Evaluation of groundwater quality and its suitability for drinking and irrigation using GIS and geostatistics techniques in semiarid region of Neyshabur, Iran

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Abstract

Groundwater is a vital source for drinking and agricultural purposes in semiarid region of Neyshabur area (Iran). The present study assessed the groundwater quality and mapped the spatial variation of water samples in terms of suitability for drinking and irrigation purposes. A total 402 groundwater samples were collected from the field with global positioning system (GPS) from 2010 to 2013 and analyzed for pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium, bicarbonate, sulfate, chloride, sodium adsorption ratio (SAR), electrical conductivity (EC), total dissolved solids, and total hardness (TH). A GIS-based ordinary kriging method with best fit semivariogram models was used for preparation of thematic maps of groundwater quality parameters. The results were evaluated and compared with WHO (2011) recommended water quality standard. Results showed that 68.40% of SAR, 25% of Mg^{2+} , 32.62% of Na^+ , and 1.74% of TH of the total groundwater samples are suitable for the irrigation purpose. Consequently, 55.57% of EC, 89.19% of TDS, 0.75% of pH, and 6.25% of K^+ of the total groundwater samples are suitable for the drinking purpose as per the WHO standard. The groundwater quality in the study area is very hard and slightly alkaline in nature. The spatial distribution map of groundwater quality showed 80% of the area suitable for drinking purpose; whereas, 90% of the area demarcated for irrigation purpose.

Keywords Groundwater quality · GIS · Kriging · Semivariogram · Spatial variability · Iran

Introduction

Most countries in the world suffer from severe water shortages, especially arid and semiarid areas (El Omran et al. 2014). The knowledge of water quality is critical to understand what management changes are necessary for long-term

and short-term productivity, particularly for crops that are sensitive to change the water quality. Traditional approaches for monitoring water quality are usually unreliable due to the lack of sample numbers (Lee and Jones-Lee 2000), labor work intensity, time consuming and the disability to provide a general image for the water status particularly in developing countries such as Iran. The assessment of spatial correlation in hydrochemical variables is a vital tool in the analysis of groundwater chemistry especially in arid and semiarid zones.

Geographic information system (GIS) has been played a key role in the management of natural resources, and therefore, it may offer an appropriate method to integrate physicochemical data analyses of groundwater (El Omran et al. 2014). However, the role of GIS in analyzing the spatial distribution of groundwater has been investigated by many authors (Verma et al. 2016; Gorai and Kumar 2013; Srivastava et al. 2012). In an earlier study, several models have been applied to estimate the hydrochemical distribution of water and soil (Nur et al. 2012; Mosaferi et al. 2014; Verma et al. 2016). Geostatistics is a spatial statistical technique

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that can be used to assess and represent the distribution of concentration over space and time based on the relationship between sample points, and estimates the uncertainty of that prediction (Yeh et al. 2009; Piccini et al. 2012). Moreover, kriging technique conceives the spatial relationship between the sample points, typically employed for mapping spatial inconsistency (Nayak et al. 2015). Remadevi (2006) compared different variogram models to fit the experimental semivariograms in identifying the spatial analysis of groundwater levels in small part of Rajasthan (India). Shamsudduha (2007) utilized different interpolation techniques in assessing the most suitable prediction method for the estimation of arsenic concentrations in a shallow aquifer in Bangladesh. Omran (2012) proposed a simple method to assess the groundwater quality and to map its spatial variation in terms of suitability for irrigation in the Darb El-Arbacin area, Southwestern Desert, Egypt. Adhikary et al. (2012) and El Omran et al. (2014) proposed a model to assess and map irrigation water well suitability using geospatial analysis. However, it is perceived that researchers have employed distinctive interpolation technique for their definite problem.

Iran is one of the arid and semiarid countries of the biosphere with mean rainfall of 251 mm/year, and summers are warm with temperatures in surplus of 55 °C. The country has six main hydrological basins and vital assets of renewable surface and groundwater—1957 CM/capita. Research reports recommended that over-exploitation upsurges in drought periods, and it is most severe around the saline lakes (Barzegar et al. 2017). The national average long-term fall in the groundwater table is about 0.5 m/year, but more recent falls are greater than this (Food and Agriculture Organization of the United Nations 2009). The less recurrent rainfall, unequal existence of precipitation with high amount during local storms, and high evaporation disturb the groundwater availability (Marko et al. 2014). Consequently, increasing population growth and subsequent economic activity have caused a high demand for water consumption in Iran (Abouie-Mehrizi et al. 2012).

