Groundwater Quality Assessment Using the Water Quality Index and GIS in Saveh-Nobaran Aquifer, Iran

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Abstract

Groundwater is the most important natural resource used for drinking by many people around the world, especially in arid and semi arid areas. The resource cannot be optimally used and sustained unless the quality of groundwater is assessed. Saveh-Nobaran aquifer in Iran is the most important groundwater aquiferous system in the region which is considered a major source for drinking and irrigation. The main objective of this study is to understand the groundwater quality status of Saveh-Nobaran aquifer and investigate the spatial distribution of groundwater quality parameters to identify places with the best quality for drinking consume within the study area. For this purpose, a set of original data, yet unpublished, is presented. In addition, this paper provides an important contribution for understanding relationship between land use and groundwater quality, and groundwater depth and groundwater quality. This goal has been achieved with the combined use of the Water Quality Index and Geographical Information System. A total of 58 groundwater samples were collected and analyzed for major cations and anions. Spatial distribution maps of pH, TDS, EC, TH, Cl, HCO, SO_4, Ca, Mg, Na and K, have been created using kriging method in a GIS environment. From the WQI assessment, over 65% of the water samples fall within the ''Poor'', ''Very poor'' and "unsuitable for drinking" categories, suggesting that groundwater from the center and north-east of the Saveh-Nobaran aquifer is unsuitable for drinking purposes. This research and its results have shown the great combination use of GIS and WQI in assessing groundwater quality. Moreover, having a clear view of the area's groundwater quality, decision makers can plan better for the operation and maintenance of groundwater resources.

Key Words: Geographic information system, Groundwater quality, Water quality index, Saveh-Nobaran.

Introduction

Groundwater contamination has become one of the most serious problems in the world since the last decades (Umar *et al.* 2009). Groundwater in many regions, especially in arid and semi arid areas, is a substantial supply of water. Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and on sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality (Vasanthavigar 2010).

Water pollution not only affects water quality but also threats human health, economic development, and social prosperity (Milovanovic 2007). The quality of groundwater has particularly received immense attention since water of high quality is required for domestic and irrigation needs. Till recently, groundwater assessment has been based on laboratory investigation, but the advent of Satellite Technology and Geographical Information System (GIS) has made it very easy to integrate various databases. GIS can be a powerful tool for developing solutions for water resources problems, assessing water quality, preventing flooding, determining water availability, understanding the natural environment and for managing water resources on a local or regional scale (Ketata-Rokbani 2011). In Iran, groundwater resources are not only the most important resources for drinking purposes, but they are also used extensively to satisfy agricultural, domestic, and industrial water demands. In addition, decrease in drinking water quality has been reported in many cases followed by groundwater pollution. Moreover, as reported by Taki (2003) the effect of groundwater pollution not only harms water supply wells and aquifers, but with moving toward the lakes and rivers, will also pollute surface water resources which may lead to serious environmental consequences.

The general Water Quality Index (WQI) was developed by Brown et al. (1970) and improved by Deininger for the Scottish Development Department (1975). The WQI method is widely used for groundwater quality assessment around the world due to the capability of fully expression of the water quality information and is one of the most effective tools and important parameters to the evaluation and management of groundwater quality. WQI has been used to determine the suitability of the groundwater for drinking purposes by many authors. Backman et al. (1998) created an index to evaluate and map the amount of groundwater contamination and applied it in Southwestern Finland and Central Slovakia. Avvannavar and Shrihari (2008) reported the results of their attempted to develop a water quality index using six water quality parameters to evaluate surface water quality for drinking purposes of river Netravathi, Mangalore, South India. Rizwan Reza and Gurdeep Singh (2010) created the WQI by using twenty-four groundwater samples to assess spatial and temporal changes in groundwater quality in Angul-Talcher region of Orissa, India. Saeedi *et al*. (2010) applied eight different parameters including K^+, Na^+, Ca^{2+}, Mg^{2+}, SO^{2-}_4 , Cl^-, pH, and TDS as the most important components of healthy water, to develop an Groundwater quality index in Iran. The work of Ketata-Rokbani el at. (2011) reports the creation of WQI for groundwater and the results of its application for assessing groundwater quality in El-Khairat deep aquifer (Enfidha, Central East Tunisia).In another study the WQI involving twelve parameters was created by Wu Jianhua *et al.* (2011) to indicate the quality of groundwater from 45 wells located in Jingyuan County, a Semi-Humid Area in Northwest China. Machiwal et al. (2011) used GIS-based water quality index to assess the groundwater quality in a hard-rock hilly terrain in Western India by analyzing calcium (Ca), magnesium (Mg), sodium (Na), sulfate (SO4), chloride (Cl), bicarbonate (HCO3), nitrate (NO3), pH, electrical conductivity (EC), total dissolved solids (TDS), and hardness parameters. El-Hames *et al.* (2011) worked on a classification approach by which, zones with acceptable groundwater quality for drinking were classified using water sample analysis methods and GIS capabilities, in Saudi Arabia. Only major cations and anions of Ca, Na, SO_4, Cl and TDS were used to locate suitable areas for consumption use in their study. Anitha *et al*. (2011) evaluated groundwater quality in and around Peenya industrial area of Bangalore, South India using GIS techniques and water quality parameters such as pH, Alkalinity, TDS, TH, Ca, Mg, Cl, SO_4 and NO_3.

This paper which follows the previous studies conducted in the study area by the same authors (Sadat Noori et al. 2012a), presents the research findings on the groundwater quality status of Saveh-Nobaran aquifer based on an integrated approach of traditional water quality analysis and GIS, to generate a Water Quality Index map. The developed WQI map can be used as a monitoring tool for groundwater quality of Saveh-Nobaran aquifer, Markazi province, Iran. Moreover, this map aims to rapidly distinguish the location of most and least suitable water for drinking in the study area concern to its water mineral content. This technique has not yet been used to investigate groundwater quality of Saveh-Nobaran aquifer which confronts growing population, industrial activities and agriculture fields. For this purpose a set of original data which has not been published until now is used. By mapping the index, the areas of high and low water quality can easily be distinguished by senior researchers as well as decision makers or the general public. In addition, an important contribution for understanding relationship between land use and groundwater quality, and also groundwater depth and groundwater quality is provided.

Material and Methods

Study area

Saveh-Nobaran plain mainly is located north of Markazi province in the center of Iran and lies between longitude 50° 8' to 50° 50' E and latitude 34° 45' to 35° 3' N, with an area of about 3245 square kilometers. It equals 30 percent of the entire Markazi province size. The mean altitude of Saveh-Nobaran plain is 1108 meters above the sea level. The climate of the area is considered to be arid and semi-arid involving Dommartin and Ambreje category, respectively, with an annual precipitation being approximately equal to 213 mm. Generally, rainfall occurs from October to May, with a maximum and minimum during February and December of each year, respectively. The mean monthly temperatures vary between 5.7◦C in February to 31.5◦C in August, and the mean annual value is 18.2◦C. The mean humidity of Saveh is 39% which October is the wettest month with a mean monthly humidity of 58% and May and June with a mean humidity of 26%, are the driest months. The annual potential evaporation far exceeds the annual rainfall with a mean annual amount (approximately estimated from 1975 to 2001) of 1505 mm for Saveh city (Mosavi-Khansari 1991). Agriculture is a major industry and the principal land use in Saveh.

Groundwater table elevation, depth and flow

Available monthly groundwater elevation levels of a total 58 observation wells monitored continually from 1993 to 2009 gained from Markazi Regional Water Corporation were surveyed. These wells are distributed across the study area to represent the fluctuations of groundwater level of the whole area as presented in Figure 1. A statistic summary of groundwater levels during 1993- 2009 in different climatic periods including wet, dry and normal are shown in Table 1.

