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EVALUATION OF GROUNDWATER QUALITY FOR SUSTAINABLE DRINKING AND IRRIGATION

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Abstract: The preservation of freshwater resources in arid and semi-arid regions, which is crucial for sustainable development, depends heavily on the identification and management of the groundwater quality. Local authorities and water resource managers might divide the use of resources between agricultural and drinking purposes depending on the quality of the groundwater in different places. In the Tabriz aquifer, which is situated in the province of East Azerbaijan, northwest Iran, this study seeks to pinpoint regions where water pumping is appropriate for harvesting and use for drinking. A groundwater compatibility study was carried out using data from 39 wells collected between 2003 and 2014, including electrical conductivity (EC), total dissolved solids (TDS), chloride (Cl), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulphate (SO_4), total hardness (TH), bicarbonate (HCO3), pH, carbonate (CO_3), and sodium adsorption ratio (SAR). Due to their significant significance in determining the quality of water resources for irrigation and drinking, the Water Quality Index (WQI) and Irrigation Water Quality (IWQ) indexes are used in conjunction with one another. Water was zoned as excellent, good, or bad according to the WQI index for drinking water. The research comes to the conclusion that the majority of drinking water gathered for urban and rural regions is "excellent water" or "good water".

Keywords: sustainable water harvesting; water quality index (WQI); irrigation water quality (IWQ); groundwater quality; hydro informatics; hydrologic cycle; earth system models; hydrology; climate change; water resource management; sustainable development

1. Introduction

There is a severe lack of freshwater resources. The amount of water on earth that is appropriate for human consumption is less than 1%. Freshwater resources must be managed and safeguarded as a result [1]. One of the key initiatives of local and national governments has been to regulate and limit freshwater consumption for agricultural purposes in order to safeguard this priceless resource for sustainable development. However, agriculture continues to be a significant part of the global economy [2]. The largest consumer of clean water is agriculture, which is also a significant factor in the degradation of surface and groundwater assets and quality [2]. In locations that are arid and nearly bone dry, groundwater assets are especially important for financial growth [3]. The natural, physical, and chemical conditions of the water are considered to represent its quality, together with any alterations that may have been brought on by anthropogenic activity [4–7]. The process of handling water from the moment it is first collected until it is kept in a well, which is frequently governed by many physicochemical characteristics, has an impact on the quality of the groundwater [8].

Groundwater resources have been severely depleted and corrupted as a result of population increase and excessive groundwater use [9]. Furthermore, it is obvious that the quality of agricultural water affects the quality of the soil and, consequently, the yields that are produced. Due to population increase, interest in farming regions and the goods produced by these farms has risen fast in the most recent century. Additionally, experts have noted that a number of factors, including an increase in the number of metropolitan areas, industrialised spaces, poorly managed fields, and ecological pollution, have added additional pressure to the production of agricultural goods [10,11]. Therefore, a key component, if not the primary purpose, of many agricultural improvement and administration designs has been the viably utilisation of both the farmed land and the irrigation water. Therefore, it is crucial to assess the quality of groundwater. A typical assessment of groundwater quality is simple, but it necessitates a step-by-step procedure taking each element into account [12]. As a result, it is inadequate for giving a detailed picture of the quality of the water. In order to get water quality information in a configuration that is both efficiently expressible and defensible, water quality indexes have been developed [13,14]. The character of a water system source is typically determined by its (a) salinity level, (b) danger of penetration or porousness, (c) quality of certain toxic ions, (d) harmfulness of trace elements, and (e) numerous other impacts. It should be highlighted that various risks or adverse consequences might manifest concurrently, making it more challenging to conduct water evaluations [15]. Simsek and Gunduz [15] proposed an irrigation water quality (IWQ) list based on the five risk areas mentioned above for harvests to characterise the quality of water systems.