Despite the large number of studies of water quality assessment, no complete assessment tool has been found in the literature that incorporates the crucial aspects of water quality analysis in the Neyshabur, Iran. In this study, 402 monitoring wells were applied to estimate the potential contamination risk of groundwater quality in the study area. Therefore, the current study is undertaken to investigate the application of various spatial models and data interpolation to interpret areas with high potential pollution and assess the efficiency of the current monitoring wells by probability risk assessment method.

Materials and methods

Study area

The study area (Neyshabur plain) locates within 58°3'29.789"E–59°23'47.383"E longitudes, 35°43'21.722"N–36°59'19.821"N latitudes (Fig. 1), covered with an area of about 9029.55 km². The study area is flat and gentle slopes range between 5 and 20 degrees, covered with an area of about 78%. About 25% of the land area is having moderate slope. The average annual precipitation ranges between 100 and 500 mm, and the mean annual rainfall is about 249 mm (35 year period) (Water Resource Management Organization, Iran; <http://en.iwpc.ir/default.aspx>). Climatic is characterized by semi-humid and arid over the entire region. The minimum and maximum temperature ranges between 4 °C and 40 °C. Most of the soils in the study area are lithosols and alluvial–colluvial. The geochemistry of the rocks in the south and southeast of Neyshabur has been resembled to that of the Urmia-Dokhtar Belt. The rocks have been accredited to moderate- to high-potassium successions with alkaline propensity and subduction-connected continental arc magmatism (Cawood and Hawkesworth 2013) (Fig. 2). Due to harsh climate, unsuitable soil and groundwater crops are not properly yield in the study area, therefore, livestock husbandry is only practiced in the uplands.

Sampling and physicochemical analysis

To access the quality of groundwater, 402 water samples were collected during the period between 2010 and 2013. The bore wells were pumped for 10 minutes (time) before collecting the water samples. Fresh groundwater samples were collected in sterilized polythene bottles of 500 ml. All water samples were filtered through 0.45 µm and physicochemical analysis in laboratory. The water quality data of major cations calcium (Ca²⁺), magnesium (Mg²⁺), sodium (Na⁺), potassium (K⁺), and anions such as bicarbonate (HCO₃⁻), chloride (Cl⁻), sulfate (SO₄²⁻) were analyzed in the laboratory using the standard methods (Table 1). The global positioning system (GPS) was used to record the geographic location (latitude, and longitude) and elevation with respect to mean sea level (MSL) of each sampling point. All the geographic coordinates of sampling location and sampling attributes were imported in ArcGIS software v9.3 for geospatial analysis.

Fig. 1 Location of the study area and sampling of groundwater data

Geostatistical analysis

A geostatistical analysis including investigation of spatial autocorrelation and the interpolation of groundwater attribute values at unsampled locations was performed using GS+8 software (Gamma Design Software 1988). Spatial distribution map of groundwater was generated by ArcGIS v9.3 software. Spatial autocorrelation analysis described the spatial continuity based on an experimental semivariogram model. Based on the regionalized variable theory and intrinsic hypotheses (Nielsen and Wendroth 2003), semivariogram analysis is expressed as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i + h) - z(x_i)]^2 \quad (1)$$

where $\gamma(h)$ is the semivariance, h is the lag distance, Z is the parameter of the water property, $N(h)$ is the number of pairs of locations separated by a lag distance h , $Z(x_i)$, and $Z(x_i + h)$ are values of Z at positions x_i and $x_i + h$ (Wang and Shao 2013; Shit et al. 2016). The empirical semivariograms obtained from the data were fitted by theoretical semivariogram models to produce geostatistical parameters, including nugget variance (C_0), structured variance (C_1), sill variance ($C_0 + C_1$), and distance parameter (k). The nugget/

Fig. 2 Lithological map of the study area (Source: USGS)

sill ratio, $C0/(C0 + C1)$, was calculated to characterize the spatial dependency of the values. In general, a nugget/sill ratio 75% indicates weak spatial dependency; otherwise, the spatial dependency is moderate (Cambardella et al. 1994). Ordinary kriging (OK) method was used for generation of groundwater quality maps in ArcGIS v9.3 software.

Performance evaluation criteria

Cross-validation technique was adopted for evaluating and comparing the performance of OK interpolation method. The coefficient of determination (R^2) was employed to determine goodness of fit (Robertson 2008). The sample points were

arbitrarily divided into two datasets, with one estimate mean value against measured mean were used to validate the model. The error-based measures employed including the root-mean-square error (RMSE) and the mean error (ME). The RMSE is an estimation of the accuracy of calculation. Precise calculations have a value adjacent to zero. The ME epitomizes the prejudice of calculation, and it should be near to 0 for balanced procedures (ESRI 2004). These measures can be calculated by the following equations:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n [Z(x_i) - Z^*(x_i)]^2} \quad (2)$$

Table 1 Specific methods of measurement of different physiochemical parameters of groundwater

