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Groundwater Quality Assessment for Drinking and Agricultural Purposes in Tabriz Aquifer, Iran

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Abstract

The key goal of the current study was to determine suitable areas of water pumping for drinking and agricultural harvest in Tabriz aquifer, located in East Azerbaijan province, northwest Iran. In the study area, groundwater is the key foundation of water for drinking and farming requirements. Groundwater compatibility study was conducted by analyzing Electrical conductivity (EC), Total dissolved solids (TDS), Chloride (Cl), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Sulfate (SO_4), Total hardness (TH), Bicarbonate (HCO_3), pH, carbonate (CO_3) and Sodium Adsorption Ratio (SAR) obtained from 39 wells in the period of 2003 to 2014. For this purpose, the Water Quality Index (WQI) and irrigation water quality (IWQ) index were utilized. The WQI index zoning exposed that the groundwater of the study area for drinking purposes is categorized as excellent, good and poor water. Most drinking water harvested for urban and rural areas are in the class of 'excellent water'. The results revealed that about 37 percent (296 km^2) of groundwater has high compatibility, and 63 percent of the study area (495 km^2) has average compatibility for agricultural purposes. The trend of IWQ and WQI indexes demonstrates that the groundwater is getting worse over time.

Keywords: Water Quality Index; irrigation water quality; Tabriz Aquifer

Introduction

About two third of the earth planet is enclosed by the life giving liquid which is named water, though 1 percent of whole amount is consisted of drinking water which is appropriate for human consumption. It is obvious that the supreme use of water is for human consumption for responding his needs. If people use water resources with caution, adequate water with decent quality is sufficient for the existing population [1]. Farming is a prevailing segment of the worldwide economy. Farming is notable as the biggest client of crisp water and a noteworthy reason for debasement of surface and groundwater assets and quality.

Groundwater assets are vital for the financial improvement, particularly in parched and semi-bone-dry areas [2]. The quality of water is identified as the normal, physical and compound condition of the water, and additionally, any adjustment that may have been initiated by anthropogenic action [3-6]. The groundwater quality is the consequence of every one of those procedures and responses that follow up on water from the minute it is gathered in the climate until the time it is stored by a well, which is regularly controlled by different physicochemical attributes [7].

The combined effects of populace development and extreme harvestation of groundwater have initiated broad exhaustion and corruption of groundwater assets [8]. Moreover, it is clear that the quality of agricultural water has an influence on the quality of the soil and accordingly on the harvests which are developed on the soil. The interest for farming area and the produces items has advanced quickly in the most recent century due to populace development. Additionally, specialists mention that some elements, for example, more urban areas, more industrialized spaces, bad management of the lands and ecological contamination has forced extra weight on production of agricultural items [9-10]. Therefore, viable exploitation of both the farming area and the irrigation water has turned into a crucial part, if not the essential goal, of several agrarian improvement and administration designs. Hence, evaluating the quality of groundwater is imperative. Conventional assessment of groundwater quality is straightforward yet point by point in view of the individual parameters [11]. Therefore, it is not adequate to give a precise representation of water quality. Hence, water quality indexes have been produced for condensing water quality information in an effectively expressible and justifiable configuration [12-13]. Normally, the nature of a water system sources is related with its (a) saltiness amount, (b) penetration or porousness danger, (c) particular poisonous ions quality, (d) trace elements harmfulness; and, (e) different various influences to defenseless products. It should be noted that these dangers or negative effects could happen simultaneously, which makes assessing harder to accomplish [14]. Simsek and Gunduz [14] suggested an irrigation water quality (IWQ) list to characterize water system quality which was based on the five risk groups that were specified above on touchy harvests.

The IWQ index is a strategy in which the linear blending of factors in a collection of water system quality that impact soil quality and harvest yield in a negative way [15]. Numerous analysts have

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used this index for irrigation water system goal in light of diverse hydrochemical parameters due to its easiness of use and thought particularly for the nontechnical chief [16-19].

The key water quality index (WQI) was created by choosing and presenting an accumulation function [20]. WQI index is utilized for qualitative zoning of the aquifers from the drinking aspect and also for determining the proper places of drinking water wells in most research plots such as [21-27].

