Physical–chemical evaluation of groundwater quality in semi-arid areas: case study—Sabzevar plain, Iran

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Abstract

Groundwater is one of the most important water sources in arid and semi-arid areas. With the increasing world population and the water demand for agriculture and urban use, the need for water resources has increased, especially in arid and semi-arid regions, where groundwater resources play a significant role. To prevent the pollution of groundwater resources, various studies for their preservation and maintenance should be carried out, including a detailed plan for proper management of water resources and establishing a balance between water quality and how to use them. It becomes important to understand the spatial change of the quality of groundwater resources. In this study, Sabzevar plain, a typical region of semi-arid climate in Iran, was selected as a case study to assess the groundwater quality of the region, using data from 24 observation wells between 2015 and 2019. Using Arc GIS software, a map of groundwater quality parameters in the study area was prepared for quality assessment and comparison with existing international standards. The results showed that (except pH and HCO_3^-) the concentration of Sodium, Magnesium, and other anions and cations is higher than the corresponding WHO standard limit, suggesting that the study area is unsuitable for drinking and agricultural use. According to the Wilcox chart, 87.5% of the samples are in the C4S4 class while 8.33% are in the C4S3 class, showing the groundwater unsuitable for agricultural use due to its high salinity and alkalinity. Piper diagrams show that more than 50% of the samples are non-carbonate alkalis, indicating a very high salinity in the area. According to the pie chart, chlorine ion and sodium ion are the dominant anions and cations in the Sabzevar plain, respectively. The Schuler diagram shows that none of the samples examined were in a good class for drinking. Therefore, considering the importance of water for agricultural activities in the study area, it is recommended to have agricultural management solutions to prevent groundwater mixing with freshwater resources.

Keywords Groundwater · Drinking water · Agriculture · Water quality · Sustainable water management

Introduction

Due to population growth in recent decades and climate changes caused by lack of rainfall and deduction of surface streams in arid and semi-arid regions, groundwater

has become the primary water source required for different purposes in these regions. Meanwhile, rapid population growth and increasing urbanization have caused significant changes in land usage, subsequently increasing demands for water consumption in various sectors such as agricultural, domestic and industrial activities (Kheirandish et al. 2020).

Considering the groundwater resources as the most reliable perennial source of freshwater (Lapworth et al. 2012), understanding and properly utilizing groundwater can lead to the sustainable development of social and economic activities in a region, especially in arid and semi-arid regions. In arid and semi-arid regions such as Iran and South Africa, about 85% and 70% of drinking water are from groundwater resources, respectively. Therefore, groundwater resources are an important part of the primary sources of water supply (Godfrey et al. 2019). Meanwhile, groundwater pollution in arid and semi-arid areas is a severe threat to drinking water

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supply, agriculture and industry in these regions (Basem et al. 2010). One of the most important factors in urban and agricultural development is the maintenance and improvement of surface water and groundwater resources. In this regard, Mansour-Bahmani et al. (2020) used intelligent models including multilayer perceptron (MLPNN) and genetic planning (GP) to predict daily urban wastewater discharge in Kerman. Their research results showed an acceptable accuracy of GP modeling. Haghiabi et al. (2018) predicted the qualitative components of the Tireh river located in southwestern Iran using artificial neural network (ANN), group method of data handling (GMDH), and support vector machine (SVM). Their results indicate that the ANN and SVM models perform well for predicting river water quality components.

Various factors can affect groundwater quality. Natural processes and human impacts are the most important factors in groundwater quality (Magesh et al. 2013). Future climate changes might increase the pressure on hydrological systems and the demand for water, which will reduce the groundwater quality. Thus, it is necessary to develop appropriate strategies to control the factors that reduce groundwater quality, especially in arid and semi-arid areas (Farid et al. 2019). Earthquakes and surface processes that interact with water might affect the quality of shallow groundwater (Babiker et al. 2007). One common method in environmental engineering studies is modeling the transfer of pollution in rivers. The use of numerical models is a good tool for managing water quality. In this regard, the research results by Parsaie and Haghiabi (2016) for River Severn in the U.K. showed that a good fit is obtained between observational data and analytical solution of the modified dispersion correction equation (MADE) model. Meshesha et al. (2021) used the SWAT model to simulate the groundwater quality of the Athabasca river basin, which showed that the use of the SWAT model for groundwater quality modeling has an effective role in the management of water resources.