Parameter	Analytical Method
Calcium (Ca ²⁺ , mg/l)	EDTA titration method Richards (1954)
Magnesium (Mg ²⁺ , mg/l)	EDTA titration method Richards (1954)
Sodium (Na ⁺ , mg/l)	Flame photometric method Osborn and Johns (1951)
Potassium (K ⁺ , mg/l)	Flame Photometric method Osborn and Johns (1951)
SAR (sodium adsorption ratio)	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$ Richards (1954)
Hardness (TH, mg CaCO ₃ /l)	EDTA titration method Richards (1954)
Electrical conductivity (EC, μS/cm)	Conductivity bridge method Richards (1954)
Total dissolved solids (TDS, mg/l)	Water quality analyzer APHA (1995)
pH	HANNA portable water quality pH m (HI-9828, USA)
Bicarbonate (HCO ₃ ⁻ , mg/l)	Acid titration method Hesse (1971)
Chloride (Cl ⁻ , mg/l)	Mohr's titration method Hesse (1971)
Sulfate (SO ₄ ²⁻ , mg/l)	Water quality analyzer APHA (1995)

$$ME = \frac{1}{n} \sum_{i=1}^n [Z(x_i) - Z^*(x_i)] \quad (3)$$

where RMSE = root-mean-square error, ME = mean error, Z = parameter of the water property.

However, RMSE and the goodness of prediction were intended as processes for correctness and efficiency, respectively, for all the produced groundwater prediction maps. Statistical analysis was performed using SPSS software (V.13.0). The physicochemical parameters of the analytical results of groundwater were compared with standard guideline value recommended by the WHO (2011).

Results and discussion

Physicochemical parameters of groundwater

Table 2 shows the hydrochemical properties of groundwater quality. Recognizing the groundwater quality is significant as it is the key feature defining its appropriateness for drinking, agricultural and industrial purposes (Mokarram 2016). Table 2 abridges the outcomes of several parameters comprising statistical measures such as average, standard deviation, kurtosis and skewness analyzed of groundwater samples from the study area. The average value of Ca²⁺ is recorded as 1.39 mg l⁻¹ with a standard deviation of 3.95. The average concentration of Na⁺ in the study areas is calculated as 7.02 mg l⁻¹ (± 13.80). The standard deviation of EC, TDS and hardness of some groundwater samples are relatively high. Except pH, all the hydrochemical parameters are having the positive skewness, indicated that the tail of their dissemination illustrations on the left-hand side

Table 2 Descriptive statistics of groundwater parameters

Parameter	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
Ca ²⁺ (mg l ⁻¹)	01	35	1.39	3.95	5.61	39.33
Mg ²⁺ (mg l ⁻¹)	02	25	0.87	1.80	3.11	12.75
Na ⁺ (mg l ⁻¹)	01	80	7.02	13.80	2.29	7.69
K ⁺ (mg l ⁻¹)	02	27	0.13	0.72	8.75	84.69
Hardness (mg l ⁻¹)	30	3625	510.83	525.12	3.27	17.24
EC (μS/cm)	322	16740	2733.90	2848.70	1.96	7.21
TDS (mg l ⁻¹)	252	9324	198.88	558.27	4.58	29.01
pH	6.5	8.9	7.91	0.25	- 1.53	9.46
HCO ₃ ⁻ (mg l ⁻¹)	1.0	10.4	3.32	1.65	1.67	5.88
Cl ⁻ (mg l ⁻¹)	0.3	108	16.77	22.51	1.90	6.45
SO ₄ ²⁻ (mg l ⁻¹)	0.7	41.6	7.63	7.21	1.95	7.69
SAR	0.08	37.89	7.35	6.30	1.19	4.47

of the likelihood density function is lengthier than the right side and the bulk of the values lie to the right of the mean. According to values of skewness and kurtosis, before geo-statistical analyses, data were transforming to normal distribution using Box-Cox power transformation technique. Kurtosis is an amount of the peakedness of the likelihood spreading of a real-valued random variable. Higher kurtosis means more of the variance is the outcome of intermittent extreme nonconformities, as disparate to recurrent diffidently sized deviations.

Correlation analysis

The Pearson's correlation coefficient was calculated to measure the degree of relation between groundwater quality variables. The greater the value of correlation coefficient is, the better and more useful the regression variables (Patil and Patil 2011). The high positive correlation

was observed between Ca^{2+} and TH ($r=0.585$), Ca^{2+} and SO_4^{2-} ($r=0.501$), Na and TH ($r=0.643$), Na and EC ($r=0.676$), Na and Cl^- ($r=0.668$), SAR and EC ($r=0.718$), SAR and SO_4^{2-} ($r=0.635$), TH and EC ($r=0.923$), TH and SO_4^{2-} ($r=0.881$), Cl^- and SO_4^{2-} ($r=0.85$), TH and Cl^- ($r=0.897$), and EC and Cl^- ($r=0.990$) at 0.005 level of significant (Table 3).