Table 1 Summary statistic of groundwater levels during 1993- 2009 (Sadat Noori et al. 2012b)

		Data							
		Year	Month	No. of wells	Mean Water Elevation (m)	SD*	CV (%)*	Max. *	Min. *
Wet Period	Max.	1994-1995	February	55	1118.432	329.626	29.47	1828.29	827.04
	Avg.		May	54	1117.538	321.605	28.78	1825.99	828.29
	Min.		September	53	1115.345	327.173	29.33	1826.49	827.09
Dry Period	Max.	1998-1999	February	58	1117.653	321.538	28.77	1826.29	828.64
	Avg.		April	58	1107.823	313.335	28.28	1827.99	830.19
	Min.		December	55	1107.595	313.205	28.28	1827.49	829.99
Normal Period	Max.	2001-2002	February	57	1119.316	313.837	28.04	1828.24	832.54
	Avg.		April	58	1117.987	313.888	28.08	1827.89	832.58
	Min.		September	57	1115.146	312.229	28.00	1828.04	831.94

*SD: Standard error, CV (%): Coefficient of variation percent, Max.: Maximum, Min.: Minimum

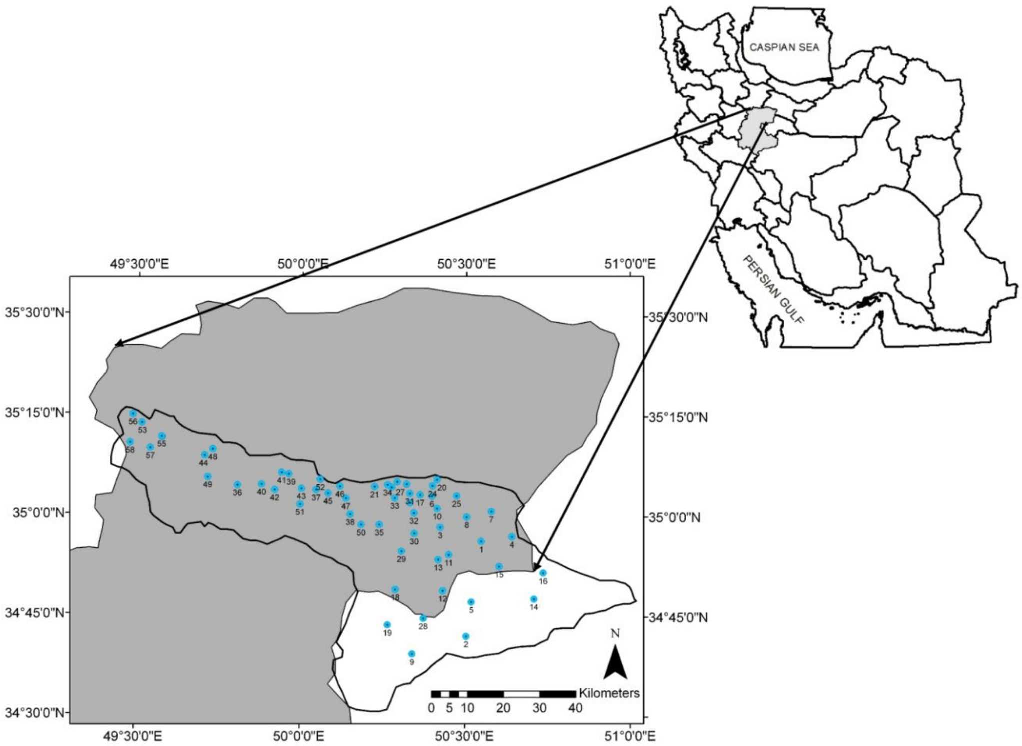

Fig. 1 The location of the study area and the observation wells

Groundwater table elevation and depth were analyzed and are presented in Figures 2 and 3, respectively. The groundwater flow direction can be determined from Figure 2 which illustrates groundwater table elevation contour lines. According to this, contour lines increase towards the southern east bounder, therefore, it can be concluded that groundwater flow direction is in south-east direction. The average depth of groundwater was to be 65 meter all –year round. Based on the Table 1, variation of groundwater level in different climatic conditions is very usual for this region. Thus, climatic variations of groundwater can influence the movement of pollutant trail. Additionally, investigating the nature of land use and its associated impact on groundwater quality is important for an appropriate understanding of the environmental conditions.

