ORIGINAL ARTICLE

An assessment of the effects of excessive groundwater abstraction on the quality of groundwater resources of the Zanjan Plain, Iran

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Abstract

In the present study, the quality of groundwater and the effects of pumping on the phreatic surface beneath the Zanjan Plain located in northwestern Iran were investigated by measuring water levels in 81 observation wells as well as various physico-chemical parameters including electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH) and pH. In addition, the results of the chemical analysis of major anions and cations from 53 boreholes that were sampled during the period 2004–2018 were evaluated. The water level measurements indicated that the elevation of the phreatic surface had declined by up to about 8 m during the studied period, indicating an average decrease of about 0.57 m per year. A comparison of the measured physicochemical parameters with WHO, ISIRI, and EPA standards for drinking water quality showed that some parameters including EC, TDS, TH, SO_4, and Cl in the northwestern and central parts of the plain exceeded the allowable level. An assessment of water quality index (WQI) values showed that most parts of the Zanjan Plain lie in the "good" quality class, although in some parts, the water quality of "poor" quality class, most likely due to the effects of urban activities. A comparison of the results from a Schoeller diagram assessment with WQI values showed some differences between the results of the qualitative classification of some parts of the Zanjan Plain groundwater based on the two mentioned methods. The results of the present study showed that groundwater of some areas of the Zanjan Plain is not suitable to be used for irrigation of agricultural lands with limited drainage. The Piper diagram also indicated that the dominant groundwater quality facies on the Zanjan Plain were $Ca–Na–HCO_3$ and $Ca–HCO_3$ water types. The results of the Spearman correlation analysis also showed a high correlation of most anions with cations. Analysis of the volume changes versus qualitative changes in groundwater also showed a general decreasing trend of water quality with decreases in the volume of groundwater in storage in the aquifer, although in some conditions due to changes in solubility of water-soluble materials because of the changes in groundwater level, other trends were also observed.

Keywords Groundwater table · Zanjan Plain · Water level fluctuations · Water quality · Water quality index

Introduction

With the increasing population and technology development, human need for water in various applications such as drinking, agriculture, and industry has greatly increased. On the other hand, due to the scarcity of surface water resources in most parts of the world, groundwater resources have become increasingly important sources of water to meet human needs. Water withdrawal from groundwater resources has increased in many parts of the world in recent decades, especially in hot and dry areas. The large increases in groundwater withdrawals combined with the impacts of human land uses have decreased both the availability and the quality of groundwater resources (Jamshidzadeh and Mirbagheri 2011; Naghipour et al. 2018; Adimalla and Qian 2019; Beyene et al. 2019; Chande and Mayo 2019; Salman et al. 2019; Shakerkhatibi et al. 2019). Additionally, groundwater use in some areas has caused other problems such as the formation of sinkholes and land subsidence (Salvati and Sasowsky 2002; Heidari et al. 2011). Therefore, it is important that management measures are implemented to prevent and control the decreasing quantity and quality of groundwater resources.

This is particularly the case in Iran, which with an average annual rainfall of 250 mm, (or less than one-third of the

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global average annual rainfall), is considered to be one of the regions with the least rainfall in the world (Baghvand et al. 2010). Due to the uneven rainfall distribution in different parts of Iran, many parts of the country (particularly in the center of the country) face rainfall deficits. These factors together with a lack of surface water resources mean that groundwater is the dominant source of water to meet the country's demands.

The presence of different gypsum and evaporate minerals in sediments that are being affected by increasing groundwater draw-off in parts of central Iran has caused significant adverse impacts on groundwater quality in the region (Baghvand et al. 2010; Jamshidzadeh and Mirbagheri 2011; Sadat-Noori et al. 2014; Ebrahimi et al. 2016). Additionally, in areas with more rainfall, such as the northwestern areas of the country, the intense groundwater withdrawal for agricultural and industrial activities has also reduced groundwater availability and quality in these areas (Azizi et al. 2019; Shakerkhatibi et al. 2019).

The changes in the quality of groundwater resources due to exploitation have been evaluated by some researchers. MacDonald et al. (2016) studied the impacts of over-abstraction from the transboundary Indo-Gangetic Basin on the quality of groundwater systems in Pakistan, India, Nepal, and Bangladesh with satellite gravity data. Zhang et al. (2017) showed that increasing groundwater abstraction along with anthropogenic pollution and infiltration of saline seawater in the Arabia Peninsula are the main reasons that influence the quality of groundwater in this area. Shaji et al. (2018) showed that excessive use of fertilizers and abstraction of groundwater in the Palakkad district, Kerala decreased groundwater quality and by increasing the volume of abstraction, the concentration of nitrate would also increase. Evaluation of the effect of excessive exploitation on the groundwater quality by geostatistical analysis of electrical conductivity (EC) and sodium adsorption ratio (SAR) during pre-monsoon and post-monsoon seasons in a region in Pakistan was done by Farid et al. (2019). El Osta et al. (2020) investigated groundwater quality in Nubian Sandstone Aquifer which was affected by excessive groundwater abstraction using multiple methods such as the Water Quality Index (WQI) and a simple geochemical model (NET-PATH). Putranto et al. (2020) analyzed the risk assessment of groundwater vulnerability due to the exploitation of groundwater resources in the Salatiga basin, Indonesia, and classified it into low, moderate, and high classes.

As excessive groundwater abstraction can cause adverse impacts on groundwater quality, it is important that a variety of hydrogeochemical assessment tools are used to assess the effects of groundwater use in one of the most intensively pumped aquifers in Iran. This has been done in the present study and for this purpose, different qualitative methods were used.

Materials and methods

Study area

Zanjan province is located in the northwest of Iran (Fig. 1). This province has an area of more than 21,773 km^2 and a population of about one million. The climate in the province is cold and dry during the winter and temperate during the summer. The province has an average annual rainfall of 330–360 mm, which mostly falls in the months of March to mid-May. Zanjan Plain, with an eastern longitude of 47°51′–49°00′ and a northern latitude of 36°20′–37°00′, is located in the northern part of the province (Fig. 1). The total area of the Zanjan Plain is 4705 km^2, of which 1667 km^2 consist of low-lying land near the Zanjanrood River margin and 3038 km^2 comprises areas with gentle to steep slopes.