The IWQ index is an approach that linearly blends the elements of the water system quality that adversely impact soil quality and crop yield [16]. Due to its simplicity of use, especially for non-technical individuals, many analysts have employed this index to meet irrigation water system goals in light of various hydrochemical characteristics [17–20]. The selection and presentation of an accumulation function led to the creation of the main water quality index (WQI) [21]. The WQI index has been used in several research works, including those of Effendi and Wardiatno [22], Chen et al. [23], Bodrud-Doza et al. [24], and Fijani, for qualitative zoning of the aquifers for drinking purposes as well as for finding the best sites for drinking water wells. A Geographical Information System (GIS) is an effective tool for storing, managing, reviewing, and mapping spatial information for choices in several locations at once, which aids in addressing pertinent basic concerns. Many research, like Narany et al. [18] and Manap et al., have successfully used GIS to show how water quality metrics are distributed. Because groundwater in the research region is primarily utilised for agricultural as well as for drinking water in rural and urban areas, GIS is essential to maintaining the sustainability of the investigated aquifer's quality. Therefore, the following goals were established in order to better understand the processes and the state of groundwater quality in the research area:

1. Identifying areas of aquifer feeding
2. Determining the WQI in the aquifer
3. Investigating the alterations in WQI for drinking water through the statistical period
4. Checking the water quality status in tapping drinking wells and determining suitable locations for extracting drinking water
5. determining the IWQ in the aquifer
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.

2. Materials and Methods

2.1. Water Quality

The irrigation water's quality is determined by the kind and quantity of dissolved substances present. In general, the quality of irrigation water is assessed using salinity, specific ion toxicity, trace element toxicity, and other impacts on delicate crops.

In general, crops may experience physiological drought when exposed to high electrical conductivity. Typically, waters classified as appropriate irrigation waters have EC values lower than 700 S/cm. The sodium adsorption ratio (SAR) and salinity are the two frequently occurring variables that influence penetration.

Irrigation water's SAR value is calculated as follows:

$$\mathrm{SAR}=\frac{[Na+]}{\sqrt{\frac{Ca++]+[Mg++]}{2}}} \qquad (1)$$

where [Na+], [Ca++], and [Mg++] represent, respectively, the concentrations of sodium, calcium, and magnesium ions in water. To assess the potential danger of penetration in the soil, a grouping of the EC-SAR paradigm was used [15]. According to reports, when soil is inundated by fluids with a high sodium content, a high sodium surface is produced that weakens the soil's structural integrity. The soil contracts, and as a result, its pores are damaged and it is dispersed into smaller components. The amount of clay in the soil is another crucial factor. Because the soil mud particles disperse when the SAR value is high, this has an adverse effect on the soil structure [15].

When the concentration of some ions in water or soil is too high, plants become poisonous, including salt, chloride, and boron. Ion concentrations in plants are considered hazardous when they are predicted to damage the plant or reduce yield. The level of toxicity varies depending on the type of plant and how well ions are absorbed. Crops that are long-lasting and resilient are more vulnerable to this form of toxicity than plants that are harvested within a year. If chloride ions build up in plants, they can reduce yields since they might come through the water system [2]. Low quantities of chloride are extremely beneficial to crops. However, toxicity begins to emerge when the concentration levels above 140 mg/L. The burning of leaves or the drying of leaf tissue are indications of injury. In contrast to other particles' obvious harmful nature, toxic sodium concentrations are subtly bothersome. The scorching of leaves or dead tissues around the exterior edges of leaves are typical toxicity manifestations on the plants. Contrarily, the negative consequences of poisonous chloride concentration typically begin with the emergence of atypical leaf tips.

It is a truth that plants and other living things require trace elements in small proportions, but larger concentrations of these elements are harmful to both plants and humans. Chromium, selenium, and arsenic pose a significant threat to groundwater resources [20]. The use of nitrogen fertilisers, farming practises, and other human activities all contribute to an increase in groundwater nitrate [2]. pH values are related to the alkalinity of water.