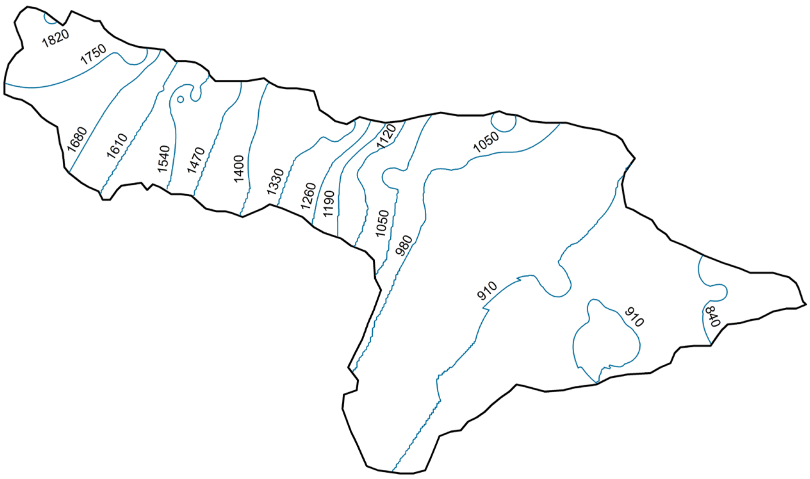

Fig. 2 The groundwater table elevation contour lines of the study area

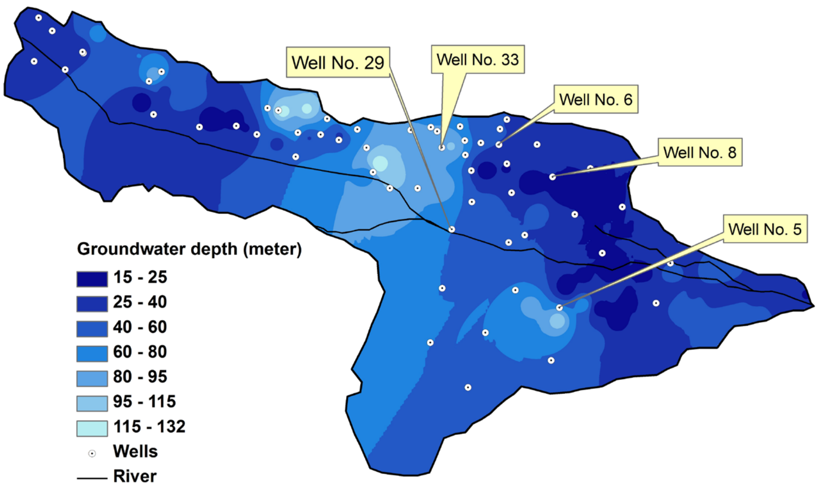

Fig. 3 Monthly mean groundwater depth of the study area in year 2009

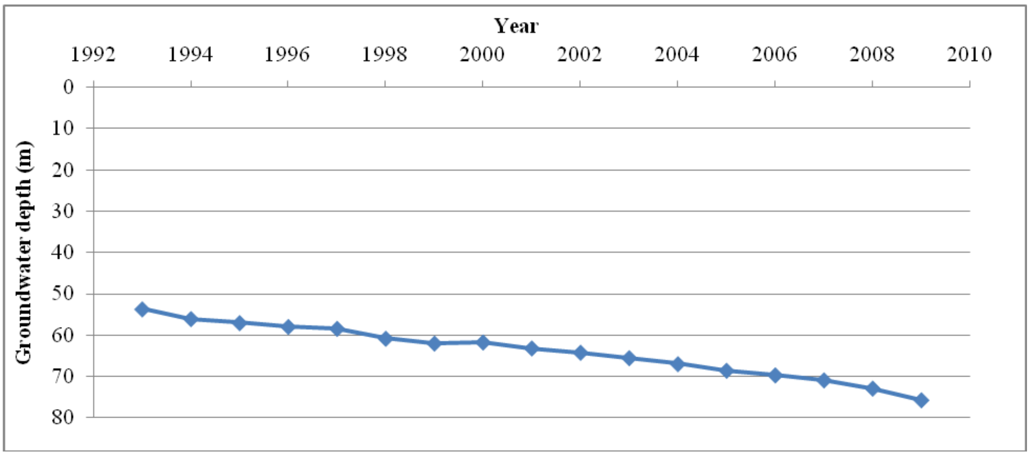

Fig. 4 Average annual groundwater depth of the study area for years 1993 – 2009

Figure 4 shows the average annual groundwater level drop in 58 observation wells of the study area between the years 1993 to 2009. It is observed that groundwater level has dropped more than 20 meters in seven years. This show the over exploitation occurring in the region without any attention to sustainable development. Furthermore, the maximum drop in groundwater level through these years is equal to 61.85 meters which has occurred in well No.33 with an average annual drop of 2.85 m. Fig. 5 shows the landuse of the study area.

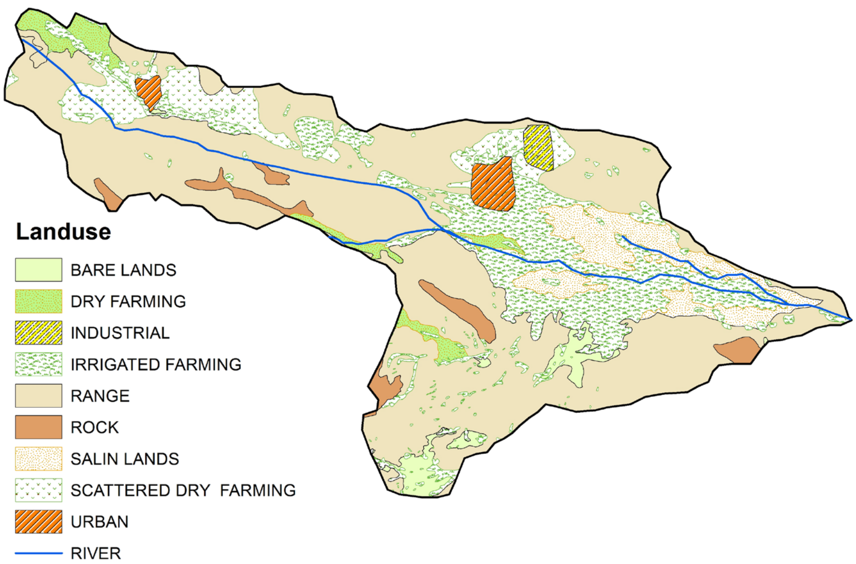

Fig. 5 The landuse map of the study area

Water Quality Index method

Water quality index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water. It is calculated from the point of view of human consumption. Water quality and its suitability for drinking purpose can be examined by determining its quality index. The standards for drinking purposes as recommended by WHO (WHO 2004) have been considered for the calculation of WQI. In this method the weightage for various water quality parameters is assumed to be inversely proportional to the recommended standards for the corresponding parameters (Mishra 2001 and Naik 2001).

The calculation procedure contains three stages. In the first stage, each of the nine parameters (pH, TDS, Cl, SO4, HCO_3, Ca, Mg, Na, and K) has been assigned a weight (w_i) based on their perceived effects on primary health (Table 2).

Table 2 The weight (w_i) and relative weight (W_i) of each chemical parameter

Parameter	WHO standard	Weight (w_i)	Relative weight (W_i)
pH	8.5	3	0.103
TDS	500	5	0.179
Cl	250	5	0.179
SO_4	250	5	0.179
Na	200	4	0.143
K	12	2	0.071
HCO_3	120	1	0.036
Ca	75	3	0.107
Mg	50	3	0.107
		$\sum w_i = 31$	$\sum W_i = 1$

The maximum weight of 5 has been assigned to parameters like total dissolved solids, chloride, and sulphate due to their major importance in water quality assessment (Srinivasamoorthy *et al.* 2008). Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, magnesium, sodium, and potassium were assigned a weight between 1 and 5 depending on their importance in the overall quality of water for drinking purposes (Ketata *et al.* 2010).

In the second stage, the relative weight (W_i) of each parameter is computed using Eq. (1):

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

Where w_i is the weight of each parameter, n is the number of parameters and W_i is the relative weight. The weight (w_i), the calculated relative weight (W_i) values, and the WHO standards for each parameter are given in Table 1.

In the third stage, a quality rating scale (q_i) is calculated for each parameter using Eq. (2):

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (2)$$

Where q_i is the quality ranking, C_i is the concentration of each chemical parameter in each water sample in milligrams per liter and S_i is the WHO standard for each chemical parameter in milligrams per liter (Table 2).

For computing the WQI, the SI is first determined for each chemical parameter using Eq. (3), which is then used to determine the WQI according to Eq. (4):

$$SI_i = W_i \times q_i$$

(3)

$$WQI = \sum SI_i \qquad (4)$$

Where SI_i is the sub-index of ith parameter, q_i is the rating based on concentration of ith parameter and n is the number of parameters.

Computed WQI values are usually classified into five categories (Table 3): excellent, good, poor, very poor, and unsuitable for human consumption (Sahu and Sikdar 2008). The calculation procedure of WQI is described in detail by many authors (Pradhan *et al.* 2001; Dwivedi and Pathak 2007; Asadi *et al.* 2007; Saeedi *et al.* 2010; Yidana and Yidana 2010).

Table 3 Classification of groundwater quality according to WQI

WQI range	Type of water
< 50	Excellent water
50 - 100.1	Good water
100 - 200.1	poor water
200 - 300.1	Very poor water
> 300	Water unsuitable for drinking purpose

GIS application

Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields (Lo and Yeung 2003).

The study is carried out with the help of topographic sheets, Arcview GIS 3.2. The 1:50,000 scale topography paper map of Saveh-Nobaran was digitized to the UTM coordinate system and entered in GIS environment. Spatial Analyst, an extention of ArcGIS 3.2, was used to find out the spatio-temporal behavior of the groundwater quality parameters (ESRI 1999). The various thematic layers on hardness, pH and ionic concentrations were prepared using a spatial interpolation technique through kriging. This contouring method has been used in the present study to delineate the locational distribution of water pollutants or constituents. Kriging technique is an exact interpolation estimator used to find the best linear unbiased estimate. The best linear unbiased estimator must have minimum variance of estimation error. Detailed discussions of kriging methods and their descriptions can be found in Goovaerts (1997).

The general equation of kriging estimator is (Goovaerts 1997):

$$Z^*(x_p) = \sum_{i=1}^{N} \lambda_i Z(x_i) \tag{5}$$

In order to achieve unbiased estimations in kriging the following set of equations should be solved simultaneously.

$$\begin{aligned} &\sum_{l=1}^{n} \lambda_i \gamma(x_i, x_j) - \mu_v = \gamma(x_i, x) \\ &\sum_{i=1}^{n} \lambda_i = 1 \end{aligned} \tag{6}$$

Where Z*(x_p) is the kriged value at location x_p, Z(x_i) is the known value at location x_i, λ_i is the weight associated with the data, μ is the Lagrange multiplier, and $\gamma(x_i,x_j)$ is the value of variogram corresponding to a vector with origin in xi and extremity in x_j.