The topographic study of the Zanjan Plain depicted that the heights in the southeastern and some northern parts of the plain had the highest elevation of about 2000 m above sea level and by moving to the central and northwestern parts of the plain, the topographic elevation decreased
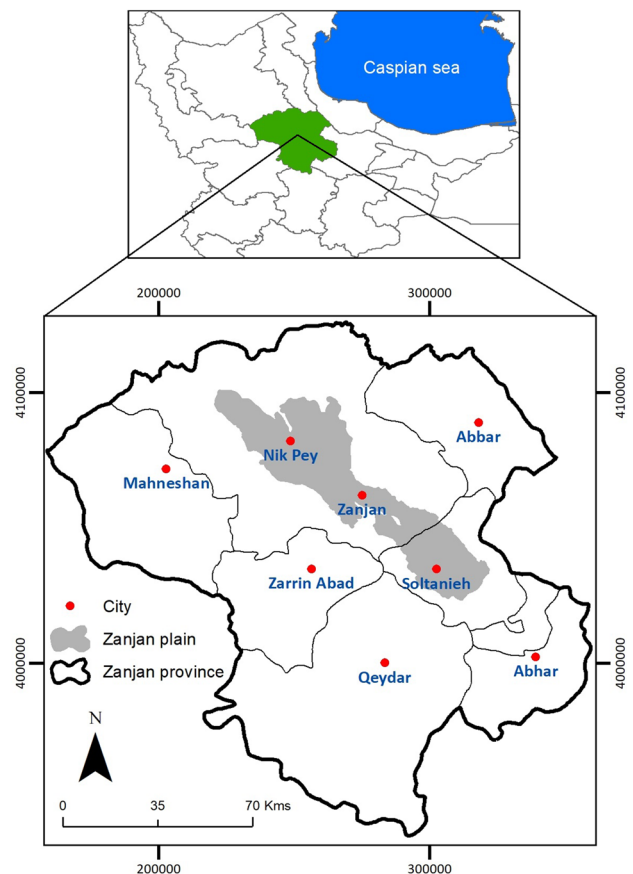

Fig. 1 Location of the Zanjan Plain, Zanjan Province, Iran

gradually. The lowest elevation of 1400 m above sea level was in the northwestern part of the plain. These circumstances revealed that the topographic slope was mainly in a southeast–northwest direction in the Zanjanrood River as the thalweg of the Zanjan Plain and from the surrounding mountains to the Zanjanrood River.

The Zanjan Plain is underlain by a sequence of alluvial sediments and river terraces in different thicknesses which are up to 500 m near the Soltanieh city and are decreasing gradually in the central and northern parts of the plain. Sediment granulation in the southern part consists of coarse-grained sediments including rubble and gravel in foothills and fine-grained ones along the Zanjanrood River. Additionally, the northern parts of the area are dominated by fine-grained sediments including silt and clay, i.e., no good aquifer in these areas. The Zanjan Plain aquifer is recharged by precipitation, melting of snow, and rivers in rainy seasons.

Zanjan Plain has a variety of agricultural activities due to the suitable weather conditions, the presence of fertile soils and due to its accessibility through major roads, rail, and through an airport. Consequently, about 72% of the Zanjan Plain area is occupied by both irrigated and rainfed agricultural land uses (Fig. 2). Most of the irrigation uses pumped groundwater from beneath the plain. However, a limited part of the farms uses surface water resources such as rivers and streams, which also play an important role in feeding groundwater aquifers in the Zanjan Plain. About 60% of the farms are rainfed, though not directly using groundwater, but prevent much of the water from penetrating deep into the ground and recharging the aquifer.
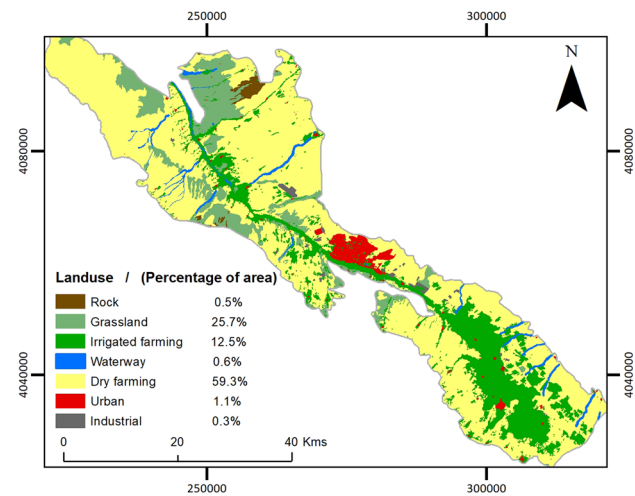
Data collection

To measure groundwater level and concentration of physicochemical parameters including pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), major cations (K^+, Na^+, Mg^{+2}, and Ca^{+2}) and major anions (Cl^-, HCO_3^-, CO_3^{2-}, and SO_4^{2-}), 81 observation wells were constructed by the Zanjan Regional Water Company and 53 existing sampling wells were used, respectively. The depth of the wells was about 100 m (Fig. 3). The groundwater levels were determined using an on-site water level measuring device. In addition, physicochemical parameters of groundwater were determined by sampling wells using a cylindrical sampler with the corresponding cable and performing laboratory tests based on the standard analysis methods (APHA 2017) (Table 1) during the period 2004–2018.
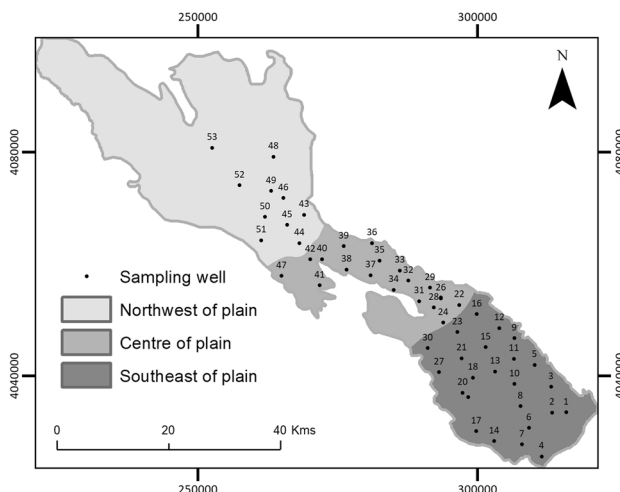

Fig. 3 Location of sampling wells in the Zanjan Plain

Table 1 Methods and equipment used for measuring different qualitative parameters from the samples

Parameters	Method used
EC	2510-B
TDS	2540-C
TH	2340-C
pH	4500-H^+B
Ca^{+2}, Mg^{+2}, Na^+, K^+	3500-Ca, 3500-Mg, 3500-NaD, 3500-KD
Cl^-, HCO_3^-, CO_3^{2-}, SO_4^{2-}	4500-Cl, 2320-B, 2320-B, 4500-SO_4B

Fig. 2 Land use map of the Zanjan Plain

Data analysis methods

Water quality index

Water quality standards are not suitable for the full evaluation of the water quality because they only indicate maximum allowable or desirable values, while a (range) floating state for water quality evaluation can give more reasonable results (Chaturvedi et al. 2018). The Water Quality Index (WQI) is a good method for evaluation of water quality that can reduce a large amount information about the chemical properties of a water sample into a single variable (Adimalla and Qian 2019). This index has been used for the evaluation of groundwater quality in many areas (Sadat-Noori et al. 2014; Adimalla and Qian 2019; Verma et al. 2020). The index was first proposed by Horton (1965) and is calculated using Eq. (1):

$$WQI = \sum SI_i, \tag{1}$$

where SI_i is calculated using Eq. (2):

$$SI = W_i \times q_i, \tag{2}$$

where W_i is the relative weight of each parameter and q_i is the water quality class, which are obtained using Eqs. (3) and (4):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i}, \tag{3}$$

$$q_i = \frac{C_i}{S_i} \times 100, \tag{4}$$

where w_i is the weight assigned to each parameter based on its influence on water quality, ranging from 1 (the minimum weight) to 5 (the maximum weight), C_i is the value of the measured parameter, and S_i is the parameter value in the standard state and n is the number of parameters. The Water Quality Index classifies water into five classes of "excellent" to "unsuitable" (unfit) for drinking purposes, as shown in Table 2.