The pH and HCO_3^- were negatively correlated with most of the groundwater parameter of the study area. The strong negative correlation coefficient was found between TH and pH ($r=-0.330$), EC and pH ($r=-0.31$), pH and Cl^- ($r=-0.313$), and HCO_3^- and Cl^- ($r=-0.320$). The results also indicated that the physicochemical parameters for groundwater in Neyshabur plain (Iran) area were moderately correlated with each other.

Table 3 Pearson's correlation coefficient of physiochemical parameters of groundwater ($n=402$)

Parameters	Ca^{2+}	Mg^{2+}	Na^+	K^+	SAR	TH	EC	TDS	pH	HCO_3^-	Cl^-	SO_4^{2-}
Ca^{2+}	1.00	0.379	0.399	0.127	0.258	0.585	0.545	0.459	-0.15	-0.168	0.534	0.501
Mg^{2+}		1.00	0.227	0.147	0.176	0.327	0.320	0.286	-0.11	-0.43	0.286	0.379
Na^+			1.00	0.125	0.477	0.643	0.676	0.332	-0.18	-0.172	0.668	0.625
K^+				1.00	0.166	0.399	0.378	0.115	-0.06	-0.064	0.366	0.363
SAR					1.00	0.445	0.718	0.253	-0.14	-0.288	0.721	0.635
TH						1.00	0.923	0.407	-0.33	-0.158	0.897	0.881
EC							1.00	0.428	-0.31	-0.277	0.990	0.909
TDS								1.00	-0.16	-0.149	0.440	0.335
pH									1.00	-0.124	-3.13	-0.27
HCO_3^-										1.00	-0.32	-0.26
Cl^-											1.00	0.850
SO_4^{2-}												1.00

Table 4 Best fit model summary of semivariogram analysis for groundwater quality parameters

Parameters	Best fit model	Nugget (Co)	Sill (Co + C)	Range Ao(m)	$C/(Co + C)$ (%)	R^2	RSS	ME	RMSE
Ca^{2+} (mg/l)	Exponential	0.72	0.76	24004	0.95	0.64	0.080	0.03	0.53
Mg^{2+} (mg/l)	Exponential	0.51	1.09	3610	0.47	0.38	0.080	0.03	0.75
Na^+ (mg/l)	Exponential	0.31	0.52	17664	0.60	0.52	0.009	0.03	0.63
K^+ (mg/l)	Spherical	0.63	1.48	2132	0.43	0.29	0.050	0.04	0.61
SAR	Exponential	0.22	0.7	18554	0.31	0.22	0.005	0.03	0.52
TH (mg CaCO_3 /l)	Exponential	0.02	1.11	1131	0.02	0.02	0.800	0.03	0.75
EC ($\mu\text{S}/\text{cm}$)	Spherical	0.32	0.49	28550	0.65	0.42	0.020	0.03	0.52
TDS (mg/l)	Exponential	0.55	1.23	2396	0.45	0.33	0.030	0.03	0.63
pH	Spherical	0.91	1.08	1816	0.84	0.53	0.090	0.03	0.68
HCO_3^- (mg/l)	Exponential	0.02	1.43	12129	0.02	0.01	0.500	0.03	0.96
Cl^- (mg/l)	Stable	0.49	0.65	24583	0.75	0.44	0.01	0.05	0.53
SO_4^{2-} (mg/l)	Stable	0.33	0.56	18564	0.59	0.39	0.005	0.03	0.58

Aorange of influence, Corandom variance, Cstructured variance, R^2 coefficient of determination, RSSresidual sum square, MEmean error, RMSEroot-mean-square error

Spatial structure of groundwater quality parameters

The semivariogram models (spherical, exponential, and stable) were tested for each parameter data set. Prediction performances were assessed by cross-validation, which examines the accuracy of the generated surfaces (data not shown). Table 4 shows the semivariogram parameters (nugget, sill, range) of groundwater quality variables using spherical, exponential and stable. Nugget indicated the microscale variability and measurement error for the respective groundwater quality parameters, whereas sill indicates the amount of variation which can be defined by the spatial correlation structure (ESRI 2004). Results of our analysis showed that the nugget component for exponential model was less for all the variables. Nugget/sill characterizes the spatial variability degree, which affected by both structural and stochastic factors. The higher ratio indicates that the spatial variability is primarily caused by stochastic factors. The value of < 0.25 , $0.25\text{--}0.75$ and > 0.75 showed the strong, moderate and weak spatial autocorrelation (Table 4). In this study, spherical, exponential and stable semivariance functional model was found to be best fit for groundwater (Table 4). The maximum groundwater samples are fitted with the exponential

curve, except for potassium, EC, pH, sulfate and chloride, where spherical and stable models fitted best. The present results also corroborated with the previous studies by Dash et al. (2010) and Adhikary et al. (2012). To ascertain the predictability of the theoretical model, prediction error statistics were estimated for all models (Table 4). The results were found that for all models RSS and ME close to zero, whereas RMSE was close to one.

