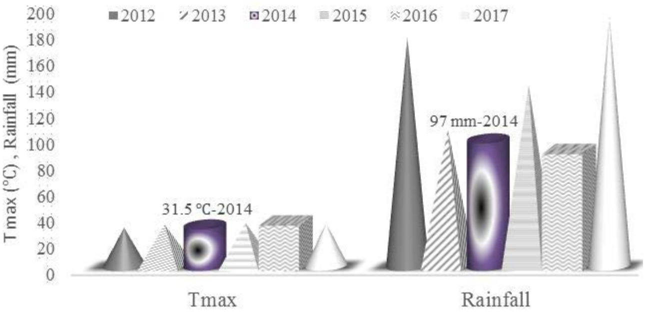

Fig. 2. Maximum and annual rainfall of Bardaskan from 2012 (left) to 2017 (right).

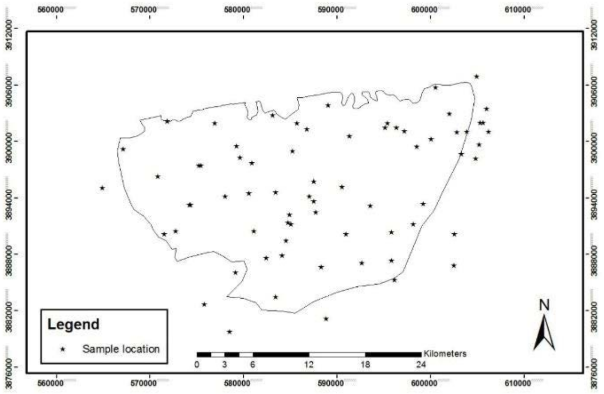

Fig. 3. Localization of groundwater samples.

Also, the various physiochemical parameters were analyzed and measurement methods are reported in Table 1.

2.3. Physicochemical characteristics

2.3.1. Spatial distribution of groundwater

Groundwater quality maps are useful in assessing the usability of the water for different purposes. The spatial and attribute data are integrated for the generation of spatial variation maps of major water quality parameters like nitrate, TDS, total hardness (TH), potassium, sodium, bicarbonate, sulfates, calcium, magnesium, electrical conductivity (EC), and pH. Based on these spatial variation maps of major water quality parameters, an integrated groundwater quality map of the study area was prepared using GIS. This integrated groundwater quality map helps us to know the existing groundwater condition of the study area.

2.4. Kriging method

Geoscientists often have to deal with spatial and modeling problems in the analyzing step of sparse data recorded from field observations. Geostatistics is an interesting tool used for describing and modeling spatial or temporal phenomena. Geostatistics provides a set of statistical tools for the analysis of data distributed in space and time domain. It allows the description of spatial patterns in a dataset, the incorporation of multiple sources of information in the mapping of features, the modeling of the spatial uncertainty and its propagation through decision making [19]. Kriging is a stochastic, local interpolation method that uses attribute of interest in the sample points to estimate the value of that attribute at unknown locations. Kriging is an optimal interpolator offering a minimum error variance. There are different types of kriging techniques, such as OK, UK, indicator kriging, cokriging, and others. One of the main advantages of kriging is that it presents the interpolation error of the values of the regionalized variable where there are no initial measurements. This feature offers a measure of the estimation accuracy and reliability of the spatial distribution of the variable [20]. A variogram (2γ) is one of the basic geostatistical tools that is used to determine spatial dependence. It is often referred to as a semivariogram (γ), which has exactly the same characteristics, except that in the denominator of the equation, number 2 is eliminated. A variogram is mathematically expressed by Eq. (1) as follows:

Table 1
Methods used for estimation of various physicochemical parameters

Parameter		Method
Physical	Temperature	Thermometer
	Color	Spectrophotometric
Chemical	EC	Conductivity meter
	pH	pH meter
	Ca^{2+}	Volumetric titration
	Mg^{2+}	Volumetric titration
	Na^{+}	Flame photometer
	SO_4^{2-}	Spectrophotometric method
	NO_3^{-}	Ultraviolet spectrophotometric
	HCO_3^{-}	Titration
	Cl^{-}	Titration with silver nitrate method
	TH	EDTA titration
	TDS	Conductivity
	K^{+}	Flame photometer

$$2\gamma(h) = \frac{1}{N(h)} \sum_{n=1}^{N(h)} [Z_n - Z_{n+1}]^2 \qquad (1)$$

where $N(h)$: number of data pairs at distance (h) (inside searching neighborhood area), Z_n: value at location n, and $Z(n + h)$: value at location $n + h$.