EC, TDS, and TH are considered to have the maximum influence on water quality in the Zanjan Plain, with the maximum assigned weight of 5. Weights in the range of 2–4 were assigned to other chemical parameters such as SO_4, pH, and Cl considering their influence on the quality of drinking water, as shown in Table 3.

Results and discussion

Quantitative changes in groundwater table

Groundwater elevation contours for the aquifer beneath the Zanjan Plain in 2018 are shown in Fig. 4. As can be seen from Fig. 4, the direction of groundwater flow beneath the Zanjan Plain is mainly in a southeast–northwest direction with some localized flow from the north to the northwest.

The temporal changes of the average water depth in the Zanjan Plain wells from 2004 to 2018 are shown in Fig. 5. As can be seen from Fig. 5, the average water depth in the Zanjan Plain wells has increased from 44.2 m in 2004 to 52.2 m in 2018. Generally, groundwater level in the Zanjan Plain has decreased by about 8.00 m over 14 years. In

Table 3 Assigned weight and relative weight of the chemical parameters in the Zanjan Plain

Parameters	WHO standard	Weight (w_i)	Relative weight (W_i)
EC	1500	5	0.208
TDS	1000	5	0.208
TH	500	5	0.208
SO$_4$	250	4	0.166
pH	6.5–8.5	3	0.125
Cl	250	2	0.083
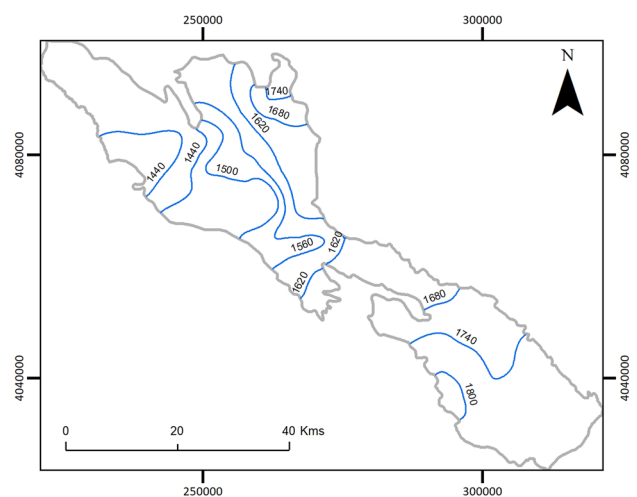
Fig. 4 Groundwater table elevation contours of the Zanjan Plain (2018)

Table 2 Water quality classification considering the water quality index

Type of water	WQI range
Excellent	< 50
Good	50–100
Poor	100–200
Very poor	200–300
Unsuitable (unfit) for drinking	> 300
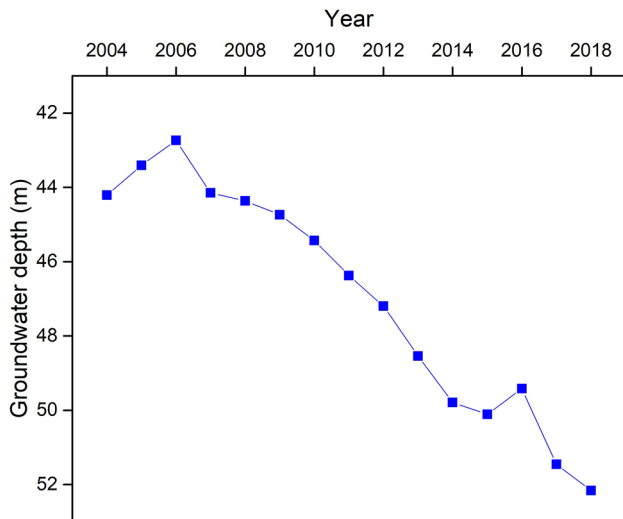
Fig. 5 Average depth of the wells in the Zanjan Plain (2004–2018)

Fig. 6 Number of water draw-off wells in the Zanjan Plain (2004–2018)

Fig. 7 Water draw-off from the Zanjan Plain aquifer (2004–2018)

Fig. 8 Groundwater applications in the Zanjan Plain

other words, an average phreatic decline of 0.57 m per year has occurred in the Zanjan Plain wells. During the studied period, the annual rainfall has fluctuated several times; whereas, generally, no significant decline was observed. Therefore, the decrease in the groundwater table was mainly due to an increase in the number of wells (Fig. 6) as well as the annual rate of groundwater abstraction from different parts of the Zanjan Plain aquifer (Fig. 7).

Figure 8 shows the proportion of groundwater that is used for drinking, industrial and agricultural uses in the Zanjan Plain and indicates that most of the groundwater abstraction (78%) is used for agricultural purposes. The groundwater abstraction has caused average annual decreases in water
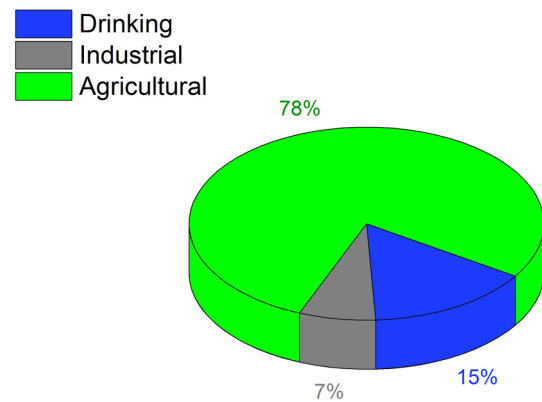
levels in the northwestern, central, and southeastern parts of the plain of 0.26, 1.02, and 1.18 m, respectively, during the mentioned period (Fig. 9). A land-use map of the Zanjan Plain (Fig. 2) indicates that the southeastern part of the plain which has the greatest water table decline also has the highest density of irrigated agricultural lands.

Groundwater quality changes

Groundwater quality parameters measured in the northwestern, central, and southeastern parts of the Zanjan Plain are shown in Table 4. As can be seen from Table 4, groundwater in the southeastern part of the plain generally meets the relevant water quality standards. However, in the central and northwestern parts of the Zanjan Plain and near the Zanjan city, water quality parameters including EC, TDS, TH, SO_4, and Cl exceed the maximum allowable standards. This is attributed to the fact that the groundwater in this area is
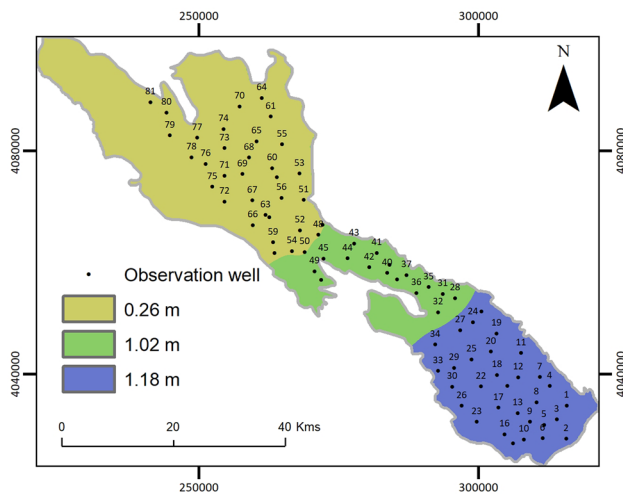
Fig. 9 Average annual phreatic decline in the southeastern, central and northwestern parts of the Zanjan Plain

influenced by urban activities, as well as the fine-grained characteristics of aquifer sediments in this area.