A Geographical Information System (GIS) is a capable instrument for putting away, controlling, examining, and mapping spatial information for making decisions in a multiple regions at one time, which natural issues is a good example of it [28]. Many studies such as Narany et al. [17] and Manap et al. [29] have effectively used GIS in demonstrating the distribution of water quality parameters. It is vital to preserve the sustainability of the quality of the aquifer because groundwater in the study area is mostly implemented for agriculture and rural and urban drinking purposes. Therefore, for achieving a better understanding of procedures and the current form of groundwater quality in the study area, the following objectives were defined:

1) Identifying areas of aquifer feeding
2) Determining the WQI in aquifer in the 24 time periods
3) Investigating the alterations in WQI for drinking water through the statistical period
4) Checking water quality status in tapping drinking wells and determining suitable locations for extracting drinking water
5) determining the IWQ in aquifer in the 24 time periods
6) Investigating the variations in WQI for agricultural water during the statistical period
7) Checking water quality status in the agricultural wells and determining appropriate and inappropriate locations for extracting agricultural water

Materials and Methods

Study Area

The study area is Tabriz plain aquifer situated in East Azerbaijan province, Iran, with an area of 791 km2 (Figure 1). The most surface of the area is cultivated as apples, pears, apricots, peaches, cherries, green beans, leek, spinach and squash. About 40 percent (50 million cubic meters) of Tabriz city (with a population of 1.7 million) drinking water is also provided from the same aquifer. The mean yearly precipitation of Tabriz is nearly 290 mm, which is very low contrasted with the world normal which is 800 mm. The average temperature is 12.5°C, and as indicated by the De Martonne aridity index, the district of study is categorized as a semiarid territory [30-31]. Water assets of the aquifers start from rainfall, energizes from the streams, groundwater spill out of encompassing mountains, water system return streams water, city and industry wasted waters. Generally, there are three harvesting types in the study area, including harvest for supplying urban water, rural water and agriculture water. The number of urban, rural and agricultural water harvesting wells in the study area are 81, 50 and is 3884 respectively. To provide the best quality drinking water, the position of Tabriz drinking water wells are embedded at the entry of the groundwater flows of the aquifer. Water depth in the area fluctuates between 1.5 and 186 meters and the overall average is 21 meters. Most of the groundwater flow entering to the aquifer is from the southern and southeastern highlands [32-33]. The highest water level is 2049.56 m and the lowest is 1262.8 m. It should be noted that the whole physical and chemical data were acquired from Iranian Meteorological Organization.

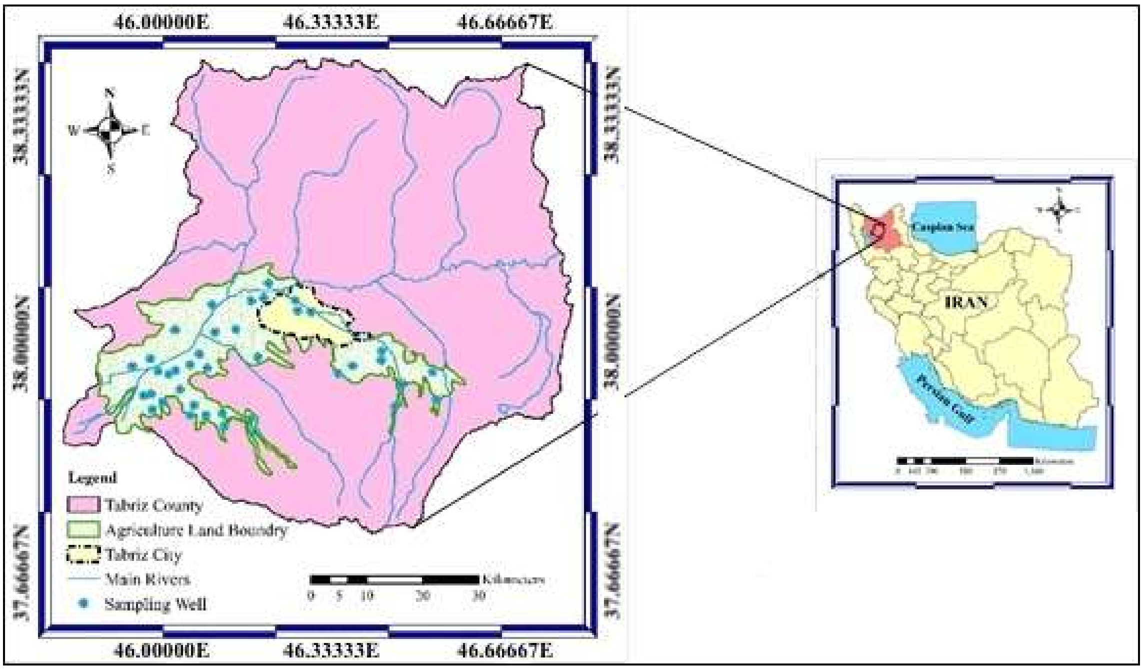

Figure 1. The geographical position of the study area with sites of sampled wells