The principle of kriging is to estimate values of a regionalized variable at a selected location (Z_k), based on the surrounding existing values (Z_i). Selected locations are assigned a relevant weighting coefficient (λ_i) which represents the influence of particular data on the value of the final estimation at the selected grid node. Variogram values express the relationship between the existing (hard) data and the estimation point, or by covariance in case of second-order stationarity [21].

OK is one of the most commonly used kriging techniques, a geostatistical interpolation technique that is described by the acronym BLUE (best linear unbiased estimator). It is the "best" because it aims at minimizing the variance of the errors, "linear" because its estimates are weighted linear combinations of the available data, and "unbiased" since it tries to have the mean residual or error equal to 0.

OK premise is a constant unknown mean in the local neighborhood of each estimation point. Local variance of the data within the search ellipsoid is used for estimation, which is useful in the case of a small number of input data (15 or 20). Then, the global variance often does not reflect local changes, so deviations of the mean and estimation can be large. In the OK technique, the amount of kriging variance is minimized using a linear external parameter called the Lagrange factor (μ). The limiting factor minimizes error and assessment becomes impartial. The condition when assessing the OK technique is that the sum of all weights is equal to 1 [22]. The OK equation in matrix form is given in Eq. (2) as follows:

$$\begin{bmatrix} \gamma(Z_1-Z_1) & \gamma(Z_1-Z_2)\ldots & \gamma(Z_1-Z_n) & 1 \\ \gamma(Z_2-Z_1) & \gamma(Z_2-Z_2)\ldots & \gamma(Z_2-Z_n) & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \gamma(Z_n-Z_1) & \gamma(Z_n-Z_2)\ldots & \gamma(Z_n-Z_n) & 1 \\ 1 & 1 \quad \ldots & 1 & 0 \end{bmatrix} \times \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \\ \mu \end{bmatrix} = \begin{bmatrix} \gamma(X_1-X) \\ \gamma(X_2-X) \\ \vdots \\ \gamma(X_n-X) \\ 1 \end{bmatrix} \quad (2)$$

where γ: variogram values; Z_1 to Z_n: real value at location 1 to n; X: location where new value is estimated; and μ: Lagrange factor.

2.5. Water quality index

WQI is computed to reduce the large amount of water quality data to a single numerical value. It reflects the composite influence of different water quality parameters on the overall quality of water. It is a very useful tool for communicating the information on the overall quality of water. The standards for purposes of drinking should have been considered for the calculation of WQI as recommended by World Health Organization (WHO). The formula used to determine the aggregated WQI is given in the following equation [23]:

$$\text{WQI} = \sum_{i=1}^{n} W_i I_i \quad (3)$$

where I_i is the subindex of ith water quality parameter and WQI is water quality index. n is the number of water quality parameters considered. W_i is the weightage of the ith water quality parameter.

2.5.1. Procedures to generate WQI

To generate the WQI map, nine parameters such as TDS, hardness, nitrate, chloride, sulfate, magnesium, calcium, sodium, and pH were selected from the dataset. Standards for drinking water were chosen since human health is taken as priority besides the high quality of water makes it suitable for drinking purposes. Those nine parameters fall under the category of chemically derived contaminants that could alter the water taste, odor, or appearance and affect its acceptability by consumers [24]. Iranian standards and WHO (2011) standards for drinking purposes have been considered for the calculation of WQI.

3. Results and discussion

3.1. Assessment of groundwater quality for drinking purposes

Groundwater quality may be degraded as a result of natural processes or human activities. Evaluation of groundwater quality for drinking determines its suitability for different purposes depending upon the specific standards set by various agencies including the drinking water standards of WHO (2011).