Spatial distribution of groundwater quality parameters

EC

The electrical conductivity indicates the concentration of ionized elements in water, with a maximum allowable standard value of 1500 µs/cm (WHO 2017). Accordingly, 92% of the Zanjan Plain wells had EC less than the maximum allowable value. As can be seen from Fig. 10, wells No. 43, 44, 47, and 51 located in the central and northwestern parts of the plain had EC values greater than the allowable limit.

TDS

The measured TDS values in the Zanjan Plain groundwater in most wells located in central and southeastern parts of the plain were less than 600 mg/l indicating a good water quality according to (WHO 2017). According to this standard, water with a TDS value of more than 1000 mg/l is considered unsuitable for drinking. Hence, 94% of the sampling wells had allowable TDS range, and only wells No. 44, 47, and 51 located in the central and northwestern parts of the Zanjan Plain had TDS values greater than the allowable limit (Fig. 10).

Table 4 Average physicochemical parameters in the Zanjan Plain (2004–2018)

| Region	pH	EC (µs/cm)	TDS (mg/l)	TH (mg/l)	Cation (mg/l)				Anion (mg/l)			
					Na	Mg	K	Ca	SO$_4$	Cl	CO$_3$	HCO$_3$
Northwest of plain												
Mean	7.6	1113	688	368	83	36	3.1	87	223	102	0.2	168
Max	7.9	2058	1216	750	167	90	5.5	152	457	279	2.4	277
Min	6.9	236	148	88	14	6	0.4	25	21	9	0	100
Center of plain												
Mean	7.6	807	510	254	69	23	2.8	64	152	46	2	197
Max	7.8	1253	1095	465	183	57	4.7	97	499	105	8.7	321
Min	7.2	443	273	134	29	12	0.8	34	42	15	0	134
Southeast of plain												
Mean	7.7	624	391	190	57	23	2.3	39	84	31	2.5	218
Max	7.9	1140	719	280	134	44	4.7	63	247	81	14.1	282
Min	7.5	332	203	108	22	10	1.2	18	21	13	0	141
Water quality criteria (drinking water quality)												
WHO (2017)	6.5–8.5	1500	1000	500	200	–	–	–	250	250	–	–
ISIRI (2009) (max desirable)	6.5–8.5	–	1000	200	200	30	–	300	250	250	–	–
ISIRI (2009) (max allowable)	6.5–9.0	–	1500	500	250	–	–	–	400	400	–	–
EPA (2018) (MCL)	6.5–8.5	–	500	–	–	–	–	–	250	250	–	–
Acceptance percentage of samples (WHO)	100%	92%	94%	94%	100%	–	–	–	86%	98%	–	–
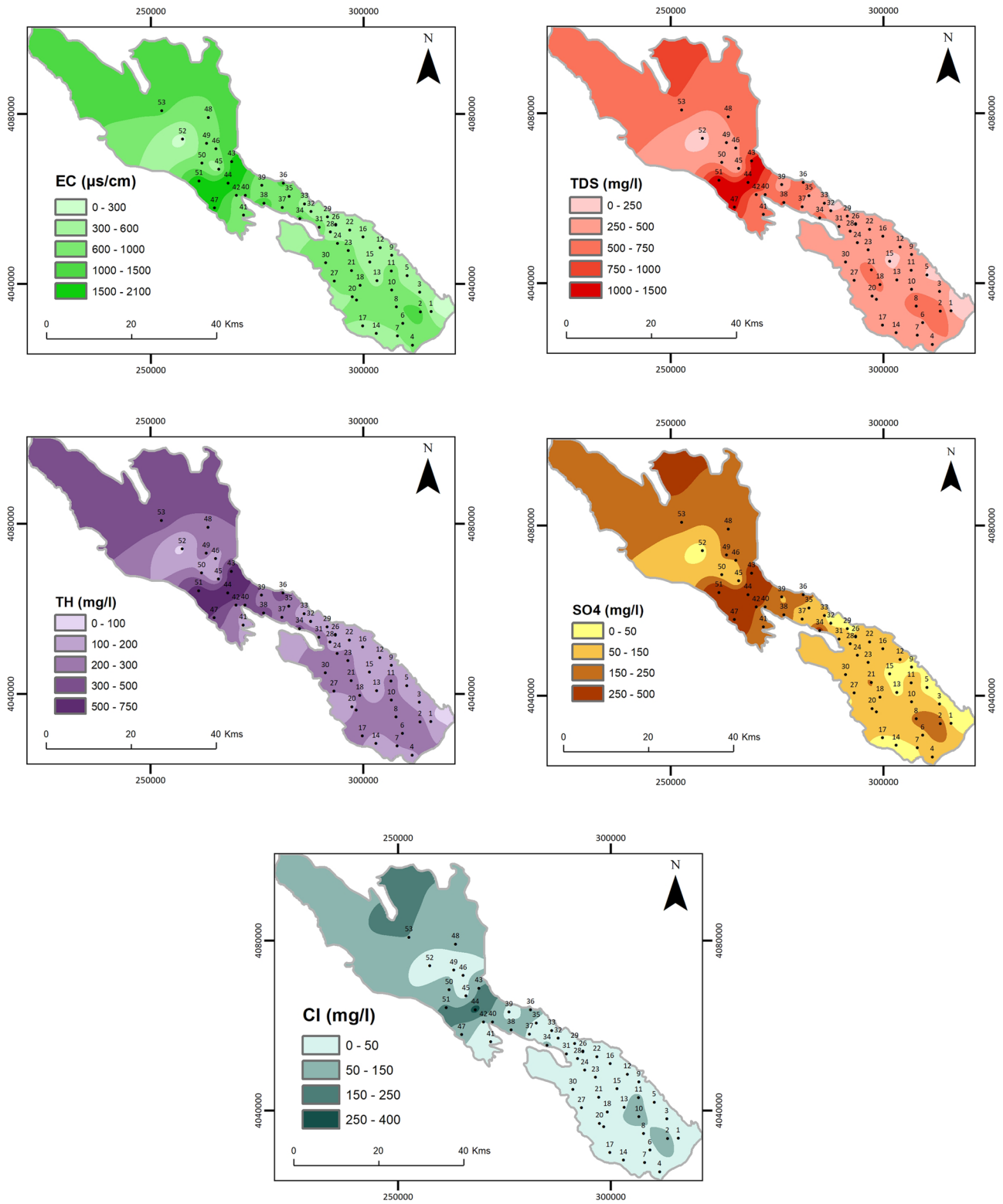
Fig. 10 Spatial changes of EC, TDS, TH, SO$_4$ and Cl in the Zanjan Plain

TH

Hardness in water is due to the variety of multivalent soluble metal ions, especially calcium and magnesium cations, and is considered a traditional measure for measuring water capacity to react with soap. In other words, the higher the water hardness, the greater the amount of soap needed to produce foam (WHO 2017). Water hardness also plays an important role in human heart disease (Jamshidzadeh and Mirbagheri 2011). The range of calcium ions is 100–300 mg/l to meet the taste limit. This limit for magnesium ions is lower, however, in some cases, consumers withstand water hardness above 500 mg/l (WHO 2017). In the Zanjan Plain, 94% of samples had hardness less than the maximum allowable standard (WHO 2017), while according to the ISIRI (2009) standard, 43% of samples lie in the desirable range. Wells No. 43, 44, and 51 in the northwestern part of the plain have a hardness greater than the maximum allowable limit according to (WHO 2017) (Fig. 10).