Data collection

EC, TDS, Cl, Ca, Mg, Na, K, SO_4, TH, HCO_3, pH, CO_3 and SAR data were obtained twice in May and September from 39 wells n the period of 2003 to 2014 (Figure 1). A total of 936 samples were utilized for analysis. Brief statistical parameters of each well in the studied period are presented in Table 1.

Table 1. The statistical properties of the qualitative parameters in Tabriz plain aquifer, during the period between 2003 to 2014

Parameters	Unit	Min	Max	Average	Standard Deviation
SO_4	(mg/L)	0.08	22.13	4.76	4.52
Cl	(mg/L)	0.20	102.50	15.05	20.47
HCO_3	(mg/L)	0.58	10.97	4.05	2.07
CO3	(mg/L)	0.00	1.03	0.12	0.19
pH	-	6.35	9.45	7.91	0.58
EC	(µmhos/cm)	186.55	11560.00	2393.27	2406.94

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K	(mg/L)	0.00	0.78	0.23	0.16
Na	(mg/L)	0.44	48.25	10.85	12.58
Mg	(mg/L)	0.25	22.60	4.97	4.76
Ca	(mg/L)	0.80	50.00	7.93	9.34
TH	(mg/L)	31.35	3625.00	620.24	682.19
TDS	(mg/L)	111.93	7514.00	1550.23	1563.50
SAR	-	0.40	24.83	3.91	3.89

Irrigation groundwater quality index (IWQ index)

The hydrochemical parameters employed for evaluating the irrigation water quality are selected according to Simsek and Gunduz [14] and Ayers and Westcot [34]. The minimum and maximum weights of 1 and 5 have been allocated to pH and EC according to their importance on irrigation water quality. Moreover, different weights among 1 and 5 were considered to other hazards due to the significance of their role on irrigation water quality. Furthermore, the scale of rating is altered from 1 as low suitability for irrigation, to 3 as high suitability for irrigation, for every single parameter [14, 19]. The suggested IWQ index, which assesses the joint effect of quality parameter is calculated according to Eqs. 2 and 3.

$$W_i = \frac{w}{N}\sum_{i=1}^{N} R_i \qquad (2)$$

$$IWQ\ Index = \sum W_i \qquad (3)$$

where W is the involvement of each one of the five mentioned hazards, w is the weight of each hazard, N is the total number parameters and R is the rating value.

According to the unavailability of all water quality data, four risk groups of Salinity, Infiltration and permeability, particularly ion toxicity and miscellaneous impacts to sensitive cops were implemented to determine the quality of the aquifer used for agricultural dedications in the study zone.

After the estimation of the index value, an appropriate examination is done in light of the three unique classes. The IWQ lower than 19 is specified as low, between 19 and 32 as Medium and higher than 32 as high. The qualities is gotten using several rating factors (i.e., 1, 2 and 3) to every parameter without changing its measuring efficiency, along these lines yielding three diverse values for index (i.e.,39, 26 and 13). The average of these values is utilized to set the upper and lower limits which are utilized as a part of every specific classification [14].

Water Quality Index (WQI index)

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Horton [35] was the first in representing the quality of groundwater by indices. WQI is among the numerous tools for presenting the data on the nature of water [36]. WQI is characterized as a rating which indicates the impact of several parameters on the general nature of water [37]. In that capacity, it is a significant marker for the evaluation and administration of groundwater. WQI is assessed in light of the appropriateness of groundwater for human utilization.

Three stages are done for calculating WQI. In the initial step, weight (w_i) of each water quality parameter is measured as indicated by its significance in the general nature of water for drinking purposes. At that point, the relative weight (W_i) is figured by Eq (4) by the following formula [38]:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{4}$$

In the formula above, n is the quantity of parameters. In the second step, a rating of quality (q_i) is ascertained for every parameter, and the ratio of its individual standard value is measured based on the rules from the WHO [39]:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{5}$$

In the formula above, C_i is the concentration of chemical parameters for water samples which is expressed in mg/L, and Si is the standard of WHO for drinking water for every substance parameter in mg/L. In the third step, the WQI is measured as [40]:

$$WQI = \sum_{i=1}^{n} W_i q_i \tag{6}$$

Values of WQI are usually processed and then grouped into five excellent, good, poor, very poor and inappropriate classes of water for drinking [13].