3.2. pH

Usually, pH has no direct impact on consumers. It is one of the most important operational water quality parameters with the optimum pH required often being in the range of 7.0–8.5 [24]. The maximum permissible limit for pH in drinking water as given by the WHO is 9.2. The spatial distribution of pH in the study area shows that all area (100%) falls under desirable groundwater quality. Spatial distributions of pH concentrations are shown in Fig. 4.

The values of the physical parameters of the groundwater in the Bardaskan region indicate that pH ranges from 7.0 to 8.6 with a mean value of 8.1, which indicates the alkaline nature of groundwater of the study area. The pH value of the water thus does not lead to the dissolution of heavy metals in the mineralized part of the study area.

3.3. Electrical conductivity

The values of EC measured were varied from 724.3 to 12,756 μS/cm (Fig. 5). The spatial distribution of EC in the study area shows that 288.87 km^2 area (47.03%) falls under desirable groundwater quality; 73.03 km^2 area (11.89%) falls under maximum permissible groundwater quality; and 252.32 km^2 area (41.08%) falls under nonpermissible groundwater quality (Fig. 5). The higher EC may cause a gastrointestinal irritation in human beings. Although the large variation in EC is mainly attributed to geochemical process like ion

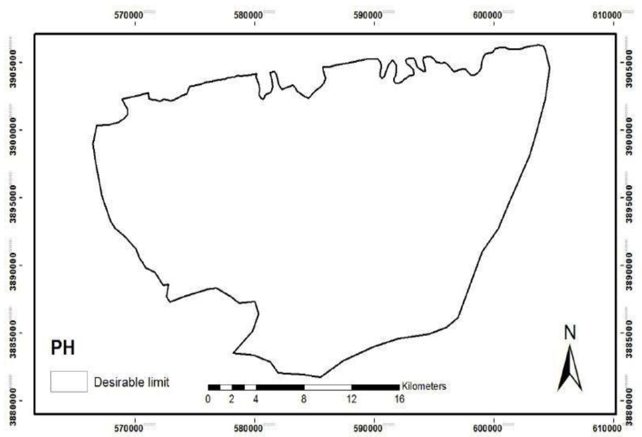

Fig. 4. Spatial distribution of pH.

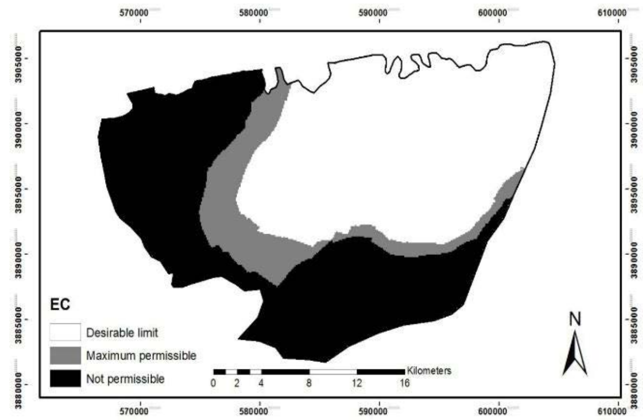

Fig. 5. Spatial distribution of EC on the study area.

exchange, reverse exchange, evaporation, silicate weathering, and oxidation processes in the study area the enrichment of salt in groundwater may possibly be due to high evaporation effect and anthropogenic including agricultural activities.

3.4. Total dissolved solids

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions [25]. The total concentration of dissolved minerals in water is a general indication of the overall suitability of water for many types of uses [26]. Different researchers (such as Refs. [26,27] classified the TDS value into different ranges. For instance, according to Ref. [26] the TDS was classified into three ranges (0–500, 500–1,000, and >1,000 mg/L). Water contains less than 500 mg/L of dissolved solids; it is generally satisfactory for domestic use and for many industrial purposes. Water with more than 1,000 mg/L of dissolved solids usually gives disagreeable taste or makes the water unsuitable. Water with high TDS often has a bad taste and high water hardness, and could result in a laxative effect. High concentrations of TDS may also reduce water clarity.

TDS concentration in the groundwater of study area is ranged from 456 to 8,000 mg/L with mean and standard deviation as 2,658 and 1,960, respectively. The spatial variation map for TDS for this study was prepared into three class ranges and presented in Fig. 5. The spatial distribution of TDS in the study area shows that 89.12 km^2 area (14.51%) falls under desirable groundwater quality; 222.04 km^2 area (36.15%) falls under maximum permissible groundwater quality; and 303.06 km^2 area (49.34%) falls under nonpermissible groundwater quality (Fig. 6).