Groundwater quality classification maps for pH, TH, EC, TDS, Cl, SO_4 , HCO_3 , NO , Ca, Mg, Na and K from thematic layers, based on the WHO Standards for drinking water, were created by GIS techniques for determining their spatial variations in Saveh-Nobaran basin.

Results and Discussion

In the following, the ten groundwater quality parameters, Ca, Mg, Na, HCO_3, SO_4 , Cl, TDS, EC, pH, and hardness, will be analysed according to their statistical measures, such as minimum, maximum, mean and standard deviation which are presented in Table 4 and the created spatial distribution maps.

TDS are compounds of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates), and of small amounts of organic matter that are dissolved in water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals (WHO 2004).

Table 4 Statistical analysis of physical and chemical groundwater quality parameters

Parameter	Unit	Maximum	Minimum	Mean	Standard division
pH		8.38	6.84	7.82	0.31
TDS	mg l^{-1}	10900	168	1923.05	2001.09
CL	mg l^{-1}	4293.02	18.46	476.70	643.71
SO4	mg l^{-1}	2108.16	24.96	668.04	594.06
Na	mg l^{-1}	1748	8.05	348.66	365.56
K	mg l^{-1}	29.25	1.17	5.60	6.88
HCO3	mg l^{-1}	610	81.74	234.02	99.19
Ca	mg l^{-1}	814.20	30.20	154.25	136.74
Mg	mg l^{-1}	459.48	15.36	83.24	75.88
TH	mg l^{-1}	3950	141	732.76	651.23
EC	µs cm^{-1}	1557	350	299	284
T c	ºC	19.7	18.30	22.93	23.27

The parameter total dissolved solid in the study area varies between 168 to 10900 milligrams per liter with an average of 1923.05 mg/l (Table 4). The permissible limit suggested by WHO for TDS is >500 mg/l therefore, both desirable and not permissible region are seen in the study area (Fig. 6). However, the distribution of TDS is uneven, the concentration of TDS in the east and center is higher than that in other parts and the concentration of TDS gradually decreases from east to west.

Water hardness is primarily caused by the presence in water of cations such as calcium and magnesium; and of anions such as carbonate, bicarbonate, chloride, and sulfate (Ravikumar *et al.* 2010). According to the grading standards of TH (as CaCO3), groundwater can be divided into soft water (TH<150 mg/L), moderately hard water (150<TH<300 mg/L), hard water (300<TH<450 mg/L), extremely hard water (TH>450 mg/L). In the study area TH varies between 141 – 3950 mg/l (Table 3) considering only one sample is in the soft category. The water with hardness above 200 mg/l may cause scale formation in the distribution system. The high hardness of 150–300 mg/l and above may cause heart diseases and kidney problems (Ramesh and Elango 2006). Near 75% of the samples locations in the center and east of the basin are placed in the hard water classification, which shows the deteriorating groundwater quality conditions for drinking propose. The TH shows a similar characteristic to TDS (Fig. 7).

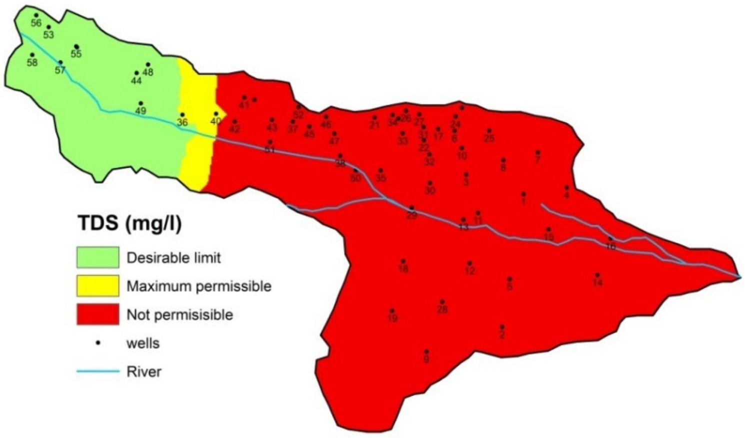

Fig. 6 Spatial distribution of TDS parameter

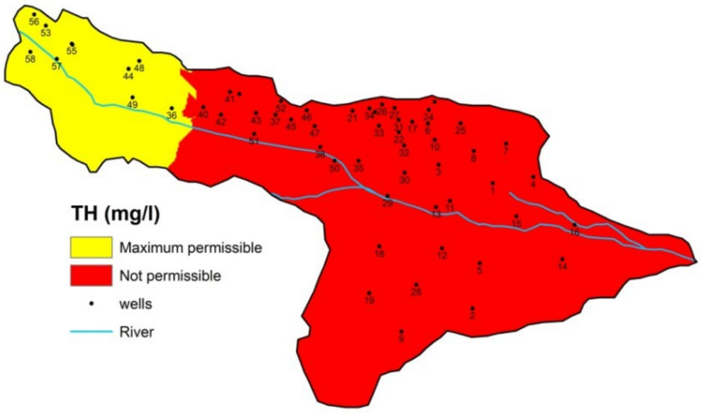

Fig. 7 Spatial distribution of Total Hardness (TH)

pH is one of the most important operational water qualities. The acidity and alkalinity of groundwater is described by the pH of groundwater and also, pH mostly controls the quantity and chemical structure of several organic and inorganic matters dissolved in groundwater. This parameter varies between 6.84-6.38 with a mean of 7.82 (Table 3). According to the distribution map (Fig. 8) all samples are in desirable limit except for GW25, GW37 and GW46 which are located in the not permissible zone.

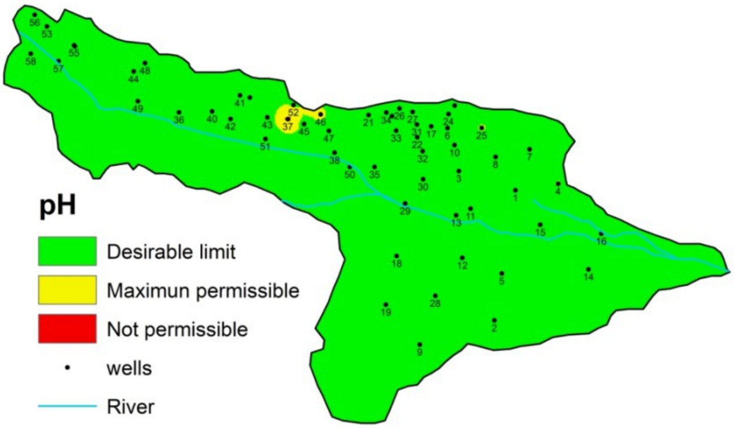

Fig. 8 Spatial distribution of pH parameter

The electrical conductivity (EC) of water at 25℃ is due to the presence of various dissolved salts. As shown in Table 3, EC values are observed to cover a wide range from (350 µS/cm) which is measured at GW58 to (1557µS/cm) which is measured at GW16 with an average of 299 µS/cm. According to WHO (2004) specification, 56.21% of the sample locations exceed allowable limits indicating, then, the unsuitability of some of the water for drinking purposes. As shown in Fig. 9 the values of EC are in desirable limit in east and some central south areas of the study region but gradually increases towards the center and west of the study area. This may be attributed to the salty geographical formation of the area.

The presence of sulphate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers. Seventy-five percent of the water samples analyzed contained sulphate within the not permissible limit. The values of sulphate ranged from 24.96 to 2108.16mg/L. Elevated sulphate concentrations were recorded in samples GW3 (1853.28mg/L) and GW4 (1999.68 mg/L), while the highest value was observed in sample GW25 (2108.16mg/L) located in the Saveh bordering the industrial area. Use of large amount of fertilizer and pesticide is the main source of nonpoint pollution which increases the concentration of sulphate. High values of sulphate are distributed in the western part of the study area and lies in the downstream region (Fig. 10).