Infiltration of saline water into groundwater resources of freshwater can cause major problems in agriculture, such as soil salinization, deduction of crop yield, and reduction of the area of arable land (Jeihooni et al. 2018). Accumulation of uncontrolled leachate at landfills also exacerbates groundwater pollution (Longe and Balogun 2010).

Based on the factors mentioned above, a comprehensive study of hydrogeochemistry is necessary to identify chemical processes affecting groundwater quality (Jeevanandam et al. 2007). One of the most practical methods for groundwater pollution management is monitoring and mapping (Hiscock et al. 1995). The results of a case study in the Xingguo region (Xie et al. 2015) showed that for the spatial characteristics of different regions, zoning is a method for better environmental management. Geostatistical methods provide the statistical characteristics of the measured data

and have been become a practical and reliable tool for better management and conservation of water resources and development (Nas and Berkay 2010). The movement of aquifers between rocks, sediments and minerals can cause extensive changes in water quality. Therefore, rocks, sediments and minerals play an important role in changing groundwater quality (Stamatis et al. 2011). Jalees et al. (2021) assessed the quality of groundwater in Pakistan using hydrochemical modeling and found that a relationship exists between water quality factors and lithology and human activities.

Ahn and Chon (1999) investigated groundwater pollution and spatial relationships between groundwater quality parameters, topography, geology, land use and pollution sources. In their study, GIS (geographic information systems) was used to investigate the spatial relationship between groundwater quality parameters and pollution sources. In a study for groundwater quality mapping by Nas and Berkay (2010), it was reported that researchers such as Hudak (2001), Hudak and Sanmanee (2003) used Arc view GIS to map and analyze groundwater data.

Hiscock et al. (1995) assessed the groundwater vulnerability and showed that the GIS is appropriate for the information extraction and is flexible in revising the classification plan.

Mallick et al. (2018) assessed the quality of groundwater in the Aseer region of Saudi Arabia. Their research showed that geochemical modeling has an important role in identifying the effective factors of groundwater quality. Rostami et al. (2019) used geostatistical techniques to model the groundwater quality index in the Marand plain in Iran. Their research results showed that the parameters of land slope, groundwater level and transferability as input data play an important role in the best WQI estimation using the combined kriging method.

Due to the importance of water quality to different uses, the World Health Organization (WHO) has set different standards for different groundwater quality parameters. Therefore, the values of physical and chemical properties recommended by the WHO are an important base for assessing groundwater quality (Honarbakhsh et al. 2019).

As described above, although many studies have been undertaken to evaluate the groundwater quality, which plays an important role in water resources management, there is still a lack of study on the water resources quality assessment of plains in arid and semi-arid areas. In this study, Sabzevar was selected as a case study to represent a region with semi-arid climate where groundwater quality plays a pivotal role for drinking and agriculture in the region. Furthermore, a hydrochemical study was taken to identify the chemical parameters affecting the groundwater quality, and GIS was used to generate groundwater quality maps for identifying the quality of selected points in the region.

Methodology

Study area

The study area is Sabzevar city located at 36.2152° N, 57.6678° E, in the west of Khorasan Razavi province, Iran. Its area is 26.76 km² with an average rainfall of 190 mm and an average temperature of 17 °C, and this area has a hot and dry climate. The Joghatai mountains are located in the north of the Sabzevar city, and the Mish mountains are located in the south of the city. In other words, Sabzevar city is surrounded by northern and southern heights. There are only two seasonal rivers called Kalshour in this region that lead the floods of Sabzevar plain to the desert salt marshes. Figure 1 shows the location of Sabzevar city in Khorasan Razavi province.