3.5. Total hardness

Hardness in water is caused primarily by the presence of carbonates and bicarbonates of calcium and magnesium, sulfates, chlorides, and nitrates. The TH of water is classified into three ranges (0–300, 300–600, and >600 mg/L) as low, medium, and high, respectively [26]. To evaluate hardness distribution based on these ranges the spatial variation map for TH of Bardaskan city has been presented in Fig. 6.

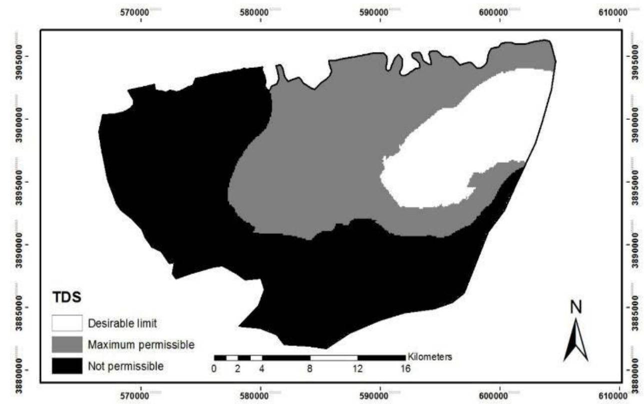

Fig. 6. Spatial distribution of TDS on the study area.

Hardness concentration in the groundwater of study area is ranged from 60 to 1,350 mg/L with mean and standard deviation as 657.5 and 410.58, respectively. From the map it was observed that for most part of the city areas, the TH value less than 300 mg/L was observed, except the western and central parts of city, which has 349 up to 1,350 mg/L. Also, the spatial distribution of hardness in the study area shows that 366.26 km^2 area (59.63%) falls under desirable groundwater quality; 119.65 km^2 area (19.48%) falls under maximum permissible groundwater quality; and 128.25 km^2 area (20.88%) falls under nonpermissible groundwater quality (Fig. 7). The most common problem associated with groundwater may be hardness, caused by an abundance of calcium or magnesium. Calcium and magnesium are found in groundwater because of the dissolving of limestone. Calcium and magnesium ions also can be released when water reacts with gypsum. Hard water causes no health problems, but can be a nuisance as it may cause soap curds to form on pipes and other plumbing fixtures [25].

3.6. Calcium (Ca^{2+})

Calcium occurs in water mainly due to the presence of limestone, gypsum, and dolomite minerals. Industrial, as well as water and wastewater treatment, processes also contribute calcium to surface waters and groundwater. Acidic

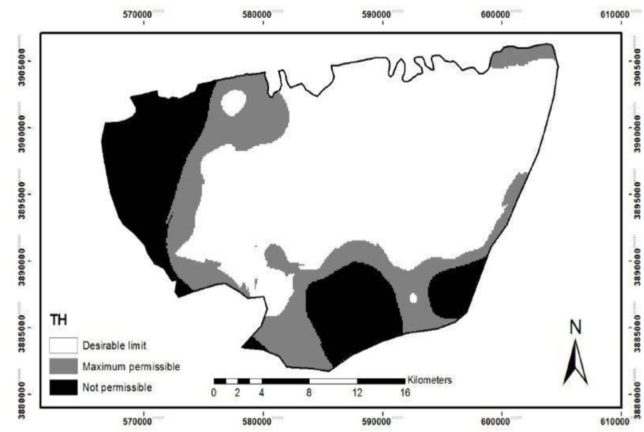

Fig. 7. Spatial distribution of TH on the study area.

rainwater can increase the leaching of calcium from soils. Calcium concentrations in natural waters are typically less than 15 mg/L but for water associated with carbonate-rich rocks, concentrations may reach 30 up to 100 mg/L. Salt water have concentrations of several hundred milligrams per liter or more [25]. According to Ref. [26] the amount of calcium in water was classified into three ranges (0–75, 75–200, and >200 mg/L) as low, moderate, and high, respectively. The spatial distribution of calcium in the study area shows that 428.11 km² area (69.7%) falls under desirable groundwater quality and 186.11 km² area (30.3%) falls under maximum permissible groundwater quality (Fig. 8). Based on these ranges the spatial variation of calcium in the study area, except the little parts of the city (western and southern) almost all area has low concentration. From Fig. 7 it is evident that the distribution of calcium is ranged from 0.3 to 23 meq/L or 6 to 460 mg/L with mean and standard deviation as 214.95 and 135.71, respectively.