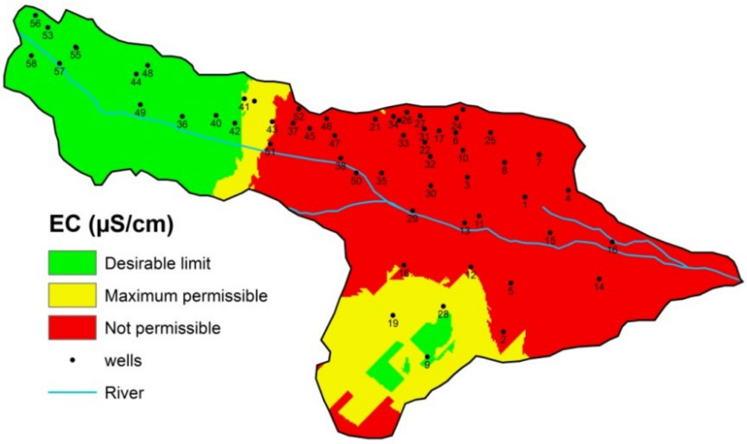

Fig. 9 Spatial distribution of electrical conductivity (EC)

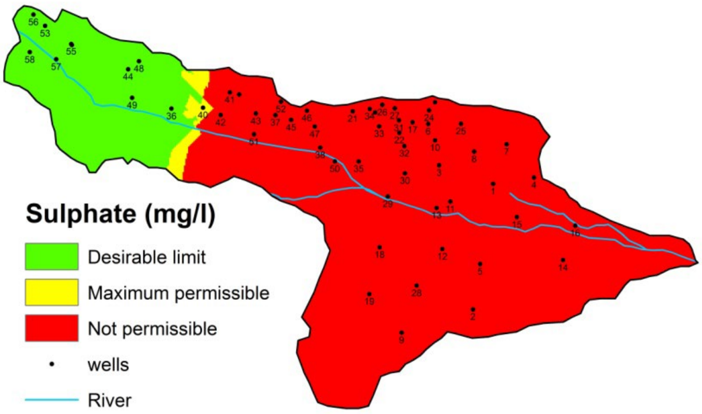

Fig. 10 Spatial distribution of Sulphate (SO_4)

The concentration of chloride in 40 samples was above the desired limit of 250 mg/L, with a maximum value as high as 4293.02 mg/L. Chloride in excess imparts a salty taste to water, and people who are not accustomed to high chloride can be subjected to laxative effects (Anitha *et al.* 2011). Sample GW16 located in the western portion of the study area recorded the highest value of 4293.02 mg/L. High concentration of chloride which are located outside the industrial area, attribute to the contamination from an unclaen system, sewage and agricultural runoff. Lower values in of chloride are located in the eastern and southern portion of the area as illustrated in Fig. 11.

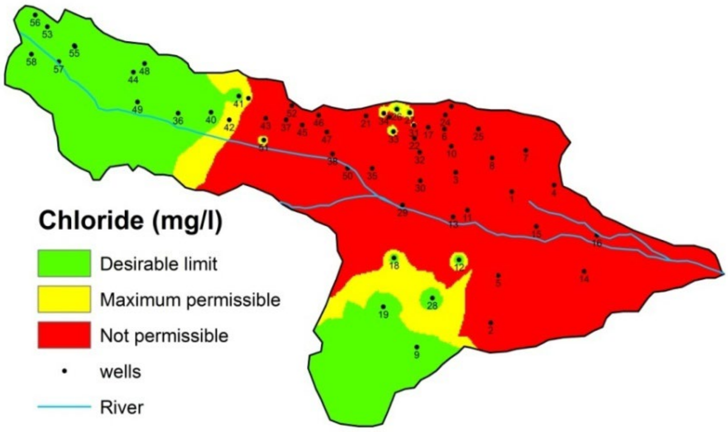

Fig. 11 Spatial distribution of chloride (Cl)

Figure 12 shows the bicarbonate spatial distribution in the study area. According to the distribution map all samples are in the not permissible limit except for sample GW18 with 1874 mg/l. This parameter varies between 81.74 – 610 mg/l with a mean of 234.02 mg/l (Table 4).

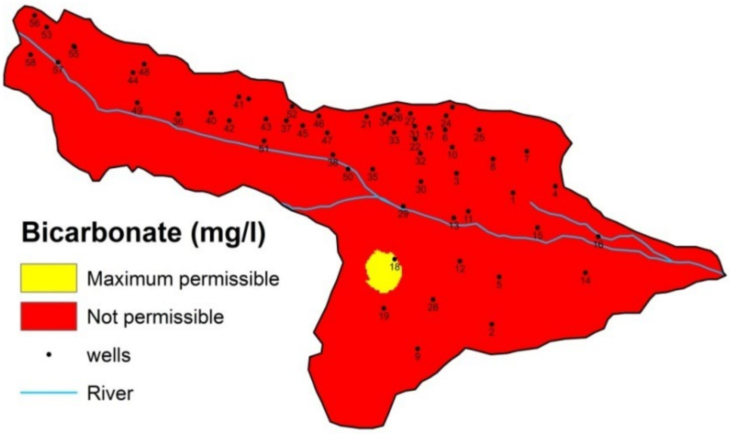

Fig. 12 Spatial distribution of Bicarbonate (HCO_3)

The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution. At room temperature, the average taste threshold for sodium is about 200 mg/l. High sodium values are observed in the center and north parts of the study area, (Fig. 13). The sodium values range from 8.05 to 1748 mg/L with mean of 348.66 mg/l. The highest concentration of sodium (169.6 mg/l) was observed in sample GW16, which is located close to the agricultural area, and may be due to contamination from a septic system, sewage and agricultural runoff that can leach and enter into the groundwater.

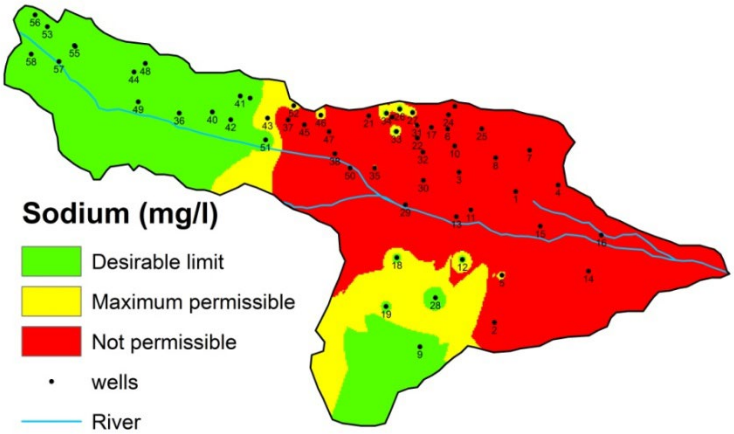

Fig. 13 Spatial distribution of sodium (Na)

The taste threshold for the calcium ion is in the range of 100–300 mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium (WHO 2004). The maximum calcium and magnesium concentrations are 814.2 and 459.48 mg/L, respectively. The high degree of hardness in the study area can definitely be attributed to the disposal of untreated or improperly treated sewage and industrial waste. Figures 12 and 13 illustrate the spatial distribution of calcium and magnesium concentrations, respectively. As it is seen in Fig. 14 the majority of the samples show a calcium amount beyond the maximum permissible limit, whereas, in Fig 15 fifty percent of the sample locations are placed in the not permissible class. The high total concentrations of Ca and Mg are important factors, which increase the hardness of waters.