2.2. Irrigation Groundwater Quality Index (IWQ Index)

Simsek and Gunduz as well as Ayers and Westcot were taken into consideration while choosing the hydrochemical criteria used to assess the irrigation water quality [15]. Based on how crucial they are to the quality of irrigation water, pH and EC have been given minimum and maximum weights of 1 and 5, respectively. Furthermore, according to the magnitude of their impacts on irrigation water quality, various weights between 1 and 5 were taken into consideration for additional dangers that have a variety of effects on sensitive crops. Additionally, the rating scale was changed for every parameter [15,20] from 1 indicating a low appropriateness for irrigation to 3 indicating a good suitability for irrigation. Equations (2) and (3) were used to produce the proposed IWQ index, which evaluates the combined influence of quality characteristics.

$$\mathrm{W_i}=\frac{w}{N}\sum\sum_{i=1}^{N} R_{\mathrm{I}} \qquad (2)$$

$$IWQIndex = \quad \sum W_i \qquad (3)$$

where W is the contribution of each of the five hazards—salinity, infiltration, particular ion toxicity, trace element toxicity, and other effects—mentioned above. N is the total number of parameters, w is the weight of each hazard, and R is the rating value.

In order to assess the quality of the aquifer utilised for agricultural water supplies in the research zone, four risk groups centred on salinity, infiltration, and permeability, specifically ion toxicity and other consequences to sensitive plants, were implemented.

Following the determination of the index value, the three distinct classes listed in Table 1 were appropriately examined. Table 1 shows that the IWQ was classified as low if it was lower than 19, medium if it was between 19 and 32, and high if it was more than 32. Each parameter's measurement coefficients were left unchanged while several rating factors (i.e., 1, 2, and 3) were used to get the attributes, resulting in three distinct index values (i.e., 39, 26 and 13). The upper and lower limits for each given categorization were determined by taking the average of these values [15].

Table 1. The evaluation limits of the IWQ index.

IWQ Index	Suitability of Water for Irrigation
<19	Low
19–32	Medium
>32	High

2.3. Water Quality Index (WQI Index)

Horton was the first to use indices to indicate groundwater quality. The Water Quality Index (WQI) is one of the many instruments available for displaying data on the nature of water [34]. A grading system known as WQI is used to show how different parameters affect the general quality of water [35]. It serves as a crucial marker for the assessment and management of groundwater in that capacity. WQI is evaluated in light of how suitable the groundwater is for human use.

For the purposes of determining WQI, three steps are taken. Due to its importance for drinking water, the weight (Wi) of each water quality parameter is assessed in the first phase. Equation (4) uses the following equation to get the relative weight (Wi): w_i

$$Wi = \frac{w}{\sum_{i=1}^{n} w} \tag{4}$$

In the formula above, *n* is the number 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:

$$q_i = \frac{C_i}{S_i} \times 100. \tag{5}$$

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

$$WQI = \sum_{i=1}^{n} Wiqi. \tag{6}$$

As shown in Table 2, WQI results are typically analysed and then categorised into five categories of drinking water: excellent, good, bad, extremely poor, and improper. The weighted arithmetic method of determining WQI included twelve parameters. Each characteristic is given a weight according on how important it is for drinking, with 5 representing total dissolved solids (TDS) and EC, 4 representing SO4 and TH, 3 representing pH, Cl, and Na, and 2 representing K, Mg, Ca, CO3, and HCO3.

Table 2. Water quality classification based on WQI value.

Classification of Drinking Water Quality

WQI Range	Class	Type of Water
below 50	I	Excellent water
50–100	II	Good water
100–200	III	Poor water
200–300	IV	Very poor water
above 300	V	Water unsuitable for drinking

2.4. Study Area

The research region is the 791 km2 Tabriz plain aquifer in Iran's East Azerbaijan province (Figure 1). Apples, pears, apricots, peaches, cherries, green beans, leeks, spinach, and squash are all grown on the majority of the land in the region. The same aquifer also supplies around 40% (50 million cubic metres) of Tabriz city's (population: 1.7 million) potable water. The average annual precipitation of Tabriz is close to 290 mm, which is extremely less when compared to the 800 mm global average. The research area may be classified as a semiarid region because of the average temperature of 12.5 C and the De Martonne aridity index. The aquifers' water resources come from rainfall and flow through streams, while the nearby mountains' groundwater seeps out. The water system also recycles industrial and municipal waste waters. In the research region, there are typically three different types of harvesting: harvests for supplying urban water, rural water, and agricultural water. In the research region, there are 81, 50, and 3884 water harvesting wells for agricultural, rural, and urban purposes, respectively. The drinking water wells in Tabriz are buried at the point where the aquifer's groundwater enters to provide the highest possible quality of drinking water. The average water depth in the region is 21 metres, however it may range from 1.5 to 186 metres.