12 parameters were included in calculating WQI by the weighted arithmetic technique. Standard of WHO for drinking water for every chemical parameter by the rules of WHO [39] are recorded in Table 2. Every parameter has a weight as for its significance for the nature of water for drinking purposes, and 5 is the maximum weight which stands for the total dissolved solids (TDS) and EC; weight of 4 is allocated to SO_4 and TH; weight of 3 is allotted to pH, Cl and Na; and weight of 2 is appointed to K, Mg, Ca, CO_3 and HCO_3.

Table 2. Desirable limits of parameters and assigned relative weight

Parameters	WHO desirable limit (mg/L)	WHO allowable limit (mg/L)	Weight (w_i)	Relative Weight (W_i)
TDS	500 (mg/L)	1,000 (mg/L)	5	0.135
pH	6.5–8.5	8.5	3	0.081
EC	1,500 µs/cm	1,500 µs/cm	5	0.135
TH	300 (mg/L)	600 (mg/L)	4	0.108

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Ca	75 (mg/L)	75 (mg/L)	2	0.054
Na	200 (mg/L)	200 (mg/L)	3	0.081
Mg	30 (mg/L)	30 (mg/L)	2	0.054
K	10 (mg/L)	10 (mg/L)	2	0.054
CL	200 (mg/L)	200 (mg/L)	3	0.081
CO_3	100 (mg/L)	100 (mg/L)	2	0.054
SO_4	200 (mg/L)	200 (mg/L)	4	0.108
HCO_3	100 (mg/L)	100 (mg/L)	2	0.054

Results and Discussion

WQI index was computed for 24 periods of May and September between, 2003 and 2014, respectively. The minimum value for WQI index in these 24 periods of time was equal to 12.14 and the maximum value was equal to 300.53. Regression equation between WQI index and time (t) was obtained in order to assess WQI index general procedures in each of the wells studied (Table 3).

Table 3. The linear regression equation between WQI index and time from 2003 to 2014

Well Number	regression equation	Well Number	regression equation
1	WQI=0.48t+17.92	21	WQI=-0.29t+29.88
2	WQI=1.91t+4.54	22	WQI=0.95t+17.08
3	WQI=-0.15t+48.38	23	WQI=1.86t+37.59
4	WQI=-0.03t+19.16	24	WQI=0.05t+17.43
5	WQI=1.01t+8.92	25	WQI=-1.28t+177.42
6	WQI=0.88t+14.60	26	WQI=-1.16t+151.8
7	WQI=1.18t+174.63	27	WQI=-1.16t+98.29
8	WQI=0.72t+42.66	28	WQI=-1.28t+168.65
9	WQI=0.17t+71.64	29	WQI=2.06t+27.58
10	WQI=1.67t+108.24	30	WQI=0.47t+59.95
11	WQI=-0.02t+18.90	31	WQI=0.47t+21.29
12	WQI=-0.02t+22.01	32	WQI=-0.20t+54.52
13	WQI=0.48t+135.20	33	WQI=-0.001t+17.22
14	WQI=-0.61t+62.01	34	WQI=0.13t+15.05
15	WQI=-0.54t+116.15	35	WQI=-0.57t+79.78
16	WQI=-0.074t+24.17	36	WQI=-2.43t+139
17	WQI=3.19t+195.82	37	WQI=-0.08t+17.75
18	WQI=0.56t+52.49	38	WQI=-0.06t+14.69
19	WQI=-0.62t+77.68	39	WQI=2.54t+71.97
20	WQI=0.50t+24.38		

According to Table 3 WQI index value has decreased in 19 wells, while in other wells an increasing trend can be concluded. The decreased WQI index procedure shows an enhancement in drinking groundwater, while an increasing trend shows reduction of drinking groundwater quality. Of the 936 samples obtained from 39 wells in the period between 2003 to 2014, 497 water samples were categorized as 'excellent water', 217 water samples were classified as 'good water', 188 water samples were classified as 'poor water', 31 water samples were classified as 'very poor water' and 3 water samples were classified as 'unsuitable water for drinking'. The average value of the WQI index was determined after calculating the area of Thiessen polygons for each of the 39 studied wells according to the area affected by each of the wells of. Figure 2a displays the average WQI index in the study area during the statistical period. According to this figure, WQI index of the area has an increasing trend. In fact, the quality of groundwater for drinking has been decreased over the time. Despite the decline in the quality of drinking groundwater, the average WQI index of aquifer still is in 'good water' class over the study time. Therefore, a serious and distributive risk of inappropriate water quality cannot be confirmed for the aquifer which is supplying urban and rural water.