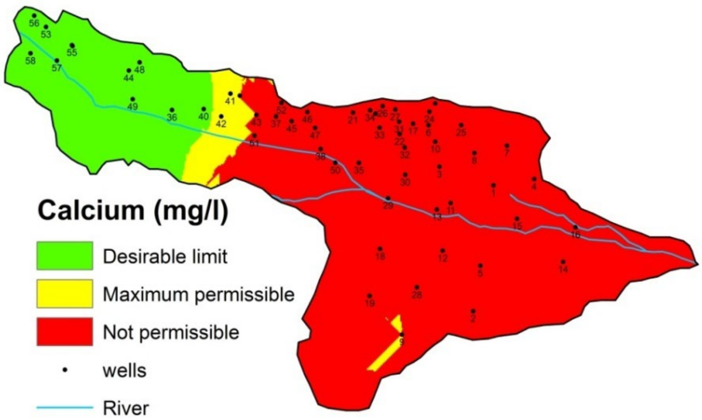

Fig. 14 Spatial distribution of calcium (Ca)

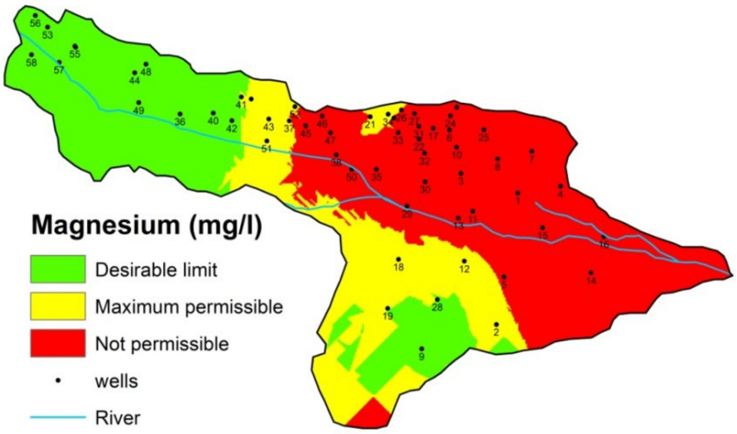

Fig. 15 Spatial distribution of Magnesium (Mg)

Potassium is an essential element in humans and is seldom, if ever, found in drinking water at levels that could be a concern for healthy humans. The recommended daily requirement is greater than 3000 mg (WHO 2004). Figure 16 shows the spatial distribution of the potassium in the study area. Potassium levels are in desirable limit in almost the entire Saveh-Nobaran basin. Only four samples GW16, GW22, GW25 and GW35 with 18.5, 23.45, 20.2 and 29.25 mg/l concentration, respectively, fall below not permissible class. The potassium parameter varies between 1.17 to 29.25 milligrams per liter with an average of 5.6 mg/l (Table 4) in the study area.

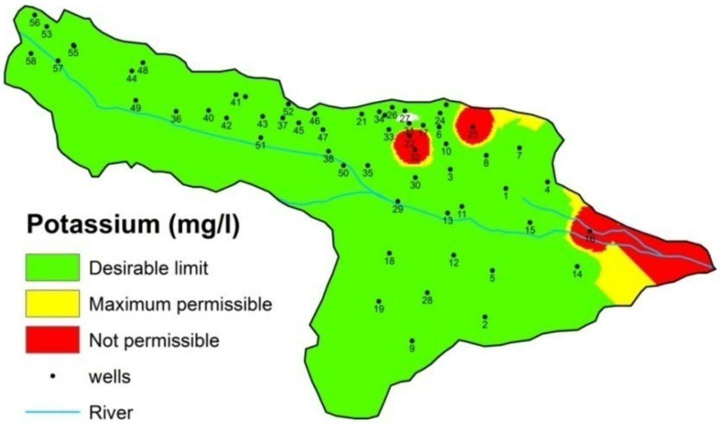

Fig. 16 Spatial distribution of potassium (K)

In addition, to analyze the groundwater quality parameters of Saveh-Nobaran aquifer, correlations between various parameters were calculated which are presented in Table 5.

Table 5 Correlation matrix between groundwater quality parameters of Saveh-Nobaran aquifer

Parameter	TH	SAR	Cation	K	Na	Mg	Ca	Anion	SO_4	Cl	HCO_3	CO_3	pH	TDS	EC
TH	1														
SAR	0.39	1													
Cation	0.89	0.62	1												
K	0.37	0.18	0.37	1											
Na	0.7	0.8	0.94	0.31	1										
Mg	0.88	0.32	0.81	0.38	0.64	1									
Ca	0.9	0.27	0.8	0.29	0.32	0.63	1								
Anion	0.89	0.6	0.99	0.37	0.93	0.81	0.81	1							
SO_4	0.67	0.53	0.76	0.22	0.72	0.55	0.66	0.77	1						
Cl	0.81	0.48	0.89	0.37	0.82	0.77	0.7	0.89	0.45	1					
HCO_3	0.02	0	0.01	0	0.01	0	0.04	0.01	0	0.03	1				
CO_3	0.01	0	0	0.01	0	0.01	0	0.01	0	0	0.01	1			
pH	0	0	0.01	0	0	0	0.01	0.01	0.01	0	0	0	1		
TDS	0.88	0.58	0.97	0.36	0.9	0.79	0.8	0.98	0.76	0.86	0.01	0	0	1	
EC	0.89	0.6	0.99	0.37	0.92	0.82	0.79	0.99	0.77	0.88	0	0.01	0	0.97	1

According to Table 5, almost all constituents are positively related to one another. EC parameter has high correlation with sodium (Na) and chloride (Cl) in the cation and anion, respectively. Also, similar results for TDS are observed. It is also distinguish that TH has high correlation with calcium (Ca) and chloride (Cl). SAR parameter also has a high correlation with sodium (Na) in cations but in the anions highest correlation amount are seen for SO_4. It is noticed that the highest correlation is among TDS and Na, Ca, Mg and Cl. This demonstrates that these four constituents are the main contributors to TDS amount in the aquifer and they indicate the majority of salts in the aquifer groundwater. High correlation between Na, Mg, and Cl also demonstrates this fact.

Water Quality Index map

Water quality index is calculated to determine the suitability of water for drinking purpose. Water quality index calculated values for each sample are shown in Table 6.

According to the results and Table 6, only WQI values for 20 samples are placed in "Excellent and Good water" classification and the rest fall below this range. This means that near 65 percent of the samples are not in good conditions and are unsuitable for drinking purposes. Figure 17 illustrates the spatial distribution WQI map. The WQI map indicates that the safest zone is in the western part of the study area, where nearly all WQI values of the samples are in excellent class for drinking consume. This area (Nobaran) has a comparatively lesser number of industries in comparison to the rest of the study area. In general, the groundwater quality decreases from the north-west to the east of the Saveh-Nobaran aquifer. This is mainly due to the effects of the hydraulic gradient and the groundwater direction moving towards the south-east bound. This decrease in quality from north-west to south-east is attributed mostly to the shallow groundwater table (<20 m) in east and the increase of contaminant input from chemical fertilizers used in agricultural fields.