Land use of Sabzevar basin

Desertification can be related to salinity due to the over-exploitation of groundwater resources. Mishra et al. (1994) conducted a study on desertification of a region in India in two periods of 11 years using the dataset of MSS, TM, and IRS-1 satellites, which showed that the area of salty regions had been increased significantly, from 0.75 to 6.19%. Satellite datasets show a correlation between a decrease in groundwater level and an increase in salinity. Figure 2 shows the land use map in Sabzevar basin. According to

Fig. 2, 958.13 km² of the basin is allocated for agricultural lands, the largest area of which is in the groundwater aquifer of Sabzevar plain, so these agricultural lands have increased the drainage of the groundwater aquifer. Also, the groundwater level will be discussed later in the discussion, causing a sharp increase in salinity in the aquifer. The decline in groundwater level, discussed later in detail, causes an increase of saltiness in the aquifer.

Sampling and analysis

To evaluate the groundwater quality in the study area, data of 24 observational wells for a period from 2015 to 2019 were used for the study (Fig. 3).

The information of 24 observation wells in this study was sampled by Khorasan Razavi Regional Water Organization (www.khrw.ir). These wells were drilled from 1976 to 1991 and had a depth of 50–100 m. Most wells have a flow rate of less than 40 l/s. Figure 3 shows the location of the wells in this area. Based on the average monthly data collected, 11 physical and chemical parameters from 2015 to 2019 were studied and evaluated. Table 1 shows the parameters used in this study.

Standard methods for examining water and wastewater published by American Public Health Association (Association et al. 1915) were used to evaluate the samples for 11 physical and chemical parameters. A pH meter and an EC meter were used to measure the pH and the EC of the samples, respectively (Richards 1954). Heat method was used

Fig. 1 a Location of Khorasan Razavi province and Sabzevar city in Iran; b The river network in the basin

Fig. 2 Land use map in Sabzevar basin

Fig. 3 Sabzevar aquifer and observational wells

to measure the total dissolved solids. The amount of water was boiled in a porcelain dish, and the rest of the boiled water was then weighed and considered as TDS (Association et al. 1915). To measure chloride in a water sample, silver nitrate was used based on the amount of silver nitrate. Flow photometer was used to measure sodium and potassium ions (Osborn and Johns 1951). EDTA titration was used to measure calcium and magnesium ions (Richards 1954) as well as bicarbonate, where titration was performed

using sulfuric acid. The amount of Sulfate was also measured using a spectrophotometer. According to Eq. (1), Ca^{2+} (meq/L) and Mg^{2+} (meq/L) were used to calculate the total hardness (TH) (Boyd 2019):

$$\text{TH (mg of CaCO}_3) = (\text{Ca}^{2+} + \text{Mg}^{2+}) \times 50. \quad (1)$$

The behavior of some ions studied includes Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , HCO_3^- and SO_4^{2-} , while some

Table 1 Characteristics used in this research

Characteristics	Definition
TDS	Total dissolved solids
TH	Total hardness
EC	Electrical conductivity
pH	Power of hydrogen
Ca ²⁺	Calcium ion
Mg ²⁺	Magnesium ion
Na ⁺	Sodium
K ⁺	Potassium
Cl ⁻	Chloride
HCO ₃ ⁻	Bicarbonate
SO ₄ ²⁻	Sulfate

physicochemical properties such as EC, TDS and pH were selected and evaluated for drinking and agricultural purposes. The World Health Organization (WHO) has provided standards for the maximum allowable values of each water quality parameter. In the present study, a comparison was made between the studied parameters and the standard values reported by the WHO (Cotruvo 2017). Pie, Schuler, Piper and Wilcox diagrams were drawn to evaluate the groundwater quality parameters for agricultural and drinking purposes.

Statistics software—SPSS Version 22 was used to statistically analyze the qualitative data of groundwater for observation wells in Sabzevar region and to find the correlation matrix. AqQA software was used to conduct the hydrochemical analyses for groundwater quality data. Based on the results obtained from the statistical and hydrochemical analyses, the spatial distribution of each studied characteristic was plotted by the ordinary kriging method using Arc GIS 10.4.1 software.