Sulfate

According to the WHO (2017) and ISIRI (2009) standards, the concentration of the sulfate ions should not exceed 250 mg/l to prevent unsuitable tastes in water. However, according to the ISIRI (2009) standard, a maximum allowable concentration of sulfate ion (SO_4) of 400 mg/l is also tolerable for drinking purposes. The range of sulfate ion concentrations in the plain was 21–499 mg/l. The lowest sulfate concentrations were measured in wells in the southeastern part of the Zanjan Plain where no wells exceeded the recommended drinking water limit (WHO 2017). Sulfate concentrations were generally higher in groundwater in the central and northwestern parts of the plain, with wells No. 34, 42, and 47 in the central part of the area and wells No. 43, 44, and 51 in the northwestern part of the area exceeded the WHO standards. Generally, 86% and 94% of the plain wells had good quality according to the WHO (2017) and the ISIRI (2009) standards, respectively. The spatial distribution of sulfate in groundwater is shown in Fig. 10.

Chloride

The recommended drinking water limit for chloride concentrations is 250 mg/l (WHO 2017). In the Zanjan Plain, most wells met the drinking water standard for chloride (Fig. 10). The exception to this was well No. 44 located in the northwestern part of the area which had a chloride concentration of 279 mg/l.
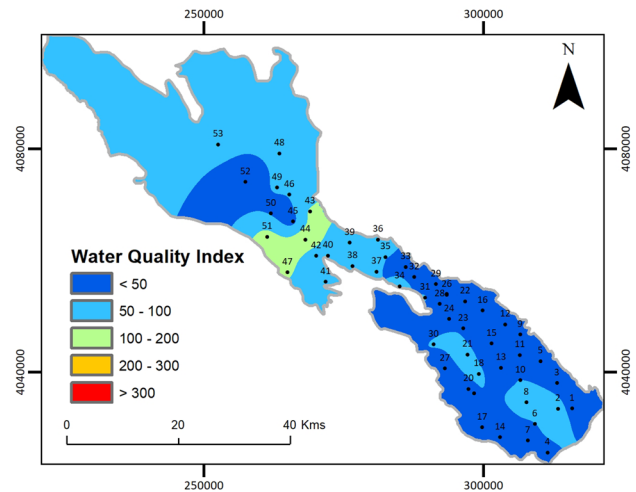

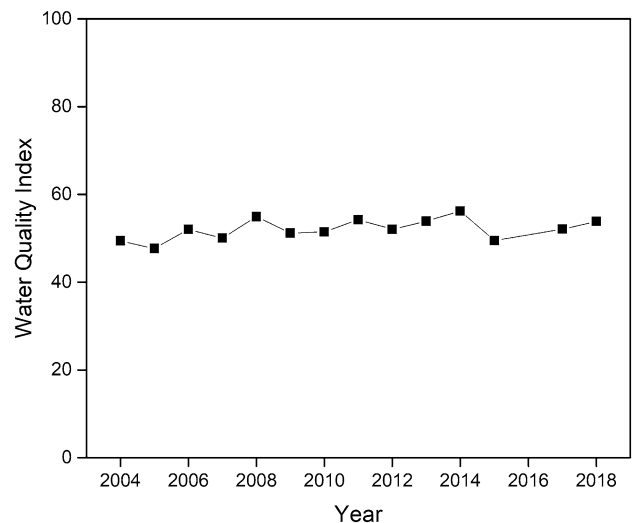**Fig. 11** Groundwater condition of the Zanjan Plain wells using the WQI

Fig. 12 Spatial changes in WQI (2004–2018)

Groundwater evaluation using the water quality index (WQI)

The evaluation of groundwater quality using the WQI showed that wells in southeastern and central parts of the Zanjan Plain lie in the "good" and "excellent" quality classes, and that some wells in the central and northwestern areas lie in the "poor" quality class due to high EC, TDS and TH values (Fig. 11), which is mainly attributed to the negative effect of urban and industrial activities of the Zanjan city. The average WQI values for the southeastern, central, and northwestern parts of the plain were 43, 55, and 74 indicating generally "good" water quality throughout the plain. Figure 12 shows the changes in the WQI from 2004 to 2018. As can be seen from Fig. 12, water quality has fluctuated

over a period of 14 years but has always been in the "good" quality class.

Schoeller diagram

Schoeller (1965) developed a diagram that utilized the physicochemical parameters to simply indicate the suitability of the water quality for drinking purposes, which has been used by many researchers (Babanezhad et al. 2018; Sunkari et al. 2019; Fallahati et al. 2020). Using this diagram, the southeastern and central parts of the Zanjan Plain were found to lie in the "good" range and the northwestern part of the plain lied in the "acceptable" range for drinking water use. Generally, it can be concluded from the use of the Schoeller diagram that, on average, groundwater quality of the Zanjan Plain lies in the "good" quality class (Fig. 13). Comparison of the water quality classification results of different parts of the plain using the Schoeller diagram and WQI showed that the northwestern part of the plain would be considered to have a "good" condition in terms of the WQI, but the Schoeller diagram indicated that water quality in this area would be classified in the "acceptable" range.

Wilcox diagram

In addition to evaluation of the quality of water for drinking, considering the widespread use of groundwater resources for agricultural use in the Zanjan Plain, it is also important to evaluate the quality of water for agricultural use. For this purpose, the Wilcox (1955) diagram is generally used.

This diagram classifies the suitability of water for irrigation purposes using the EC and sodium adsorption ratio (SAR) parameters (Iqbal et al. 2018; Barik and Pattanayak 2019; Beyene et al. 2019; Owoyemi et al. 2019). Considering the obtained values for the EC and SAR parameters in the Zanjan Plain (Fig. 14), most of the samples plotted in the C2-S1 area on the Wilcox diagram which indicated that groundwater in the region was generally suitable for irrigation use. In addition, some samples of the central and northwestern parts of the plain plotted in the C3-S1 area of the Wilcox diagram, indicating that the relatively high water salinity in these areas was classified as being in the "medium" water quality class, and unsuitable for the irrigation of the soils with limited drainage (Liu et al. 2020).