Table 6 Groundwater classification based on WQI

Number	Utmx	Utmy	WQI	Classification
GW1	458206	3865220	201.746	Very poor water
GW2	454500	3840000	122.358	poor water
GW3	446141	3873780	592.905	Water unsuitable for drinking purpose
GW4	467288	3867613	719.166	Water unsuitable for drinking purpose
GW5	456000	3849500	106.355	poor water
GW6	442250	3878500	377.640	Water unsuitable for drinking purpose
GW7	461555	3874583	496.277	Water unsuitable for drinking purpose
GW8	449000	3873600	598.868	Water unsuitable for drinking purpose
GW9	443500	3842300	179.036	poor water
GW10	442760	3874520	422.546	Water unsuitable for drinking purpose
GW11	449750	3862600	101.784	poor water
GW12	451130	3849230	100.426	poor water
GW13	446850	3861264	237.728	Very poor water
GW14	468520	3858760	116.337	poor water
GW15	462435	3862923	420.667	Water unsuitable for drinking purpose
GW16	472336	3861660	1170.801	Water unsuitable for drinking purpose
GW17	441850	3879200	353.575	Water unsuitable for drinking purpose
GW18	442470	3853020	110.255	poor water
GW19	442630	3844280	105.593	poor water
GW20	446550	3883400	401.354	Water unsuitable for drinking purpose
GW21	429250	3881500	224.526	Very poor water
GW22	439055	3877014	363.433	Water unsuitable for drinking purpose
GW23	434010	3881275	278.603	Very poor water
GW24	445300	3881700	338.536	Water unsuitable for drinking purpose
GW25	447846	3877813	602.105	Water unsuitable for drinking purpose
GW26	435500	3882850	43.795	Poor water
GW27	444042	3890582	40.038	Poor water
GW28	446813	3850722	98.403	Good water
GW29	436647	3863633	232.89	Very poor water

Table 6 (continued) Groundwater classification based on WQI

Number	Utmx	Utmy	WQI	Classification
GW30	440231	3868520	310.594	Water unsuitable for drinking purpose
GW31	446700	3890200	84.0213	Good water
GW32	440130	3874200	503.483	Good water
GW33	442200	3888050	54.4371	Good water
GW34	432850	3882000	51.9835	Good water
GW35	430500	3871000	194.231	poor water
GW36	391250	3882050	53.7259	Good water
GW37	413065	3880692	313.990	Water unsuitable for drinking purpose
GW38	422458	3873889	313.443	Water unsuitable for drinking purpose
GW39	405467	3885038	115.757	poor water
GW40	397900	3882250	70.3921	Good water
GW41	403508	3885470	63.2497	Good water
GW42	401590	3880713	110.426	poor water
GW43	408970	3881030	199.341	poor water
GW44	382200	3890300	44.6552	Excellent Water
GW45	416350	3879700	271.526	Very poor water
GW46	419645	3881628	111.676	poor water
GW47	421300	3878300	391.660	Water unsuitable for drinking purpose
GW48	384450	3892000	65.667	Good water
GW49	402950	3900300	36.7131	Excellent Water
GW50	425500	3871000	180.156	poor water
GW51	419000	3891400	61.105	Good water
GW52	414210	3883534	140.959	poor water
GW53	364800	3899400	36.214	Excellent Water
GW54	370400	3895400	46.044	Excellent Water
GW55	370250	3895600	42.316	Excellent Water
GW56	362350	3901750	26.004	Excellent Water
GW57	365500	3905150	27.284	Excellent Water
GW58	360300	3903950	22.840	Excellent Water

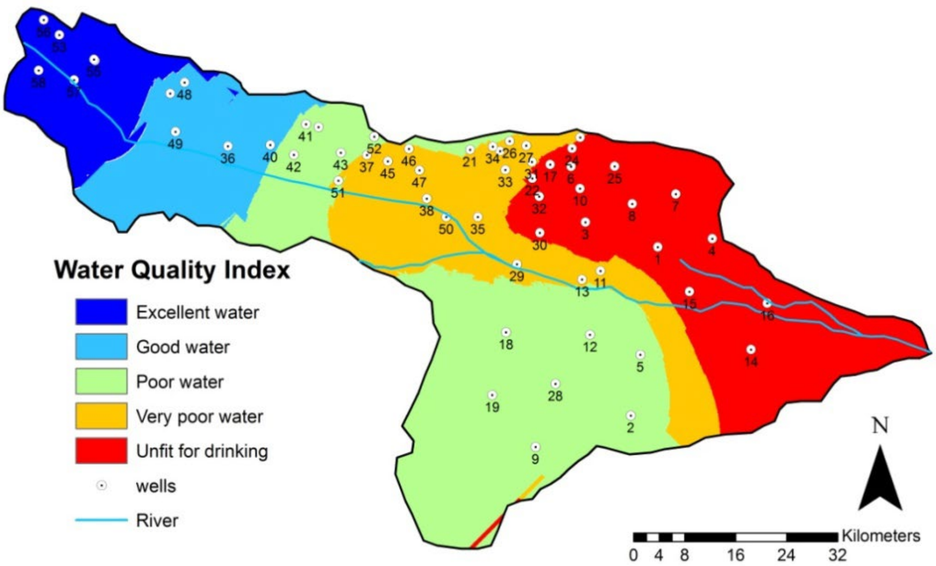

Fig. 17 The WQI spatial distribution map

Correlation of water table depth and land use with water quality

An assessment was carried out to find out the existing correlation between water quality, water table depth and landuse. Figure 18 shows the correlation of water table depth with water quality classes. It was found that from the total 30 percent of the samples assigned to unsuitable for drinking class, almost 11 percent are placed in a depth of 15-20 meters from the ground surface. It is also observed that no groundwater with very bad quality is in areas were water-level is higher than 80 meters from the ground surface. In north-west regions of the study area which the water-level is 25- 40 meters, water sample with excellent and good quality exists. This is mainly due to less urban, agricultural and industrial activities in the region. It can be concluded that as the groundwater-level increases, water quality will have better conditions. Moreover, Shallow water tables pose a greater chance for the contaminant to reach the groundwater surface as opposed to deep water tables.

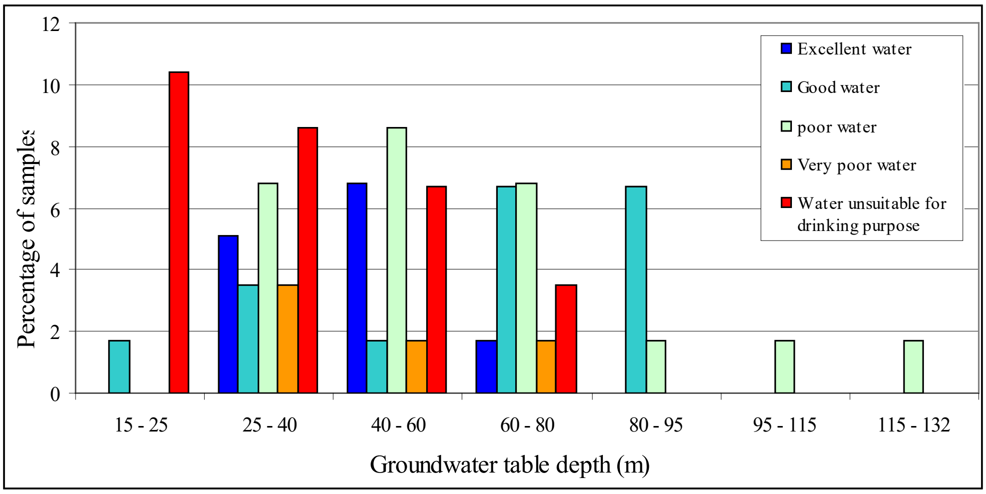

Fig. 18 Correlation of groundwater table with water quality

In order to investigate the correlation of groundwater depth with water quality more deeply, chloride concentration of four wells (No. 8, 6, 29 and 5) with different groundwater depth including shallow, mediocre, deep and very deep were analyzed (Wells are distinguished in Figure 3). It was observed that well No. 8 located in an area with shallow groundwater had the highest amount of chloride concentration followed by well No. 6 which is located in an area with mediocre groundwater level. Well No. 5 which has very deep groundwater level was less contaminated by due to having the lowest amount of chloride concentration. Figure 19 shows this correlation. Therefore, in can be concluded that a negative liner regression correlation exsists. Additionally, groundwater quality in wet and dry seasons was assessed by chloride concentration of the four mentioned wells in the 2004 – 2009 years. In this case April and September were assigned as wet and dry months. As illustrated in Figure 19 it is observed that in wet months with the increase of precipitation, chloride concentration is decreased slightly throughout the years. Whereas, in dry months a rise in the graph is recognized. This event is more distinguished in well No. 8 in the year 2005.