Spatial distribution of physicochemical properties of groundwater

Groundwater quality for drinking purpose

The quality standards for drinking water have been specified by the World Health Organization (WHO 2011). The behavior of major ions (Ca^{2+} , Mg^{2+} , Na^+ , Cl^- , K^+ , HCO_3^- , SO_4^{2-}) and important physicochemical parameters (pH, EC, TDS, TH, SAR) have been studied for groundwater quality analysis. The analytical results have been evaluated to ascertain the suitability of groundwater in the study area for drinking and agricultural use. The analytical results for all the parameters for the groundwater sample are presented in Table 5.

Table 5 Groundwater sample of the study area exceeding the permissible limits recommended by WHO (2011) for drinking purpose

Sl no.	Parameter	WHO international standard 2011		Range of the study area	% samples exceeding WHO (2011)	Undesirable effect produced beyond the MPL (Sharma et al. 2016)
		DL	MLP			
1	Ca^{2+} (mg l^{-1})	75	200	1–35	0.0	Insufficiency causes a severe type of rickets, excess causes concretions in the body such as kidney or bladder stones and irritation in urinary
2	Mg^{2+} (mg l^{-1})	30	100	2–25	0.0	Its salts are cathartic and diuretic. High concentration may have laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes. It is essential as an activator of many enzyme systems
3	Na^+ (mg l^{-1})	–	200	1–80	0.0	Impact distinctly unpleasant taste
4	K^+ (mg l^{-1})	–	12	2–27	6.25	High concentration laxative effect on human
5	Hardness (mg l^{-1})	100	500	30–3625	31.84	Calcification of arteries. It may cause urinary concretions, diseases of kidney and stomach disorder
6	EC ($\mu\text{S/cm}$)	–	1400	322–16740	55.57	High concentration laxative effect on human
7	TDS (mg l^{-1})	500	1000	252–9324	89.19	Palatability decreases and may cause gastrointestinal irritation of human bodies
8	pH	6.5	8.5	6.5–8.9	0.75	Taste effects, mucus membrane and water supply system
9	Cl^- (mg l^{-1})	200	250	0.3–108	0.0	May be injurious to some people suffering from diseases of hearts or kidney. Taste, indigestion, and palatability are affected.
10	Sulfate (mg l^{-1})	200	250	0.7–41.6	0.0	Causes gastrointestinal irritation along with Mg or Na, can have a cathartic effect on users, concentration more than 750 mg/l may have laxative effect along with magnesium

MLP maximum permissible limit, DL desirable limit

Calcium and magnesium (Ca^{2+} and Mg^{2+}) Calcium and magnesium are most abundant element in the natural surface and groundwater and exist mainly as bicarbonates and to a lesser degree in the form of sulfate and chloride (Prasanth et al. 2012). The average value of calcium ion concentration in the study area is calculated as 1.39 mg/l, with standard deviation of ± 3.94 . The western part of the study area is illustrated medium to high concentration of Ca^{2+} , and the east central and northern part is represented as low concentration (Fig. 3a). The magnesium ion concentration varies from 0–9.6 mg/l with an average value of 0.87 mg/l

(± 1.81). The spatial distribution map of Mg^{2+} ion is illustrated in Fig. 3b. The results showed eastern, northern and small pockets of southwest part of the study area are covered with the low concentration of magnesium. The maximum permissible limit of calcium and magnesium concentration of drinking water is 200 mg/l and 100 mg/l, respectively, recommended by WHO (2011). The present results revealed that all water samples falls below the maximum permissible limit (Table 5). Magnesium is essential as an activator of many enzyme systems, but it is also cathartic and diuretic.

Fig. 3 Spatial distribution of cations **a** Calcium (Ca^{2+} , mg/l). **b** Magnesium (Mg^{2+} , mg/l). **c** Sodium (Na^{+} , mg/l) and **d** Potassium (K^{+} , mg/l)

Both Ca^{2+} and Mg^{2+} are derived from the silicate rocks as well as dolomite deposits (Sharma et al. 2016).