3.7. Magnesium (Mg^{2+})

Magnesium occurs typically in dark colored minerals present in igneous rocks such as plagioclase, pyroxenes, amphiboles, and the dark colored micas. It also occurs in metamorphous rocks as a constituent of chlorite and serpentine. Magnesium is common in natural waters as Mg^{2+}, and along with calcium, is a main contributor to water hardness. Natural concentrations of magnesium in freshwaters may range from 1 to 100 mg/L [25]. Magnesium is usually less abundant in waters than calcium, because magnesium is found in the Earth's crust in much lower amounts as compared with calcium [7]. Similarly, to this idea as it shown in Fig. 8 in the groundwater of Bardaskan the distribution of magnesium (which is 0.6–16 meq/L or 7.2–192 mg/L) is less than calcium (which is 0.3–23 meq/L or 0.6–460 mg/L). The spatial distribution of magnesium in the study area shows that 454.03 km² area (73.92%) falls under desirable groundwater quality; 160.13 km² area (26.07%) falls under maximum permissible groundwater quality (Fig. 9).

The spatial patterns of Mg^{2+} are illustrated in Fig. 8. It can be observed from Fig. 8 that magnesium concentration in the groundwater from 21 wells is very high and unsuitable for some of the domestic applications. Mg^{2+} may probably have been derived from the same source as that of Ca^{2+}.

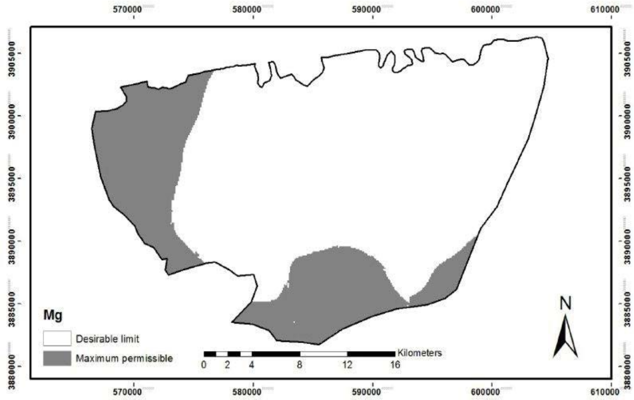

Fig. 9. Spatial distribution of magnesium on the study area.

3.8. Sodium concentration (Na^+)

Na^+ concentration in groundwater ranges from 4 to 89 meq/L or 92 to 2,047 mg/L with an average of 1,108.5 mg/L. According to WHO (2011) guidelines, the maximum admissible limit is 200 mg/L. The spatial distribution of chloride in the study area shows that 160.25 km² area (26.09%) falls under desirable groundwater quality; 100.79 km² area (16.41%) falls under maximum permissible groundwater quality; and 353.17 km² area (57.50%) falls under nonpermissible groundwater quality (Fig. 10). Excess Na^+ causes hypertension, congenial diseases, kidney disorders, and nervous disorders in human body [9]. According to the spatial map of Na^+ in the study area, most of the part of the city has high concentration of Na^+.