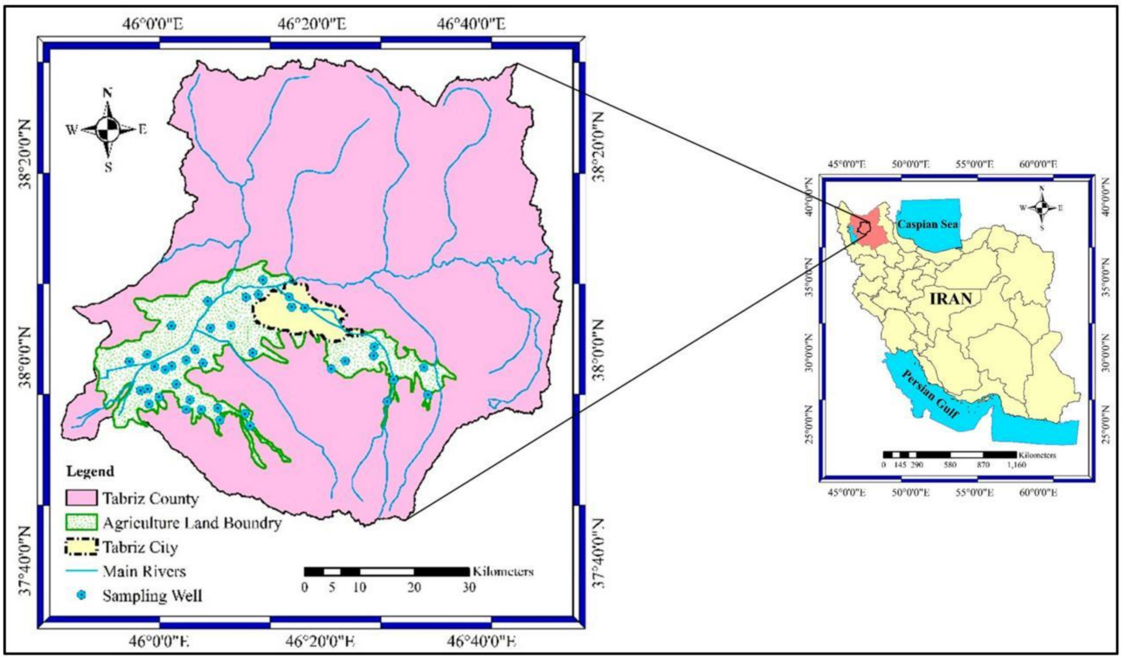

Figure 1. The geographical position of the study area with sites of sampled wells.

2.5. Data Collection

39 wells from the years 2003 to 2014 were sampled twice, in May and September, for electrical conductivity (EC), total dissolved solids (TDS), chloride (Cl), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulphate (SO4), total hardness (TH), bicarbonate (HCO3), pH, carbonate (CO3), and sodium adsorption ratio (SAR) data (Figure 1). Only two measurements of the water quality in the study region were made, one in May when the groundwater level was at its peak and the other in September when it was at its lowest. Additionally, the usefulness of the aforementioned criteria for irrigation and drinking purposes was taken into consideration. 936 samples in total were used for the analysis. Table 3 shows brief statistical characteristics of each well throughout the time period under consideration.

Table 3. The statistical properties of the qualitative parameters in Tabriz plain aquifer during the period between 2003 to 2014.