Sodium and potassium (Na^+ and K^+) Sodium is one of the most abundant substances found in natural water in higher quantities in the rocks. Sodium in the study area varied from 0 to 58 mg/l, with an average value of 7.02 mg/l (± 13.80). This might be because of the granitic topography (e.g., the landforms are composed with granitic rocks). An upper sodium consumption may cause hypertension, an amiable heart disease, nervous ailment and kidney difficulties (Magesh et al. 2012). The suggested limit for sodium concentration in drinking water is 200 mg/l (WHO 2011). Concentration of Na^+ does not surpass the suggested level of the groundwater samples. The spatial aspect of sodium distribution in the study area is portrayed in Fig. 3c.

Potassium is a naturally occurring element; however, its concentration remains quite lower compared with Ca^{2+} , Mg^{2+} , and Na^+ . Potassium occurs in drinking water as a consequence of the use of potassium permanganate as an oxidant in water treatment (WHO 2011). The concentration of potassium is varied between 0.0 and 7.2 mg/l with a mean value of 0.13 mg/l in the study area. The maximum permissible limit of K^+ in the drinking water is 12 mg/l, and it is found that 93.75% the samples are below the permissible limit of the WHO (Table 5). The high concentration of K^+ is due to the effect of fertilizer and other industrial activities located near the site. The spatial distribution map of the K^+ is illustrated in Fig. 3d. Results showed the concentration of potassium decline toward the eastern and northern part of the study area.

Chloride (Cl^-) Chlorides are one of the major inorganic anions present in natural water. Chloride may be origin or accumulated in groundwater from weathering, leaching of sedimentary rocks and soils, agricultural activities and domestic sewage. The high concentration of chloride is considered to be the indicator of pollution by high organic wastes of animal or industrial region (Selvakumar et al. 2017). In this study, chloride concentration varied from 0.4 to 109.2 mg/l with an average value of 16.76 mg/l (± 22.51). The maximum permissible limit of chloride is 250 mg/l for drinking water (WHO 2011), and it reveals that all samples does not exceed the maximum permissible limit of the WHO. The spatial distribution of chloride in the study area is represented in Fig. 4a. The higher concentration in Cl^- is observed in the western and southern part of the study area. The northern and southeastern parts are covered with the medium concentration of Cl^- (5–17 mg/l). The central east is covered with the low concentration of Cl^- (< 2.5 mg/l). However, the increase in concentration of Cl^- leads to heart and kidney damage, indigestion, taste and palatability (CPCB 2008).

Sulfate (SO_4^{2-}) Sulfate concentration varied from 1.00 to 39.8 mg/l. The average value of sulfate concentration is recorded as 7.63 with a standard deviation of ± 7.21 , indicating that all samples fall within the desirable limit. The concentration of sulfate is possible to retort with human organs if the value surpasses the extreme permissible limit of 250 mg/l, (WHO 2011) for drinking water which will cause purgative consequence to the human system with the additional magnesium in groundwater (Ravi et al. 2014). The spatial distribution of sulfate ion concentration in groundwater is illustrated in Fig. 4b. The results showed that the maximum concentration of sulfate is observed in the western part, while the low concentration is observed in the eastern part of the study area.

Bicarbonate (HCO_3^-) Bicarbonate in the study area varies between 1.16 and 9.0 mg/l, with an average value of 3.320 mg/l (± 1.65). The spatial aspect of bicarbonate is illustrated in Fig. 4c. The results of the study showed that western and southwest of the study area is covered with low concentration of bicarbonate (< 3.0 mg/l) and the eastern part is covered with the high concentration of bicarbonate. The higher concentration of HCO_3^- in the groundwater source points to be dominance of minerals dissolution (Stumm and Morgan 1996).

pH The pH is a measure of the balance between the concentration of hydrogen ions (H^+) and hydroxyl ions (OH^-) in water and indicates the acidity or alkalinity of a solution (Prasanth et al. 2012). The pH of groundwater provides vital information in many types of geochemical solubility calculation (Hem 1985). The permissible limit of pH values for drinking water is specified as 6.5–8.5 (WHO 2011). In our study, pH varies from 6.5 to 8.32, with an average value of 8.90 (± 0.25). This shows that groundwater is slightly alkaline in nature. The results reveals that only 0.73% ($N=3$) of groundwater samples have crossed the maximum permissible limit. Spatial distribution map of pH is portrayed in Fig. 4d. The results showed southwest of the study area having slightly acidic nature of groundwater while the eastern and northern part showed slightly basic in nature. It is perceived that the pH value of the water seems to be reliant on the relative amounts of calcium, carbonates and bicarbonates. The water inclines to be extra alkaline when it retains carbonates (Shrivastava and Patil 2002).