3.9. Chloride concentration (Cl^-)

Chloride is present in all natural waters, mostly at low concentrations. It is highly soluble in water and moves freely with water through soil and rock. High concentrations of chloride can make water unpalatable and, therefore, unfit for drinking or livestock watering [25]. A concentration of Cl^- in groundwater varies from 1.5 to 97 meq/L (53–3,443.5 mg/L). The desirable limit of Cl^- for drinking water is specified as 250 mg/L as per WHO 2011. The spatial distribution of chloride in the study area shows that 312.64 km² area (50.90%)

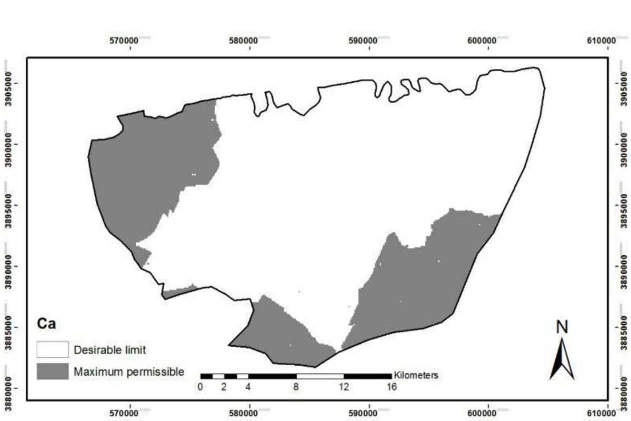

Fig. 8. Spatial distribution of calcium on the study area.

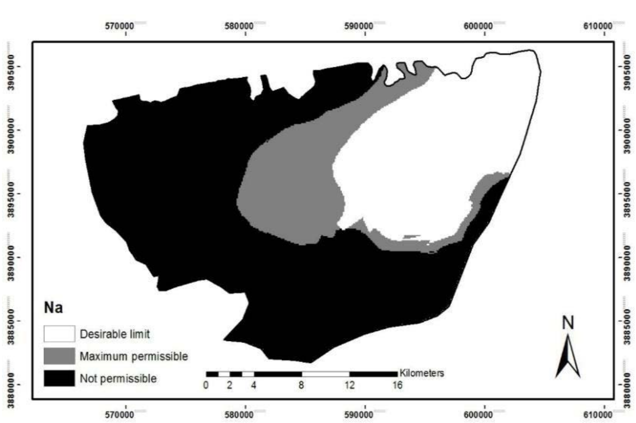

Fig. 10. Spatial distribution of sodium on the study area.

falls under desirable groundwater quality; 54.17 km^2 area (8.82%) falls under maximum permissible groundwater quality; and 247.41 km^2 area (40.28%) falls under nonpermissible groundwater quality (Fig. 11). The high chloride ion concentration of groundwater in the study area (white and bright gray) was observed only in a small part of the city (north-west and southern of the study area). Chlorides are harmless at low levels but at levels higher than 250 mg/L, it causes odor and salty taste apart from aggravating heart problems and contributing to high blood pressure. The concentration of Cl^- in groundwater is high, may possibly be due to domestic wastages and/or leaching from upper soil layers in dry climates [28].

3.10. Sulfate (SO_4^{2-})

Sulfate (SO_4^{2-}) occurs naturally in many soil and rock formations. In groundwater, most sulfates are generated from the dissolution of minerals, such as gypsum and anhydrite. Saltwater intrusion and acid rock drainage are also sources of sulfates in drinking water. Man-made sources include industrial discharge and deposition from burning of fossil fuels [24]. Sulfate concentrations in natural waters are usually between 2 and 80 mg/L. High concentrations greater than 400 mg/L may make water unpleasant to drink [25].

It was found that amount of SO_4^{2-} ions ranges from 2 to 30 meq/L (96–1,440 mg/L) with an average of 141 mg/L, and 51.29% (315.03 km^2) and 17.71% (299.18 km^2) of samples are in desirable limit and above the maximum permissible limit of 250 mg/L [24]. Also, 190.41 km^2 area (31%) falls under nonpermissible groundwater quality as shown in Fig. 12. Water samples with higher concentration of SO_4^{2-} in drinking water are associated with respiratory problems [28]. Sulfate minerals in drinking water can increase corrosion of plumbing and well materials. Sulfur bacteria may produce a dark slime or deposits of metal oxides that develop as a result of the corrosion of metal pipes.