Groundwater level fluctuations in Sabzevar plain

Based on the monthly measurements of groundwater level, the hydrograph of Sabzevar plain from 1978 to 2020 has been drawn by the Thiessen method for an alluvial zone with an area of 1726 km² (Fig. 4). The results show an average annual drop of 37 cm in groundwater level. The plotted hydrograph (Fig. 4) shows that the aquifer groundwater level declines and has fallen sharply in recent years.

Geophysical studies in Sabzevar plain include 286 electrical soundings with a length of AB1000 to 2000 m. Six exploratory wells was also drilled. The exploratory studies included the bottom rock and its changes, aquifer thickness and hydrodynamic coefficients. The bedrock of the eastern parts is mainly made of igneous rocks and in most of the plain is Neogene gypsum and evaporative salt sediments.

Fig. 4 The hydrograph of Sabzevar plain from 1978 to 2020

This bedrock is folded and protrudes in some parts of the plain center. The thickness of the alluvium reaches almost 300 m in the northwest of the plain, while it is less than 50 m in the central and southern areas, and only in the southeastern part, the aquifer is relatively suitable. The hydrodynamic coefficients of the aquifer in Sabzevar plain were obtained by testing the pumping of exploratory wells and the geophysical RT map. The coefficient of transferability varies from a minimum of 85 m²/day in the central area to a maximum of 3000 m²/day in the northwest alluvial fan of the plain, and the average storage coefficient is 5% (Maghfouri et al. 2017).

Figure 5 indicates the fluctuation of groundwater level in the basin of Sabzevar. After entering the data into the GIS using satellite images of the geological site (<https://earthexplorer.usgs.gov>), and creating a DEM map of the study area using the kriging method, a groundwater potential level map was obtained. The groundwater level of the eastern regions in the Sabzevar basin is different from that in the central and western regions. Therefore, the groundwater level in the eastern and southeastern regions is higher than that in the central areas. The reason for this rise can be related to agricultural lands and the discharge of agricultural and urban wastewater to these areas, as shown in Fig. 5, where the general direction of groundwater flow in this basin is from east to west.

Geology of the region

Aquifer's physical condition, bed mineralogy and climatic conditions are influenced by various factors such as rock weathering, vegetation. Figure 6 shows the geological map

Fig. 5 Groundwater level in the basin of Sabzevar

of Sabzevar basin. Sabzevar basin is geologically composed of ultrabasic to basaltic and semi-acidic igneous rocks of the upper cretaceous. The northern elevations of this basin are composed of harzburgite and dunite, while the southern elevations of the region are composed of andesite, tuff, diabase and granite. These igneous rocks, along with calcareous sediments, have disintegrated at different times under the influence of tectonic forces and formed colored mixtures. Also, a series of flysch sediments and destructive and evaporitic rocks have been widely developed in the southeastern areas of the basin. During the Neogene, a series of marls and gypsum marls and conglomerates with marl layers in the southeast of the basin were formed. The names of the stones in Sabzevar basin are shown in Table 2.

Results

Groundwater description

Table 3 shows the statistical analysis results for 11 studied characteristics and the maximum allowable limit for each of them, presented by the World Health Organization (Cotruvo 2017). The average TDS for Sabzevar plain is 4155 mg/L, showing that the groundwater is unsuitable for drinking (Cotruvo 2017). Water hardness (TH), caused by

the accumulation of salts due to the contact with geological formations (Patil and Patil 2011), is between 197 and 2846 mg/L with an average of 1077.5 mg/L, which is considered higher than the limit recommended by the WHO (Cotruvo 2017). The value of electrical conductivity is from 1812.4 to 12071.3 $\mu\text{S}/\text{cm}$ with an average of 6596.6 $\mu\text{S}/\text{cm}$, which is much higher than the allowable limit.