Piper diagram

The Piper diagram is a tool for determining the water hydrochemical facies from the relative proportions of major ions in water samples (Piper 1944). Using this diagram, the cations of most groundwater samples from the Zanjan Plain were found to plot in the calcium and sodium–potassium range. Additionally, the anions in most of the samples plotted in the carbonate-bicarbonate field, although some of the samples plotted in the sulfate field (Fig. 15). By fitting the obtained data from measuring the physicochemical parameters of the samples, it was found that the dominant facies in groundwater in the plain were $Ca–Na–HCO_3$ and $Ca–HCO_3$.
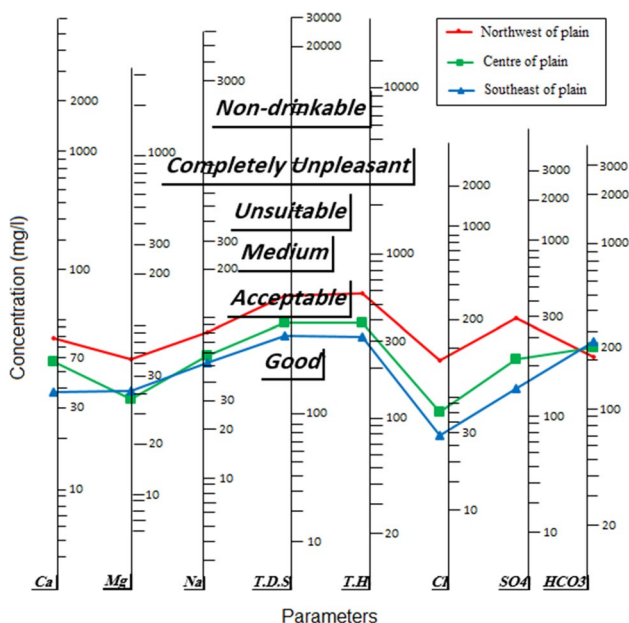

Fig. 13 Groundwater classification of the northwestern, central, and southeastern parts of the Zanjan Plain using a Schoeller diagram
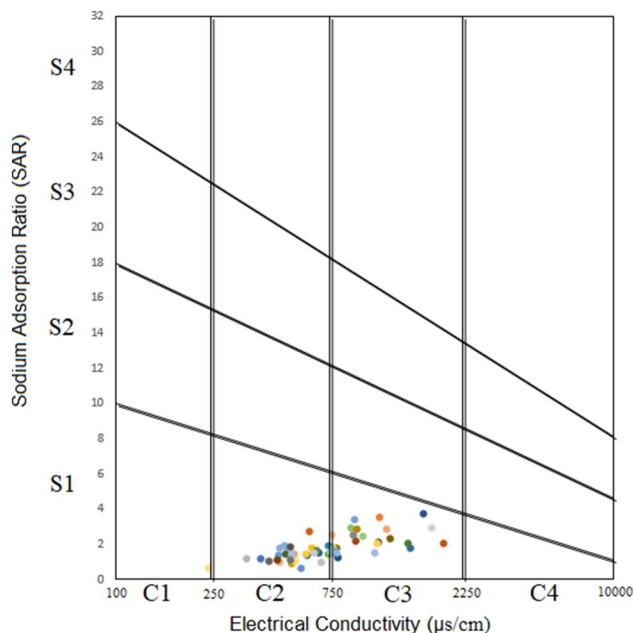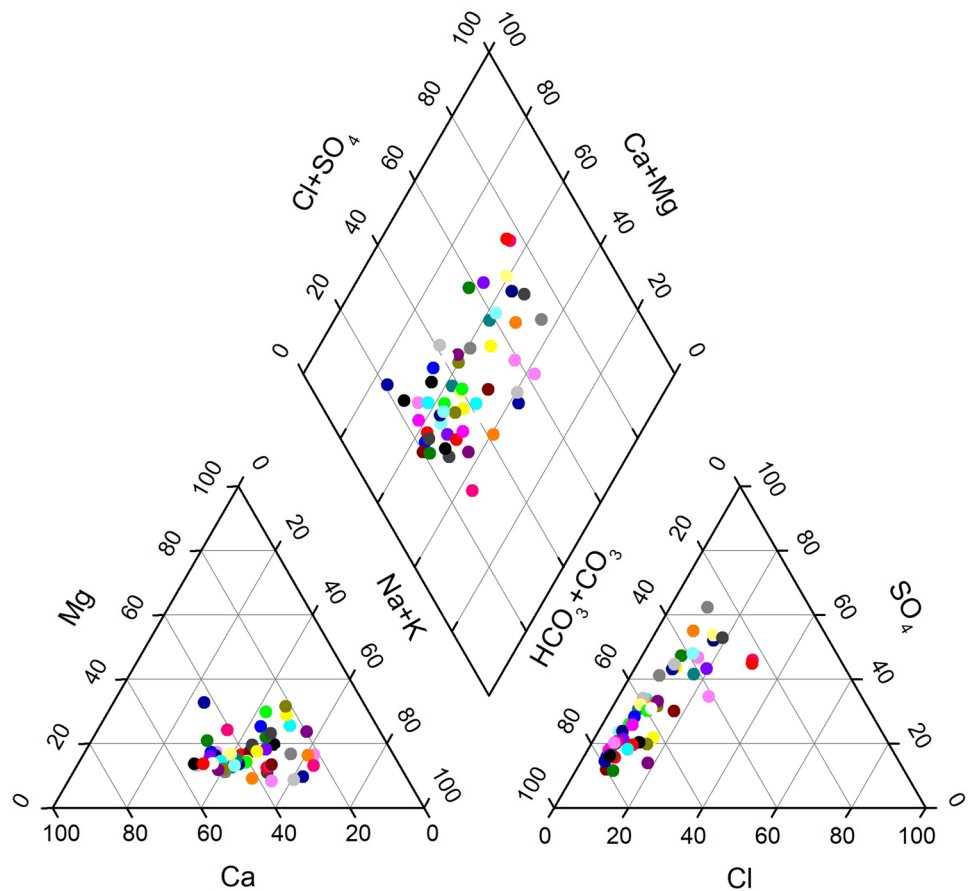

Fig. 14 Classification of the Zanjan Plain samples using the Wilcox diagram for agricultural use

Fig. 15 Hydrochemical facies of the Zanjan Plain samples using the Piper diagram

Spearman correlation analysis

The results of the Spearman (1904) correlation analysis of the physicochemical parameters of the Zanjan Plain groundwater showed that there is a corresponding relationship between some of the parameters. As can be seen from Table 5, there was generally a strong correlation between the SO_4^{2-}, Cl^-, and HCO_3^- anions and the Ca^{+2}, Mg^{+2}, K^+, and Na^+ cations, indicating that the relationship could be due to the effects of evaporative concentration of these parameters along groundwater flowpaths or the common sources of them. There was a strong correlation between EC and both the anions and cations, except CO_3^{2-}. The weak correlation between EC and CO_3^{2-} is attributed to the low correlation

Table 5 Relationship matrix between the physicochemical parameters of the Zanjan Plain groundwater using the Spearman Correlation Analysis

Parameters	EC	TH	pH	SO$_4$	Cl	HCO$_3$	CO$_3$	Ca	Mg	K	Na
EC	1										
TH	0.91[b]	1									
pH	−0.19	−0.33[a]	1								
SO$_4$	0.93[b]	0.87[b]	−0.24	1							
Cl	0.87[b]	0.81[b]	−0.14	0.81[b]	1						
HCO$_3$	0.39[b]	0.38[b]	−0.08	0.19	0.17	1					
CO$_3$	0.01	−0.04	0.40[b]	−0.09	0.05	0.21	1				
Ca	0.74[b]	0.80[b]	−0.54[b]	0.82[b]	0.67[b]	0.05	−0.25	1			
Mg	0.8[b]	0.84[b]	−0.04	0.66[b]	0.70[b]	0.58[b]	0.14	0.45[b]	1		
K	0.91[b]	0.77[b]	−0.11	0.88[b]	0.80[b]	0.31[a]	0.02	0.68[b]	0.64[b]	1	
Na	0.90[b]	0.72[b]	−0.06	0.86[b]	0.82[b]	0.38[b]	0.05	0.56[b]	0.67[b]	0.9[b]	1

[a]Correlation is significant at the 0.05 level

[b]Correlation is significant at the 0.01 level

of the CO_3^{2-} in the measured samples as well as the error of the measurement equipment.