Total hardness (TH) The maximum permissible limit of total hardness for drinking water is 500 mg/l (WHO 2011). TH ranges from 30 mg/l to 3625 mg/l with an average value of 510.83 mg/l. The results showed that 31.84% exceed the maximum permissible limit (Table 5). The classification of groundwater sample based on Sawyer and McCarty (1967) showed that 1.74, 8.21, 35.32 and

Fig. 4 Spatial distribution of anions. **a** Chloride (Cl^- , mg/l). **b** Sulfate (SO_4^{2-} , mg/l). **c** Bicarbonate (HCO_3^- , mg/l), and **d** pH

54.72% of water samples are soft, moderately hard, hard, and very hard, respectively, for irrigational uses (Table 6). However, the high levels of hardness may affect water supply system, excessive soap consumption, calcification

of arteries. This may cause urinary concretions, disease of kidney of bladder and stomach disorder (CPCB 2008). Figure 5b showed the spatial distribution of TH within the study area. The western part of the study area is covered

Table 6 Irrigational quality parameters results in groundwater sample

Parameters	Reference	Range	Groundwater class (irrigation uses)	Samples		Area (Sq. km)
				In (no.)	In (%)	
SAR	Todd (1959) and Richards (1954)	< 10	Excellent	275	68.40	5866.06
		10–18	Good	104	25.87	2497.24
		18–26	Doubtful	16	3.98	663.25
		> 26	Unsuitable	7	1.75	3.00
Mg ²⁺ hazard (mg/l)	Paliwal (1972)	< 50	Suitable	17	25.00	2319.13
		> 50	Unsuitable	51	75.00	6710.42
Na ⁺ hazard (%)	Wilcox (1955)	< 20	Excellent	30	32.62	2908.85
		20–40	Good	26	28.26	2526.12
		40–60	Permissible	29	31.52	2884.17
		60–80	Doubtful	07	7.60	710.41
		> 80	Unsuitable	00	00	0.0
TH (mg/l)	Sawyer and McCarty (1967)	< 75	Excellent	07	1.74	5.63
		75–150	Good	33	8.21	65.89
		150–300	Doubtful	142	35.33	3598.58
		> 300	Unsuitable	220	54.72	5359.45
EC (μS/cm)	Richards (1954)	< 250	Excellent	00	00	0.0
		250–750	Good	85	21.15	25.87
		750–2000	Permissible	132	32.84	1898.47
		2000–3000	Doubtful	65	16.16	2362.18
		> 3000	Unsuitable	120	29.85	4743.03

with maximum value of TH that exceeds the maximum allowable limit (Fig. 5b). A small pocket in the central part of Neyshabur represents the minimum value of TH, i.e., permissible limit for irrigation purpose.

Groundwater quality for irrigational purpose

In general, groundwater consideration for irrigation purpose depends on the effects of mineral constituent of soil and plants (Ketata et al. 2011). Present of excess dissolved ions in irrigation water affects agricultural soils and plants both physically and chemically, hence could lead to low productivity (Ebong et al. 2017). The suitability of groundwater for irrigation is evaluated and concentrations of groundwater quality parameters using electrical conductivity (EC), sodium adsorption ratio (SAR), percent of sodium (Na²⁺%) and total hardness (TH). USSL diagram (SAR vs. EC plot) and Wilcox diagram (Na²⁺% vs. EC plot) were also applied to evaluate the irrigation suitability of groundwater in many instances.

Sodium adsorption ratio (SAR) The relative activity of sodium ion in the exchange reacting with soil is expressed in terms of SAR. It is an important parameter for determining the suitability of irrigation water, because it is a measure of alkali/sodium hazard for crops. The SAR value of water for irrigation purpose has a significant relationship with the

extent to which sodium is absorbed by the soils. Irrigation using water with high SAR value may require soil amendments to prevent long-term damages to the soil, because the sodium in the water can displace the calcium and magnesium in the soil (Prasanth et al. 2012). The SAR value in the study area varies from 0.32 to 31.04 with an average of 7.35 (± 6.30). The classification of groundwater samples on SAR value are shown in Table 6. 94% of SAR values (< 18) are found within the range of excellent to good categories for irrigation water. The study showed a very low alkalinity hazard cover an area of only 6%, concentrated at the extreme of southern and northern part (Fig. 5a). Figure 5a showed that southwest of the study area covered with moderate SAR value (> 17), while the eastern and east central area covered with the low value of SAR. There is an important association between SAR and irrigation water. If the water used for irrigation is maximum in sodium and minimum in calcium content, then redeemable calcium in soil may substitute sodium by Base Exchange reaction in water (Ogunfowokan et al. 2013). Saleh et al. (1999) recommended that if the SAR value varies from 6 to 9, irrigation water will cause permeability complications in dwindling and puffiness types of clayey soils.