The analysis results show the range of pH changes, defined as the balance between the concentration of hydrogen ions and hydroxyl ions (Prasanth et al. 2012), is between 7.63 and 8.65 with an average of 8.05. Calcium concentration is 21.2–711.7 mg/L with an average of 230.4. According to Table 2, Magnesium concentration is between 29.72 and 711.7 mg/L with an average of 120.3 mg/L. Sodium concentration is 323.8 to 1966 mg/L with an average of 1003, from which groundwater is unsuitable for drinking (Cotruvo, 2017). The concentration of Chlorine, which is mainly sourced by the discharge of industrial wastewater, is between 320.92 and 3513.8 mg/L with an average of 1669.4, which is more than the allowable limit recommended by the standard (Cotruvo 2017). Bicarbonate concentration is 64.76–495.3 mg/L with an average of 197, which is lower than the limit recommended by Cotruvo (2017).

Furthermore, according to Table 3, the amount of Sulfate that increases as a result of discharge of industrial and

Fig. 6 Geological map in the basin of Sabzevar

domestic wastewater (Patil and Patil 2011), is between 219 and 1449 mg/L with an average of 850 mg/L, which is beyond the value recommended by Cotruvo (2017).

To measure the relationship between groundwater quality variables, the correlation coefficient, which is the interaction of two variables (Patil and Patil 2011), was calculated for Sabzevar area (Table 4). The highest positive correlations are between TDS and Cl ($R=0.991$), K and Cl ($R=0.967$), and Magnesium and electrical conductivity ($R=0.863$), respectively, which is in line with a study done by Magesh et al. (2013): The electrical conductivity and total hardness are controlled by the ions of Magnesium, Sodium, Calcium, Sulfate, and Potassium, and caused by the interaction and dissolution of natural processes such as rock–water. The results also showed that there is a strong significant positive correlation between SO_4 and EC, Mg and Na. It can also be stated that HCO_3 has a significant positive correlation with pH with a Pearson coefficient of 0.899, indicating that the carbonate content plays an important role in controlling the pH of water (Magesh et al. 2013). As shown in Table 4, TDS has a strong and significant positive correlation with Calcium, Magnesium, Sodium, Potassium, Chlorine and TH, which is consistent with the results by Patil and Patil (2011).

The pie chart of different parameters is shown in Fig. 7, which reveals that Cl^- is a dominant anion because of Cl^-

$> \text{SO}_4^{2-} > \text{HCO}_3^-$ (mg/L) and that Na^+ is a dominant cation based on $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$ (mg/L).

Based on the Schuler diagram shown in Fig. 8, none of the samples tested were suitable for drinking, because 62.5% SO_4^{2-} , 33.33% TH, 33.33% Cl^- , 50% Na^+ and 45.83% TDS in the results are over the limits. Higher TDS values are due to the longer time when groundwater is associated with the body of the aquifer and the presence of its salts (Selvam et al. 2013).

Piper diagram was introduced to describe water chemistry by Hill (1940) and Piper (1944). The Piper diagram applied in this study area is represented in Fig. 9, which shows the chemical properties of water based on the relative concentration of the constituent substance to the total solution. This rhombus-shaped complex is located in region 7, which means that non-carbonate alkali is more than 50% and is different from other alkalis and that strong acids are superior, indicating very high salinity of water. In this diagram, the right triangle shows the anions, and based on the data density, the strong acids are more than the weak acids, which are located in region 4. The left triangle represents the cations, the data densities show region 2, where the alkali is higher than the earth alkaline. The combination of the two