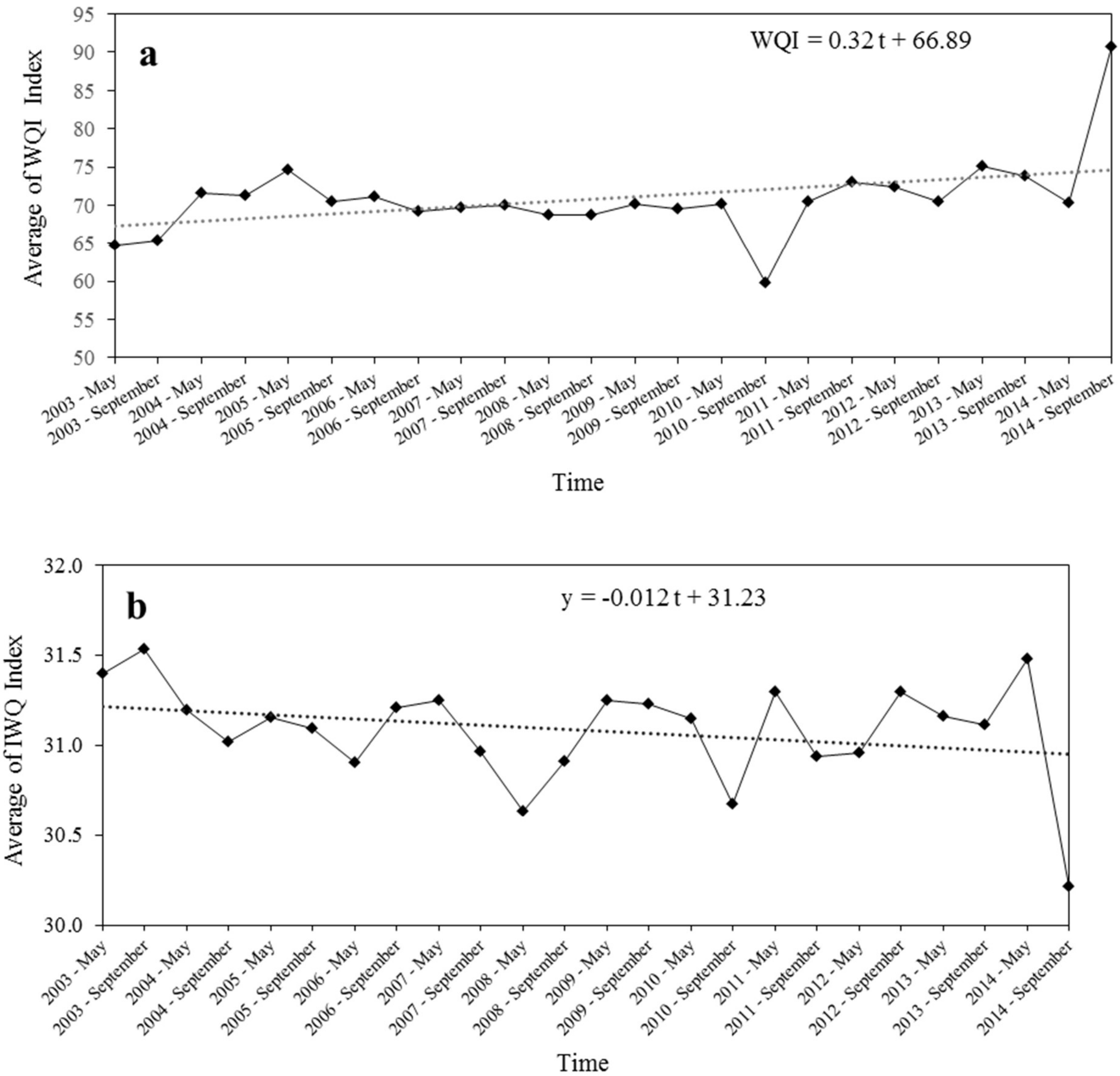

Figure 2. Moderate gradual changes in the WQI and IWQ indexes in the entire study area