Electrical conductivity (EC) EC is the measure of salt content of water in the form of ions. EC value of the study area ranges from 367.33 μS/cm to 14892 μS/cm with an

Fig. 5 Spatial distribution of **a** sodium adsorption ratio (SAR). **b** Hardness (TH, mg CaCO_3/l). **c** Electrical conductivity (EC, $\mu\text{S}/\text{cm}$), and **d** total dissolved solids (TDS, mg/l)

average value of 2733.9 $\mu\text{S}/\text{cm}$. It is observed that 55.97% of the samples are maximum permissible limits (i.e., 1400 $\mu\text{S}/\text{cm}$) as per the WHO standards (2011). The EC are classified according to Richards (1954) into five groups. 53.98% of the total samples are suitable for irrigational purpose (Table 6). The spatial distribution of the EC within the study area is represented in Fig. 5c. Results

showed that western, southern and north-eastern part of the study area is covered with the higher EC, whereas the lower value of EC is extended in some small pockets (25.87 km^2) of EC of eastern region (Table 6).

United States Salinity Laboratory (USSL) diagram depicts a detailed analysis of groundwater quality for irrigational purpose (USSL 1954). As per this classification,

Fig. 6 USSL diagram for classification of irrigation water quality, with respect to salinity hazard and sodium hazard

low salinity water ($< 250 \mu\text{S/cm}$) can be used in all types of soils. In the present study, 54% water sample is medium to high salinity. Only 29.89% samples are indicated very high salinity, i.e., not suitable for agriculture uses (Fig. 6).

Total dissolve solids (TDS) The dissemination of TDS values evidently illustrated that the entire study area ranges from 252 to 9324 mg/l with an average value of 198.88 mg/l. As per the WHO standards, 11% of the samples has surpassed the acceptable limits ($< 1000 \text{ mg/l}$) and only 89% of the samples are not suitable for drinking purpose. The spatial variation map of TDS showed that about 10% of total area comes under safe limit as per the WHO standard (2011) (Table 5), portrayed in the northern and eastern part of the study area (Fig. 5d). Approximately 90% of the study area falls under unsafe zone. Therefore, there is an urgent need for planners, decision maker to look after the situation and

took the necessary steps. The higher value of TDS can be accredited to the involvement of salts from the subsurface lithology because of higher residence time of groundwater in connection to the aquifer body (Selvam et al. 2013).

Sodium hazard ($\text{Na}^+\%$) Sodium hazard was also measured in terms of another index know as sodium percent ($\text{Na}\%$) to evaluate groundwater suitability for agricultural use (Wilcox 1955). It is calculated using following equation:

$$\text{Na}^+\% = (\text{Na}^+ + \text{K}^+) \times 100 / (\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)$$

The water quality classification for irrigation purpose performed using Wilcox diagram (Wilcox, 1955) showed that 7.6% the groundwater samples were sodium hazards (Table 6). $\text{Na}\%$ varied between 3.03 and 96.59 with a mean value of 56.10. The study area showed very low sodium hazard, covering with an area about 710.41 km^2 . Moreover, 32.61, 28.26, and 31.52% samples come under

Fig. 7 Wilcox diagram irrigation samples for groundwater quality (after Wilcox 1955)

excellent, good and permissible for irrigational water, respectively (Fig. 7).

Magnesium hazard Based on the calcium and magnesium ratio, a water suitability classification for irrigation water was developed by Paliwal (1972). Magnesium hazard is expressed by the following equation:

$$\text{Magnesium ratio} = (\text{Mg}^{2+} \times 100) / (\text{Ca}^{2+} + \text{Mg}^{2+})$$

The magnesium hazard values in the study are ranges from 25 and 100 with an average value of 66.25, and only 25% of the samples are considered suitable for irrigation purpose (Table 6). The study found that, out of the total 9029.55 km² study area, 6710.42 km² is an unsuitable for irrigation purpose.

Conclusions

The present study is conducted to evaluate hydrochemical properties of groundwater in the arid and semiarid region in Neyshabur, Iran. Most of the groundwater samples are acceptable (permissible limits) for irrigational and drinking purpose recommended by the WHO standard (WHO 2004). Results suggest that the groundwater quality in this

study area is very hard and slightly alkaline in nature. The spatial distribution maps of groundwater quality parameters were carried out through GIS and geostatistical techniques. These techniques have successfully demonstrated its capability in groundwater quality mapping in Neyshabur, Iran. Conversely, consistent investigation of groundwater table along with hydrochemical characteristics will reduce the prospect for further deterioration. However, the outcome of the present result may help to comprehend the excellence of the groundwater resources to improve appropriate management plan. The application of water quality in this study has been found useful in assessing the overall quality of water. It is also helpful for the public to understand that the water quality is a useful tool in many ways in the field of water quality management.

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