Table 2 The complete names of the stones in Sabzevar area

No	Description	No	Description
0	Low-level piedmont fan and valley terrace deposits	23	Light-red to brown marl and gypsiferous marl with sandstone intercalations
1	Harzburgite	24	Conglomerate and sandstone
2	Tectonic melange—association of ophiolitic components, pelagic limestone, radiolarian chert, and shale with or without Eocene sedimentary rocks (Colored Melange complex)	25	Gabbro to diorite, diorite and trondhjemite
3	Andesitic to basaltic volcanic tuff	26	Nummulitic limestone
4	Dacitic andesitic volcanic tuff	27	Red and green silty, gypsiferous marl, sandstone and gypsum (Lower Red FM)
5	Submarine, vesicular basalt, locally with pillow structure in association with radiolarian chert	28	Andesitic and basaltic volcanic rocks
6	Radiolarian chert and shale	29	Eocene flysch in general, composed of shale, marl, sandstone, conglomerate and limestone
7	Pelagic limestone, radiolarian chert and shale in association with basalt and basaltic andesite pillow lava	30	Andesitic volcanics
8	Serpentine	31	Globotruncal limestone
9	Basaltic volcanic rocks	32	Thick bedded to massive, white to pinkish orbitolina-bearing limestone (TIZKUH FM)
10	Spilitic rocks locally with pillow structure	33	Granite
11	Salt flat	34	Limestone, marl and sandstone
12	Polymictic conglomerate and sandstone	35	Red sandstone and shale with subordinate sandy limestone (DORUD FM)
13	High-level piedmont fan and valley terrace deposits	36	Albian—Cenomanian marl and argillaceous limestone
14	Gypsiferous marl	37	Marl, gypsiferous marl and limestone
15	Diabase	38	Nummulitic limestone
16	Rhyolitic to rhyodacitic subvolcanic	39	Stream channel, braided channel and flood plain deposits
17	Layered and isotropic gabbro	40	Red conglomerate and sandstone
18	Diorite	41	Conglomerate and sandstone
19	Granite to diorite	42	Marl, shale, sandstone and conglomerate
20	Clay flat	43	Pale-red, polygenic conglomerate and sandstone
21	Sandstone, calcareous sandstone and limestone	44	Fluvial conglomerate, Piedmont conglomerate and sandstone
22	Unconsolidated windblown sand deposit including sand dunes		

Table 3 Statistical analysis of the studied parameters of Sabzevar groundwater (2015–2019)

Characteristic	Unit	Minimum	Maximum	Mean	Std. deviation	Coefficient variation	WHO (2017)
TDS	mg/L	1141.8	7604.9	4155.9	2041.9	49.13	1000
TH	mg/L	197	2848.67	1077.5	795.3	73.809	500
EC	μS/cm	1812.4	12,071.3	6596.6	3241.1	49.13	1500
pH	–	7.63	8.65	8.049	0.268	3.32	7.5–8.5
Ca ²⁺	mg/L	21.2	711.7	230.4	205.6	89.21	75
Mg ²⁺	mg/L	29.72	358.6	120.3	90.08	74.85	30
Na ⁺	mg/L	323.8	1966	1003	396.9	39.59	200
K ⁺	mg/L	0	256.1	79.39	85.33	107.5	12
Cl [–]	mg/L	320.92	3513.8	1669.4	1038.3	62.19	200
HCO ₃ [–]	mg/L	64.76	495.3	197	112.4	57.06	300
SO ₄ ^{2–}	mg/L	219.8	1449	850.8	327.5	38.48	200

Table 4 Pearson correlation coefficient between different groundwater quality parameters (2015–2019)

	EC	TDS	pH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	TH
EC	1										
TDS	1.000**	1									
pH	-0.643**	-0.643**	1								
Ca ²⁺	0.819**	0.819**	-0.814**	1							
Mg ²⁺	0.863**	0.863**	-0.422*	0.590**	1						
Na ⁺	0.943**	0.943**	-0.505*	0.639**	0.760**	1					
K ⁺	0.961**	0.961**	-0.628**	0.805**	0.856**	0.877**	1				
HCO ₃ ⁻	-0.542**	-0.542**	0.899**	-0.656**	-0.325	-0.464*	-0.531**	1			
Cl ⁻	0.991**	0.991**	-0.704**	0.841**	0.853**	0.921**	0.967**	-0.595**	1		
SO ₄ ²⁻	0.812**	0.812**	-0.385	0.581**	0.689**	0.826**	0.728**	-0.397	0.740**	1	
TH	0.916**	0.916**	-0.764**	0.963**	0.786**	0.744**	0.903**	-0.611**	0.929**	0.676**	1

*Denotes significant differences at 95% level

right and left triangles, which shows the total community of water, is located in the upper rhombus.