Parameters	Unit	Min	Max	Average	Standard Devision
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	(µmho/cm)	186.55	11,560.00	2393.27	2406.94
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

3. Results and Discussion

Between 2003 and 2014, the WQI index was calculated 24 times, twice in May and once in September. The WQI index ranged from 12.14 as the least value to 300.53 as the greatest value. To evaluate the general WQI index processes in each of the investigated wells, the regression equation between the WQI index and time (t) was obtained (Table 4).

Table 4. The linear regression equation between the WQI index and time from 2003 to 2014.

Well Number	Regression Equation	Correlation Coefficient	Well Number	Regression Equation	Correlation Coefficient
1	$WQI = 1.6939t + 15.355$	0.55	21	$WQI = -0.2128t + 28.505$	0.40
2	$WQI = 0.2421t + 18.094$	0.94	22	$WQI = -0.3667t + 24.643$	0.55
3	$WQI = -0.2941t + 49.447$	0.63	23	$WQI = 1.0321t + 44.451$	0.84
4	$WQI = -0.0729t + 19.488$	0.61	24	$WQI = 0.1134t + 17.292$	0.36
5	$WQI = 0.3631t + 15.272$	0.71	25	$WQI = -0.9066t + 171.89$	0.49
6	$WQI = 3.0499t + 7.8392$	0.82	26	$WQI = -1.3891t + 149.53$	0.63
7	$WQI = 3.288t + 171.85$	0.83	27	$WQI = -1.5646t + 97.094$	0.71
8	$WQI = 3.1769t + 21.563$	0.69	28	$WQI = -5.2218t + 210.01$	0.73
9	$WQI = -0.7188t + 77.803$	0.57	29	$WQI = 0.0781t + 45.126$	0.08
10	$WQI = 3.4849t + 109.04$	0.98	30	$WQI = -0.3709t + 64.842$	0.50
11	$WQI = -0.0508t + 19.439$	0.26	31	$WQI = 1.149t + 19.474$	0.93
12	$WQI = -0.038t + 22.085$	0.52	32	$WQI = -0.3804t + 53.272$	0.44
13	$WQI = 1.9223t + 131$	0.74	33	$WQI = -0.1622t + 17.845$	0.71
14	$WQI = -1.3849t + 63.949$	0.83	34	$WQI = 0.0509t + 16.505$	0.18
15	$WQI = 1.2416t + 118.07$	0.62	35	$WQI = -0.9229t + 79.56$	0.66
16	$WQI = 0.1337t +$	0.47	36	$WQI = -3.5949t +$	0.90

	23.677			128.41	
17	WQI = 7.9565t + 208.11	0.78	37	WQI =-0.1744t + 17.907	0.37
18	WQI = 1.1912t + 51.941	0.89	38	WQI =-0.0247t + 13.77	0.10
19	WQI = 1.7036t + 66.614	0.88	39	WQI = 2.015t + 98.716	0.96
20	WQI = 0.1387t + 28.494	0.46			

Table 4 shows that the WQI index value has reduced in 19 wells while showing a rising tendency in the remaining wells. Drinking groundwater quality has increased as shown by the WQI index procedure, but has worsened as shown by an increasing trend. Out of the 936 samples collected from 39 wells between 2003 and 2014, 497 samples were labelled as having "excellent water," 217 samples as having "good water," 188 samples as having "poor water," 31 samples as having "very poor water," and three samples were labelled as having "unsuitable water for drinking." After calculating the size of Thiessen polygons for each of the 39 analysed wells based on the region impacted by each well, the average value of the WQI index was established. The average WQI index for the study region for the statistical period is shown in Figure 2a. This data shows that the WQI index for the region is trending upward. Drinking-quality groundwater has gotten worse over time. The average WQI index of the aquifer remains in the "good water" class across the research period, despite the deterioration in the quality of drinking groundwater. As a result, the aquifer, which provides water to both urban and rural areas, cannot be proved to pose a major and widespread danger of unsuitable water quality.