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Geographical distributions of studied parameters in the study area are illustrated in Figure 3. It should be noted that the distribution figures were pictured using inverse distance weighting (IDW) interpolation method. Seventy out of 81 wells supplying urban drinking water are classified as 'excellent water' and the rest of the wells are classified as 'good water' (Figure 3a). 27 out of 50 wells supplying rural drinking water are classified as 'excellent water', 19 are marked as 'good water' and 4 wells are in class of 'poor water'. According to the results, the condition of urban drinking water wells is very good. But the situation of 4 rural drinking water wells is not appropriate and the position of the wells or the water source of the villages covered by these 4 wells should be changed. Therefore, generally the position of the urban and rural water wells has been chosen carefully. It is recommended that drinking water is supplied from South and Eastern areas of the study range which are the main areas feeding the aquifer and has very good water quality.

Salinity and Permeability and infiltration hazard weights equal to 5 and 4, respectively, have the greatest impact on agricultural water quality index. Spatial distribution of electrical conductivity average measured in 39 wells is shown in Figure 3b. Aquifer feeding regions which mostly include the south and eastern parts of the study area have the lowest amount of EC, and the closer to the center of the study area, the increase in the EC values (Figure 3b). Mosaedi et al. [41] showed that the central regions of Tabriz plain have high salinity and the eastern regions have low salinity. The quality of underground water in the central regions of Tabriz plain is more undesirable than the aquifer feeding areas [42].18% of the total area has EC amount less than 700 (μs / cm) (143 km^2), 48% of the area has more EC than 3000 (μs / cm) (380 km^2) and 34 percent (268 km^2) has EC between 700 to 3000 (μs / cm). The highest and lowest average amount of SAR is respectively 0.69 and 14.96 (Figure 3c). SAR amount is low in the aquifer feed zone as well as the EC, and it will increase as getting close to the North and West of the aquifer. Studies have shown that groundwater quality in the aquifer feeding areas of Tabriz plain is better than other areas of this plain [42-43].

The study area is classified as Hazard from the infiltration and permeability aspect (Figure 3d). Increased amount of EC and SAR values in a region can neutralizes the negative effects of each parameter. Therefore, due to the large quantities of EC and SAR in central, northern and western region of the study area, infiltration and permeability hazard in these areas are low. According to Figure 3d, the average 4.21 percent of the area (33 km^2) was rated 1 to 2 and 95.79 percent (758 km^2) of the region was rated 2 to 3. In fact, agricultural water in this area is not a limiting factor for infiltration and permeability hazard.

IWQ index for the 24 periods, the months of May and September 2003 and 2014 was calculated in the study. IWQ lowest index value in the 24 periods was 21 and the maximum was 35. Area IWQ index average was calculated based on the area of Thiessen polygons corresponding to each of the wells. IWQ index change trend over the time is shown in Figure 2b. According to this figure, IWQ index is suitable over the time in terms of climate adaptation for farming in the area. Very little negative IWQ indicator over the time suggests the sustainability of groundwater quality for agricultural purposes in the study area as well. For maintaining the quality of the aquifer, necessary measures should be taken in order to eliminate the negative trend and then progress to a positive

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trend for the IWQ index be done. The values of IWQ vary from 25.9 to 34.55 for the whole region (Figure 3e). According to the abovementioned ranges, the values of IWQ in Figure 3e suggest that about 37 percent (296 km²) of groundwater in the study area has high compatibility and the remaining 63 percent (495 km²) has a moderate adaptation for agricultural purposes. The results also show that 2227 agricultural wells harvest groundwater with medium Suitability and 1657 agricultural wells harvest groundwater with high Suitability.