Figure 10 shows the Wilcox diagram for groundwater samples from wells in the Sabzevar plain. Figure 10 reveals that 4.17% of the groundwater samples are in C3S3 class with moderate salinity and alkalinity. Furthermore, 8.33% of the samples are in C4S3 class and 87.5% are in C4S4 class, which have a lot of salinity and alkalinity for agricultural use.

Figure 11 shows the distribution of each studied quality parameter in the groundwater of Sabzevar plain. In each map, the distribution of each groundwater quality parameter in Sabzevar city was examined.

As seen in Fig. 11a, the highest values of solid particles (TDS) in the water are located in the middle part of this plain, while the lowest values of TDS are located in the western part of the plain. The TDS has an average of 4155.9 mg/L with a standard deviation of 2041.9 mg/L (Table 3). Since the standard of TDS given by the WHO (2017) is 1000 mg/L, the amount of TDS in the groundwater of this plain is twice its allowable limit.

Another parameter investigated is the total hardness (TH) shown in Fig. 11b. The higher values of TH are seen in the central and southern regions of this plain, whereas the lower values are seen in the western and northern regions. The average TH of groundwater in this plain is 1077.5 mg/L with a standard deviation of 795.3 mg/L. According to the allowable limit 500 mg/L of TH for drinking water by the WHO, the water in the study region is not suitable for drinking. Dissolution of formations with saline and gypsum in Sabzevar plain has increased salinity, TDS and TH.

Figure 11c reveals that the higher values of electrical conductivity (EC) are in the central area whereas the lower values are in the western parts of the plain. The average of EC is 6596.6 μ S/cm with a standard deviation of 3241.1 μ S/cm. According to the standard value (1500 μ S/cm) for the

Fig. 7 Pie chart for different groundwater quality parameters

electrical conductivity of drinking water provided by the WHO (2017), the average EC of groundwater in this plain is much higher than the allowed limit, hence suggesting the groundwater is not suitable for drinking. The electrical conductivity (EC) of groundwater increases with a raise in amounts of Sulfate, Chloride, Sodium, Potassium, Calcium and Magnesium. Due to the rising of bedrock in the southern part, the EC of groundwater in this region is much more than in the northern areas.

The maximum pH values are located in the northern to northwestern regions of the Sabzevar plain and its minimum values are in the central, southern and parts of the southeastern regions (Fig. 11d). Geological and biological factors can have some effects on pH of groundwater (Qishlaqi et al. 2017) that the average of pH in this area is 8.049 with a standard deviation of 0.268, which indicates that the

Fig. 8 Schuler diagram of different groundwater quality parameters

Fig. 9 Piper diagram of different groundwater quality parameters

samples studied in this study are alkaline. The WHO (2017) suggests a maximum limit of 7.5–8.5 for this parameter, so the groundwater in Sabzevar plain is suitable in terms of pH, because its average of pH is within the suggested range.

Calcium (Ca) is another ion which was studied in this study. Figure 11e shows that the higher concentration of calcium is in the central and southern regions whilst the

lower amount of calcium is located in the northern and western regions. The average concentration of Calcium in the groundwater of this plain is 230.4 mg/L with a standard deviation of 205.6 mg/L. The WHO (2017) stated that 75 mg/L is the allowable limit for calcium. Therefore, the concentration of Calcium in the groundwater of Sabzevar plain is very high. The high concentration of this ion in this

Fig. 10 Wilcox diagram for groundwater samples of wells in the Sabzevar plain

study can be related to the weathering of calcite and dolomite (Honarbakhsh et al. 2019), because the dissolution of limestone, gypsum and dolomite is the main source of this ion (Qishlaqi et al. 2017).

The Magnesium distribution in this plain is given in Fig. 11f, which shows that the higher amounts of Magnesium are located in the central and eastern regions, whereas the lower values of Magnesium are located in the western regions of the plain. Sources of magnesium ions are found in limestone aquifers.

The average concentration of Magnesium in the groundwater is 120.3 mg/L with a standard deviation of 90.08 mg/L. The WHO (2017) has reported that a permissible concentration of this ion for drinking water is 30 mg/L, which implies that the groundwater in the region is not appropriate with respect to the content of Magnesium.