Groundwater quality in the Zanjan Plain considering the water table changes

Changes in the volume of groundwater resources can significantly influence their quality due to the effect of the volume and quality of the input and output flows, changes in the solubility of soluble materials, changes in groundwater flow velocity, as well as changes in dissolved material concentration because of a decrease or increase in the volume of groundwater. Figure 16 shows the changes in EC, TDS, TH as well as the total studied cations and anions in the Zanjan Plain aquifer versus changes in water depth in the observation wells, as an index of aquifer volume changes. There was a good agreement between increased depth of the wells and increased values of the studied parameters, indicating a decrease in groundwater quality of the Zanjan Plain due to a decrease in groundwater volume. However, in some years, there were different changing trends between some of the quality parameters and the volume of groundwater. For example, despite the decreasing trend of the water depth in the plain wells from 2005 to 2006, the EC parameter increased which may be due to an increase in the concentration of the dissolved materials because of the saturation of some substrates as a result of an increase in the groundwater table

Conclusions

The main purpose of the present research was to study changes in the availability and the quality of groundwater resources in the Zanjan Plain over time and to evaluate how the excessive groundwater usage had affected groundwater quality. The study was undertaken using data from 81 observation wells and 53 sampling wells for the period 2004–2018. Changes in the groundwater table showed an average groundwater phreatic decline of 8 m during the studied period in the Zanjan Plain due to increased groundwater abstraction for various uses, especially for irrigated agriculture.

The results showed that the rate at which the groundwater table decline varied throughout the plain, but was highest in the southeastern part of the plain where there was a high rate of groundwater abstraction for irrigated agriculture. The evaluation of groundwater quality using the WHO, ISIRI and EPA standards showed that the quality of groundwater beneath the southeastern part of the Zanjan Plain was generally better than the central and northwestern parts due to lower physicochemical parameters including EC, TDS, TH, Cl, and SO_4.

Using the WQI it was found that, on average, groundwater in all three parts of the plain could be categorized in the "good" quality class, but this classification varied throughout the plain. The southeastern part was classified as having an "excellent" and sometimes "good" quality class with an average WQI value of 43. The central part was also classified as having an "excellent–good" quality class with an average grade of 55. The water quality index values in the northwestern part of the plain were generally in the "good" to "excellent" classes with an average score of 74, but some wells in this area were classified as having "poor" water quality. The water quality classification using the Schoeller diagram produced similar results to the WQI, although differences were observed in the northwestern part of the plain.

An assessment of the suitability of groundwater for use for irrigated agriculture using the Wilcox diagram indicated that groundwater in the southeastern part of the plain was
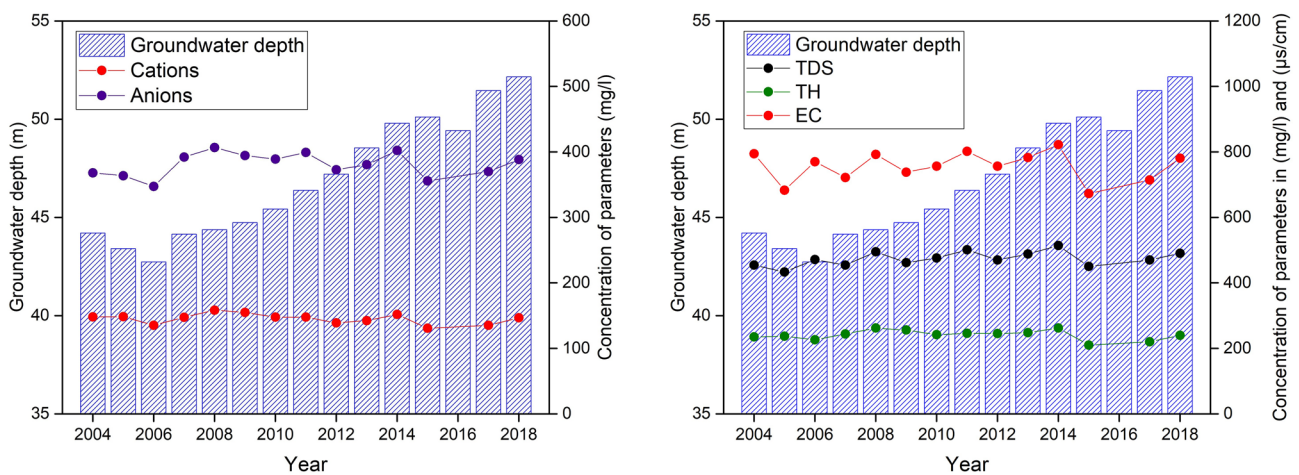

Fig. 16 Groundwater quality versus groundwater table changes in the Zanjan Plain

generally suitable for this purpose (class C2-S1) but was less suitable in the central and northwestern parts of the plain (class C3-S1) because of higher EC levels.

An assessment of groundwater quality using a Piper diagram indicated that the dominant groundwater facies on the plain were Ca–HCO$_3$ and Ca–Na–HCO$_3$. The results of the Spearman correlation analysis showed a significant correlation between the cations and anions and with EC, with the exception of CO$_3$ because of its low concentration. An assessment of the association between the decline in the groundwater table and water quality indicated that there was a direct relationship between the amount of drawdown and the degradation of water quality because of the reduction of the volume of stored groundwater. However, due to the effect of different substrates on the solubility of water-soluble materials, differences were observed in this trend.