3.11. Nitrate (NO_3^-)

The concentration of nitrate in groundwater in the study area 0.1–60 mg/L is within the maximum permissible limit (100 mg/L) as per the WHO (2011) standard indicating that the groundwater is potable. The spatial distribution of nitrate

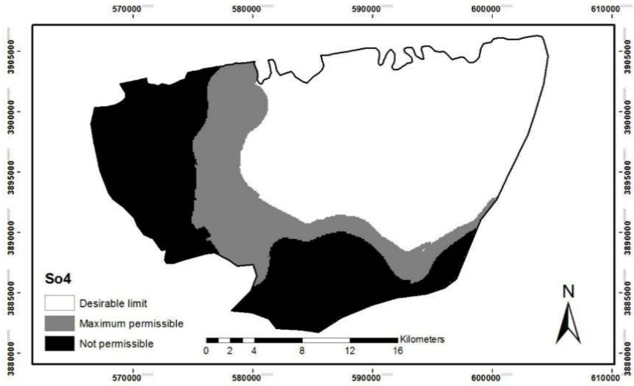

Fig. 12. Spatial distribution of sulfate on the study area.

in the study area shows that whole study area falls under desirable groundwater quality (Fig. 13).

3.12. Bicarbonate (HCO_3^-)

Bicarbonate (HCO_3^-) concentration of water samples ranges from 11.26 to 400 mg/L. The spatial variation map for bicarbonate has been presented in Fig. 14. The spatial distribution of bicarbonate in the study area shows that 84.39 km^2 area (13.74%) falls under desirable groundwater quality; 449.61 km^2 area or (73.2%) falls under maximum permissible

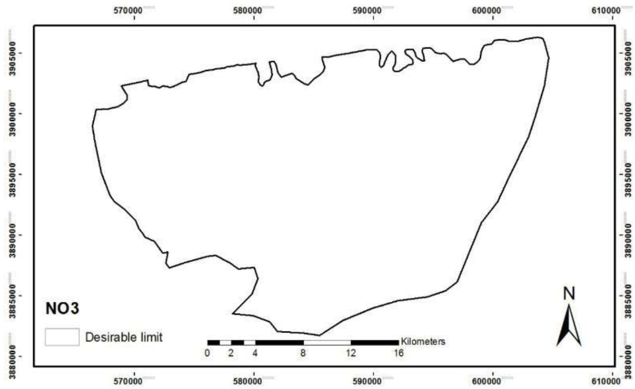

Fig. 13. Spatial distribution of nitrate on the study area.

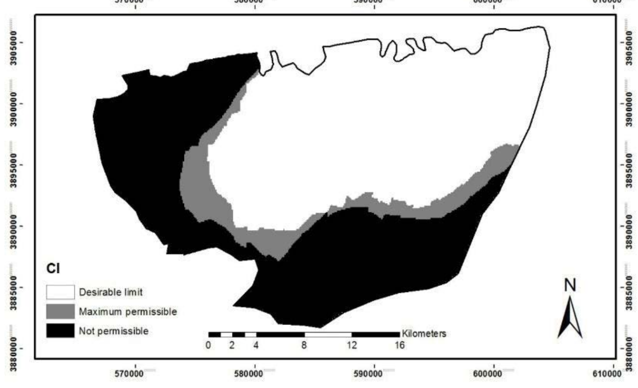

Fig. 11. Spatial distribution of Cl^- on the study area.

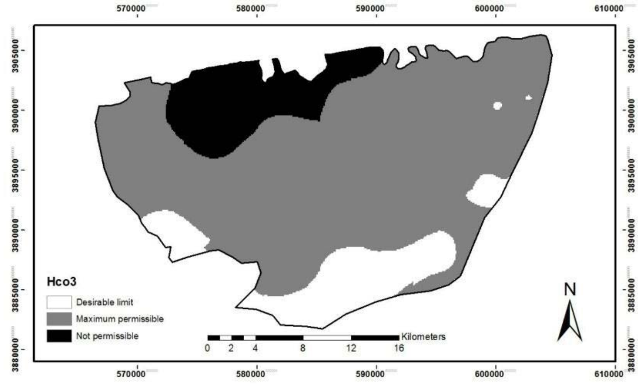

Fig. 14. Spatial distribution of bicarbonate on the study area.

groundwater quality; and 80.09 km² area (13.04%) falls under nonpermissible groundwater quality.