Sodium is another characteristic studied in this study. The Sodium distribution of the groundwater in Sabzevar plain is

shown in Fig. 11g. The higher value of Sodium is in the central areas, whereas its lower value is in the western areas of this plain. The statistical analysis results show that the average of Sodium in the groundwater of the plain is 1003 mg/L with a standard deviation of 396.9 mg/L. The high concentration of this ion can be related to the weathering of salt domes and the process of evapotranspiration in Sabzevar plain (Honarbakhsh et al. 2019). The WHO (2017) has suggested a maximum concentration 200 mg/L of Sodium for drinking water. In this regard, the groundwater of this plain is almost five times more than the recommended limit, so it is not appropriate for use of drinking water.

In Fig. 11h, the Potassium content in the central and southern parts of Sabzevar plain are higher than in the western parts of this plain. The average concentration of Potassium is 79.12 mg/L with a standard deviation of 85.33 mg/L. The maximum allowable amount of Potassium for drinking water is 12 mg/L as reported by the WHO (2017), which is much

Fig. 11 Map of groundwater quality parameters in Sabzevar city

Fig. 11 (continued)

lower than the average value in this region, indicating that the groundwater in this plain is not usable for drinking water.

Figure 11i shows that the concentration values of Chlorine are higher in the central and southern regions but lower in the western regions of the study plain. The average of Chlorine is 1669.4 mg/L with a standard deviation of 1038.3 mg/L, which is much higher than the maximum allowable amount 200 mg/L for drinking water, which inferred the high concentration of this ion is in such a way that the dissolution of gypsum and halite increased the chloride (Mallick et al. 2018). Therefore, the groundwater of Sabzevar plain is not suitable for the use of drinking water.

Figure 11j shows the distribution of Bicarbonate in the plain. Higher values of Bicarbonate are observed in the northern and northwestern regions of this plain in contrast with the lower values of Bicarbonate in the central and southern regions of this plain. The study showed that the average of bicarbonate in the groundwater of this plain is 197 mg/L with a standard deviation of 112.4 mg/L. According to the standard of 200 mg/L for drinking water provided by the WHO, the groundwater quality in the study plain is acceptable with regards to this characteristic.

Finally, the distribution of Sulfate concentration of groundwater is shown in Fig. 11k, which reveals that its higher values are in the central and eastern parts of the plain, while the lower values are in the western parts. The average of Sulfate is 850.8 mg/L with a standard deviation of 327.5 mg/L. The Sulfate level in the plain is much higher than the maximum allowable concentration 200 mg/L suggested by the WHO (2017), indicating that the groundwater in the plain is not appropriate for use. This result can be related to the discharge of industrial and agricultural effluents in the Sabzevar plain.

Conclusion

In the present study, 24 groundwater samples were collected for evaluating the groundwater quality from Sabzevar plain, which is located in a semi-arid region of Iran. Analyses were performed to evaluate physicochemical processes on water quality for drinking and agricultural uses. To evaluate the hydrochemical parameters, various maps of groundwater quality were generated based on GIS software. Pie and Schuler diagrams show that Chlorine is the predominant anion, while sodium cation is predominant in the study area. The Wilcox diagram shows that in the study area only 4.17% of the groundwater samples are in C3S3 class which have moderate salinity and alkalinity, and 8.33% of the samples are in C4S3 class and 87.5% are in C4S4 class which have salinity risk and a lot of alkali. Groundwater quality parameter maps in Sabzevar area show that groundwater quality is low in the central parts of the aquifer.

The results showed that most of the samples studied are not suitable for drinking water and agricultural uses based on the standard by the WHO (2017). In general, the groundwater in the study area indicated high alkalinity and salinity. The results of the present study imply the importance and necessity of implementing groundwater resources management to reduce pollution and prevent its spread in this area. Furthermore, based on the results of the Wilcox diagram, the large percentage of water samples is in the C4S4 class, which suggests that the groundwater would be used for agricultural purposes to salinity-resistant plants. Meanwhile, the results of Schuler diagram suggested that new methods for water treatment are needed for drinking purposes in this region.

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