References

Adimalla N, Qian H (2019) Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. Ecotoxicol Environ Saf 176:153–161. https://doi.org/10.1016/j.ecoenv.2019.03.066

APHA (2017) Standard methods for the examination of water and wastewater 23rd edition

Azizi F, Moghaddam AA, Nazemi A, Gorgij AD (2019) Introducing a novel method in evaluation of groundwater hydrochemical characteristics, GWQI SI index: case study—Malekan Aquifer, Northwest of Iran. Arab J Geosci 12:343. https://doi.org/10.1007/s12517-019-4360-x

Babanezhad E, Qaderi F, Ziri MS (2018) Spatial modeling of groundwater quality based on using Schoeller diagram in GIS base: a case study of Khorramabad, Iran. Environ Earth Sci 77:339. https://doi.org/10.1007/s12665-018-7541-0

Baghvand A, Nasrabadi T, Bidhendi GN et al (2010) Groundwater quality degradation of an aquifer in Iran central desert. Desalination 260:264–275. https://doi.org/10.1016/j.desal.2010.02.038

Barik R, Pattanayak SK (2019) Assessment of groundwater quality for irrigation of green spaces in the Rourkela city of Odisha, India. Groundw Sustain Dev 8:428–438. https://doi.org/10.1016/j.gsd.2019.01.005

Beyene G, Aberra D, Fufa F (2019) Evaluation of the suitability of groundwater for drinking and irrigation purposes in Jimma Zone of Oromia, Ethiopia. Groundw Sustain Dev 9:100216. https://doi.org/10.1016/j.gsd.2019.100216

Chande MM, Mayo AW (2019) Assessment of groundwater vulnerability and water quality of Ngwerere sub-catchment urban aquifers in Lusaka, Zambia. Phys Chem Earth Parts A/B/C 112:113–124. https://doi.org/10.1016/j.pce.2019.03.004

Chaturvedi A, Bhattacharjee S, Singh AK, Kumar V (2018) A new approach for indexing groundwater heavy metal pollution. Ecol Indic 87:323–331. https://doi.org/10.1016/j.ecolind.2017.12.052

Ebrahimi M, Kazemi H, Ehtashemi M, Rockaway TD (2016) Assessment of groundwater quantity and quality and saltwater intrusion in the Damghan basin, Iran. Geochemistry 76:227–241. https://doi.org/10.1016/j.chemer.2016.04.003

El Osta M, Masoud M, Ezzeldin H (2020) Assessment of the geochemical evolution of groundwater quality near the El Kharga Oasis, Egypt using NETPATH and water quality indices. Environ Earth Sci 79:1–18. https://doi.org/10.1007/s12665-019-8793-z

EPA (2018) Edition of the drinking water standards and health advisories tables

Fallahati A, Soleimani H, Alimohammadi M et al (2020) Impacts of drought phenomenon on the chemical quality of groundwater resources in the central part of Iran—application of GIS technique. Environ Monit Assess 192:64. https://doi.org/10.1007/s10661-019-8037-4

Farid HU, Ahmad I, Anjum MN et al (2019) Assessing seasonal and long-term changes in groundwater quality due to over-abstraction using geostatistical techniques. Environ Earth Sci 78:386. https://doi.org/10.1007/s12665-019-8373-2

Heidari M, Khanlari GR, Beydokhti ART, Momeni AA (2011) The formation of cover collapse sinkholes in North of Hamedan, Iran. Geomorphology 132:76–86. https://doi.org/10.1016/j.geomorph.2011.04.025

Horton RK (1965) An index number system for rating water quality. J Water Pollut Control Fed 37:300–306

Iqbal J, Nazzal Y, Howari F et al (2018) Hydrochemical processes determining the groundwater quality for irrigation use in an arid environment: the case of Liwa Aquifer, Abu Dhabi, United Arab Emirates. Groundw Sustain Dev 7:212–219. https://doi.org/10.1016/j.gsd.2018.06.004

ISIRI (2009) Drinking water—physical and chemical specification 1053 5th revision

Jamshidzadeh Z, Mirbagheri SA (2011) Evaluation of groundwater quantity and quality in the Kashan Basin, Central Iran. Desalination 270:23–30. https://doi.org/10.1016/j.desal.2010.10.067

Liu F, Zhao Z, Yang L et al (2020) Phreatic water quality assessment and associated hydrogeochemical processes in an Irrigated Region along the Upper Yellow River, Northwestern China. Water 12:463. https://doi.org/10.3390/w12020463

MacDonald AM, Bonsor HC, Ahmed KM et al (2016) Groundwater quality and depletion in the Indo-Gangetic Basin mapped from in situ observations. Nat Geosci 9:762–766. https://doi.org/10.1038/ngeo2791

Naghipour D, Ashrafi SD, Taghavi K (2018) Data of heavy metals in soil and groundwater at Kiwi gardens of Amlash in Guilan Province, Iran. Data Br 18:1556–1561. https://doi.org/10.1016/j.dib.2018.04.046

Owoyemi FB, Oteze GE, Omonona OV (2019) Spatial patterns, geochemical evolution and quality of groundwater in Delta State, Niger Delta, Nigeria: implication for groundwater management. Environ Monit Assess 191:617. https://doi.org/10.1007/s10661-019-7788-2

Piper AM (1944) A graphic procedure in the geochemical interpretation of water-analyses. Eos Trans Am Geophys Union 25:914–928. https://doi.org/10.1029/TR025i006p00914

Putranto TT, Winarno T, Susanta APA (2020) Risk assessment of groundwater abstraction vulnerability using spatial analysis: case study at Salatiga Groundwater Basin, Indonesia. Indones J Geosci 7:215–224. https://doi.org/10.17014/ijog.7.2.215-224

Sadat-Noori SM, Ebrahimi K, Liaghat AM (2014) Groundwater quality assessment using the water quality index and GIS in Saveh-Nobaran aquifer, Iran. Environ Earth Sci 71:3827–3843. https://doi.org/10.1007/s12665-013-2770-8

Salman SA, Arauzo M, Elnazer AA (2019) Groundwater quality and vulnerability assessment in west Luxor Governorate, Egypt. Groundw Sustain Dev 8:271–280. https://doi.org/10.1016/j.gsd.2018.11.009

Salvati R, Sasowsky ID (2002) Development of collapse sinkholes in areas of groundwater discharge. J Hydrol 264:1–11. https://doi.org/10.1016/S0022-1694(02)00062-8

Schoeller H (1965) Qualitative evaluation of groundwater resources. Methods Tech Groundw Investig Dev UNESCO 54–83

Shaji E, Gómez-Alday JJ, Hussein S et al (2018) Salinization and deterioration of groundwater quality by nitrate and fluoride in the Chittur block, Palakkad, Kerala. J Geol Soc India 92:337–345. https://doi.org/10.1007/s12594-018-1017-4

Shakerkhatibi M, Mosaferi M, Pourakbar M et al (2019) Comprehensive investigation of groundwater quality in the north-west of Iran: physicochemical and heavy metal analysis. Groundw Sustain Dev 8:156–168. https://doi.org/10.1016/j.gsd.2018.10.006

Spearman C (1904) The proof and measurement of association between two things. Am J Psychol 15:72–101

Sunkari ED, Abu M, Bayowobie PS, Dokuz UE (2019) Hydrogeochemical appraisal of groundwater quality in the Ga west municipality, Ghana: implication for domestic and irrigation purposes. Groundw Sustain Dev 8:501–511. https://doi.org/10.1016/j.gsd.2019.02.002

Verma P, Singh PK, Sinha RR, Tiwari AK (2020) Assessment of groundwater quality status by using water quality index (WQI) and geographic information system (GIS) approaches: a case study of the Bokaro district, India. Appl Water Sci 10:27. https://doi.org/10.1007/s13201-019-1088-4

WHO (2017) Guidelines for drinking-water quality, 4th edn. Geneva

Wilcox LV (1955) Classification and use of irrigation waters. US Department of Agriculture, Washington, DC

Zhang HW, Sun YQ, Li Y et al (2017) Quality assessment of groundwater from the south-eastern Arabian Peninsula. Environ Monit Assess 189:411. https://doi.org/10.1007/s10661-017-6092-2