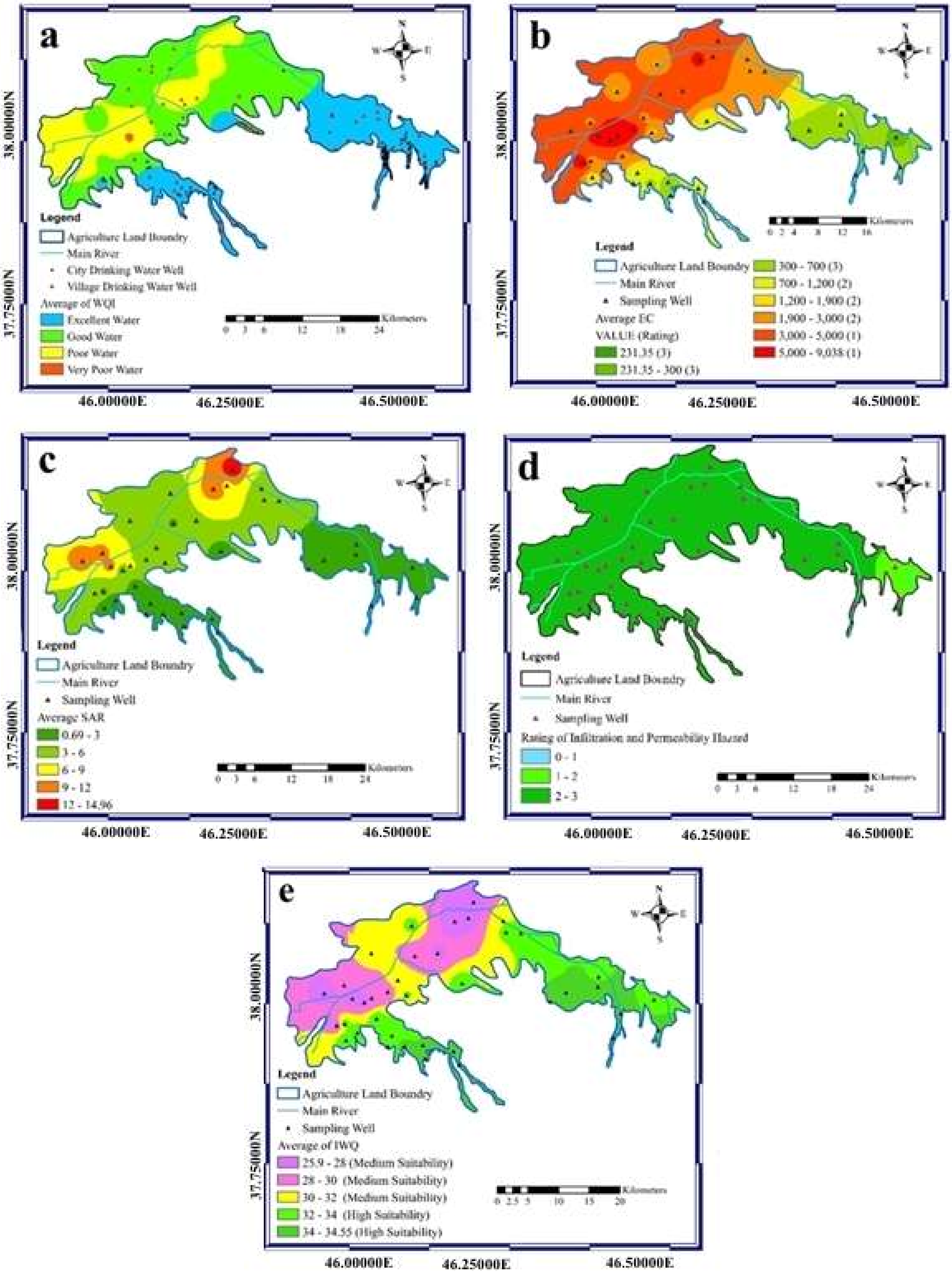

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Figure 3. Geographical distribution of studied parameters in the study area

Conclusions

This study disclosed that the use of indicators for evaluating the quality of groundwater can provide a good general overview to water and environmental managers in order to make better management decisions on Tabriz aquifer. WQI and IWQ indexes offer suitable areas for harvesting drinking and agricultural water, respectively. The suitability of water taken from wells in the study area by the type of application is also determined using these indexes. Therefore, water and environmental managers can use drinking and agricultural water suitability maps to change the inappropriate wells location. Agriculture managing organizations can also determine the type, amount, and irrigation of each produvt of the region products based on the suitability of groundwater in that area in order to increase the production and maintain the stability of soil type. The results showed that in terms of consistency, the most urban and rural water wells were classified as 'excellent water' and 'good water'. Due to the agricultural water compatibility zoning map in the study area, there is no low suitability range, and the area has high and medium suitability groundwater for agricultural purposes. The WQI and IWQ index changes over the time in the study area show the decrease in groundwater quality for drinking and agriculture purposes, respectively. Water contamination can be controlled by limiting natural, farming run-off and urban land utilizes contamination.

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