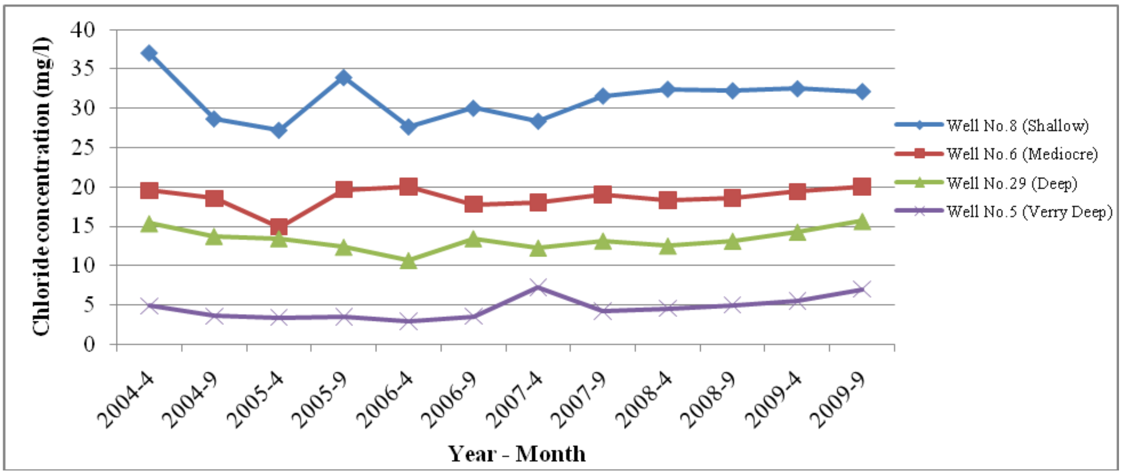

Fig. 19 Correlation of groundwater table with water quality

The correlation of land use with groundwater quality is shown in Figure 20. It is observed that the number of samples rated as unsuitable for drinking in irrigated farming, industrial and urban areas were high when compared to areas with other land use. Near 30 percent of the samples assigned with poor, very poor and unsuitable for drinking were placed in irrigated farming class. The samples exhibiting excellent and good water quality were comparatively greater in range and dry farming areas than other land use classes. There were no samples exhibiting good water quality in neither industrial nor urban classes. From the results obtained it is clear that the agricultural land use with varying crop pattern and irrigation systems with regular irrigation schemes along with fertilizers, play a major role on the groundwater quality of the area.

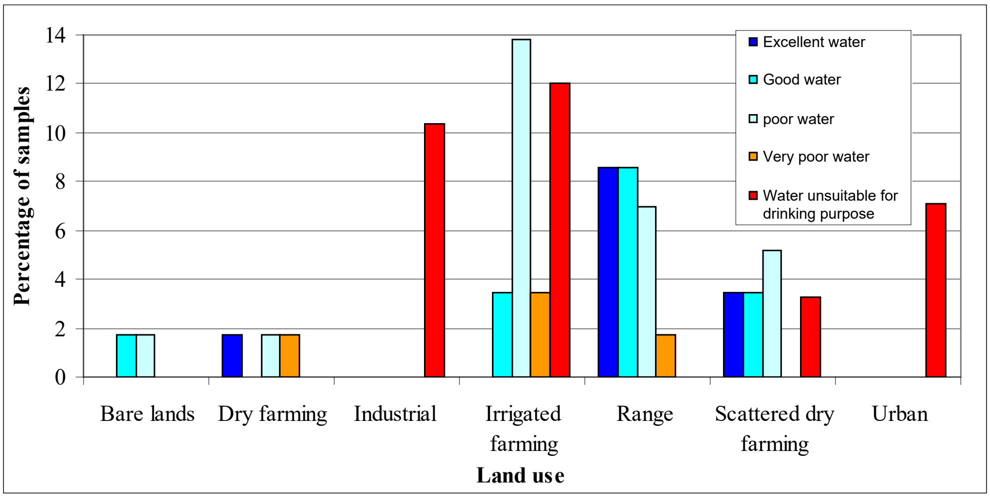

Fig. 20 Correlation of land use with water quality

Statistical Analysis

Statistical Analysis was carried out by SPSS software to determine the parameters contributing to the water quality index. Multiple regression analysis using standardization of the coefficient was done to find out which of the independent variables (quality parameters) had a greater effect on the dependent variable (water quality index). B coefficient shows the coefficient in the model to predict the water quality. Standard Error demonstrates the standard error of beta-coefficient, which is the standardized beta weight of each independent variable. The main focus is on this because the aim here is to evaluate the influence of predictors on water quality rather than predict the water quality. The multiple regression analysis results are presented in Table. It can be noticed that all parameters are statistically significant (0.001) in contribution to the water quality index. However, Chloride, Calcium and Magnesium had the most influence due to having the highest standardized beta coefficient. The ranking based on the standardized beta coefficient is demonstrated in Table 7. It can be mentioned that Chloride, Calcium and Magnesium are very important indicators in determining groundwater quality. Therefore, preparing accurate, detailed, and representative data about these parameters can surely improve the outcome of the model. Moreover, these three parameters can be analyzed to save time, money and energy in regular checkups and have acceptable results.

Table 7 Multiple regression analysis to determine the parameters contributing to the water quality index

physicochemical parameters	B coefficient	Standard Error	Standardized beta	Rank	*ρ* value
TDS	0.0358	0.0000004	0.03	VII	0.001*
CL	0.0716	0.0000007	0.834	I	0.001*
SO4	0.0716	0.0000006	0.033	VI	0.001*
Na	0.0715	0.0000001	0.23	VIII	0.001*
K	0.591666667	0.0000001	0.042	V	0.001*
HCO3	0.03	0.0000008	0.087	IV	0.001*
Ca	0.142666667	0.0000003	0.421	II	0.001*
Mg	0.214	0.0000005	0.267	III	0.001*

* Highly Significant

Conclusion

In this study an attempted has been made to investigate groundwater quality status by the combined use of the Water Quality Index and GIS, applied on a set of original data. The GIS had a major role in the progress and is considered an effective tool, as with GIS software various maps showing spatial distribution of various water quality parameters were prepared and analyzed. Spatial distribution maps were used to confine the locational distribution of water pollutants in a thorough producer and assisted in indicating groundwater contamination control and remedial measures in a comprehensive way. The WQI spatial distribution map clearly shows best sites for drinking in the area. Water quality indices are used to provide valuable tools for decision makers to be able to understand the status of the water quality in a water source and to have the opportunity to make adequate decisions for better use in future. Monitoring of pollution patterns and its trends with respect to urbanization is an important task for achieving sustainable management of groundwater. An integrated GIS study proves to be an essential tool to evaluate and quantify the impacts of land use on ground water quality. This research and its results have shown the great combination use of GIS and WQI in providing a valuable tool for managers to monitor and assess groundwater quality and make necessary decisions in aquifer management of Saveh-Nobaran plain for human consume of groundwater. Moreover, a set of new groundwater data were presented. The overall results show that groundwater quality for drinking consume decrease from west to east of the study area. This is mainly due to the flow direction moving from northeast to southwest. It is recommended future studies should focus on chlorinated solvents, PCBs, perchlorate, pesticides, heavy metals and investigate other common contaminants. Finally, in it is suggested a comprehensive sewerage system for safe disposal of wastes should be developed to safeguard groundwater quality in the study area

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