3.13. Potassium (K^+)

Potassium ranks seventh among the elements in order of abundance, behaves similar to sodium, and remains low. A concentration of K^+ in groundwater varies from 3.6 to 21.8 meq/L. The desirable limit of K^+ for drinking water is specified as 250 mg/L as per WHO (2011). The spatial distribution of potassium in the study area shows that whole study area falls under desirable groundwater quality (Fig. 15).

3.14. Water quality index

Water quality assessment of the study area was done by calculated WQI. The WQI was calculated by using water quality parameters, drinking water standard of WHO (2011). Nine parameters such as: pH, TDS, TH, calcium, magnesium, sulfates, chlorides, EC, and nitrates have been used to produce WQI. The final result shows that the WQI value is ranged from 9.95 to 131.622 (Fig. 16).

The WQI classification results showed that 70.061% (430.33 km²) of the groundwater of the city were found to be in the excellent water class, 8.212% (50.44 km²) good, 7.019% (43.25 km²) moderate, 5.287% (32.47 km²) poor, 3.627% (22.28 km²) very poor, and the remaining 5.794%

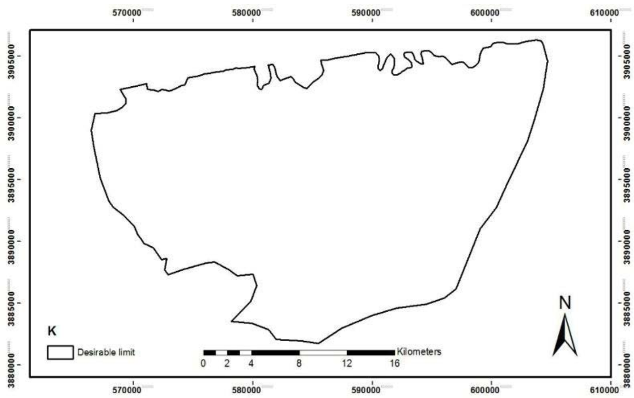

Fig. 15. Spatial distribution of potassium on the study area.

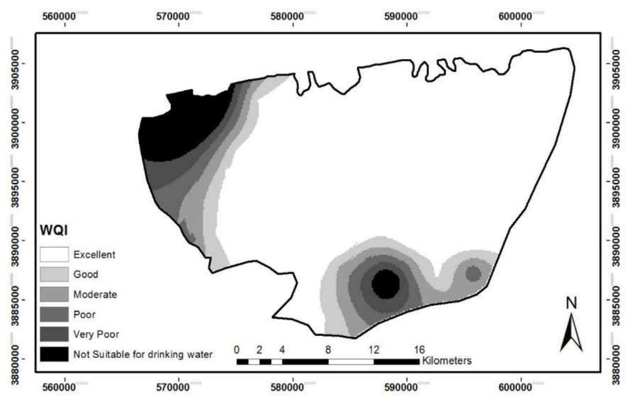

Fig. 16. Groundwater quality index of the study area.

Table 2
The WQI range and classification of groundwater in the study area

WQI range	Class	% of area	Area (km²)
<35	Excellent	70.061	430.33
35–45	Good	8.212	50.44
45–55	Moderate	7.019	43.25
55–65	Poor	5.287	32.47
65–75	Very poor	3.627	22.28
>75	Not suitable	5.794	35.59

(35.59 km²) was classified under nonsuitable water for drinking purpose (Table 2).

4. Conclusions

In the study area groundwater drawn from 65 bore wells was analyzed for their chemical contents. The analytical results of physical and chemical parameters of groundwater were compared with the standard guideline values recommended by the WHO for drinking purpose. Assessment of the quality of the groundwater from wells indicates that the groundwater belongs to hard to very hard category and groundwater from majority of the bore wells of the study region is unfit for drinking purposes. This preliminary study calls for continuous monitoring of the quality of the groundwater in the region as further exploitation of groundwater may increase the values of the some of the parameters viz., EC, pH, TDS, NO_3^-, HCO_3^-, Mg^{2+}, Ca^{2+}, K^+, Na^+, TH, and Cl^- and deteriorate the water quality in near future which ultimately will prove to be disastrous for the entire living beings in the region. Spatial distribution map of certain parameters prepared from the hydrochemical data in GIS environment is useful in assessing the best groundwater quality zone in the study area.

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