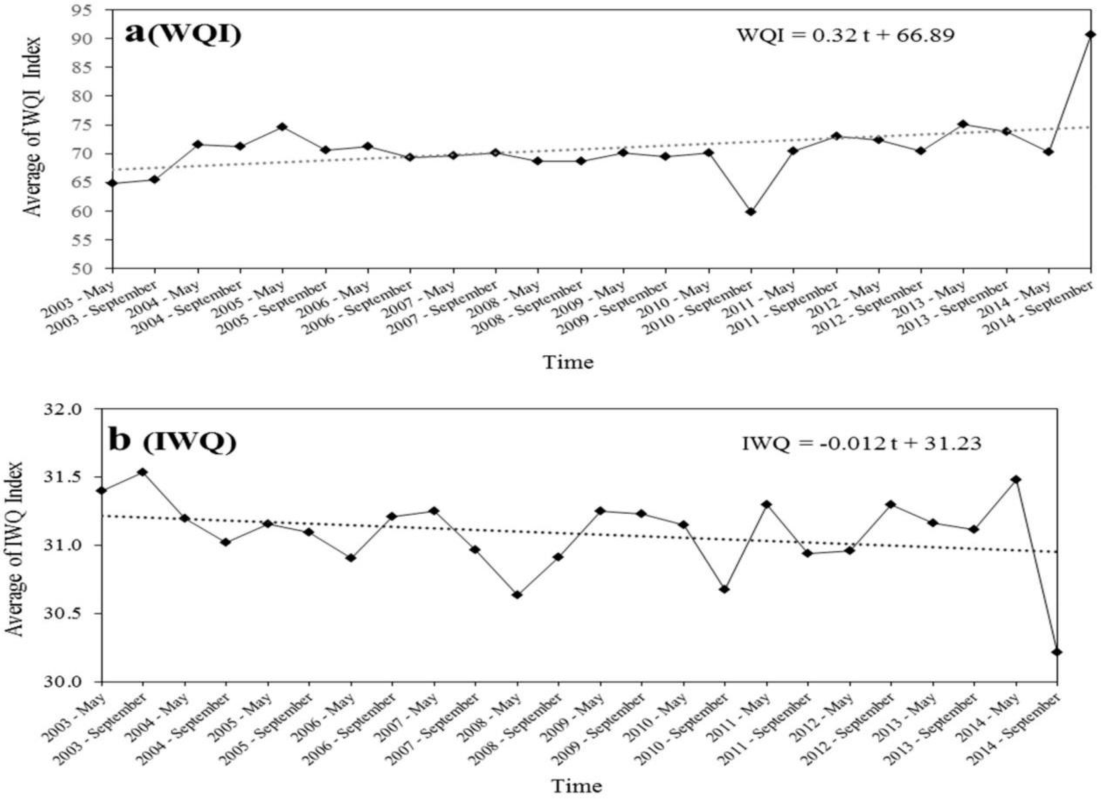

Figure 2. Moderate, and gradual changes in the WQI (**a**) and IWQ (**b**) indexes in the entire study area.

Figure 3 shows the geographical distributions of the analysed parameters in the research region based on sample information from 39 wells. It should be noted that the inverse distance weighting (IDW) interpolation technique was used to visualise the distribution numbers. One of the widely used interpolation methods for a variety of engineering issues is the IDW (see, for instance, [44–46]). Based on neighbouring sites, the IDW makes particular parameter predictions. In addition, it was previously noted that there are 81 urban water collecting wells in the research region. Figure 2 shows that the groundwater quality was declining as the WQI grew and the IWQ fell over the period, which is also consistent with Tables 1 and 2's finding that the groundwater quality has a falling tendency. Accordingly, 70 out of 81 wells that feed urban areas with drinking water were classed as having "excellent water," while the other wells were given the "good water" designation (Figure 3a). Out of 50 rural drinking water wells, 27 were rated as having "excellent water," 19 as having "good water," and four as having "poor water." The findings show that urban drinking water wells are generally in extremely good condition. Four rural drinking water wells, however, are in an inappropriate location, therefore either their locations or the water supply for the communities they serve should be altered. In general, it has been discovered that the locations of the urban and rural water wells were deliberately picked. It is advised that drinking water be sourced from the study range's southern and eastern regions, which are the primary aquifer-feeding regions and have extremely good water quality.

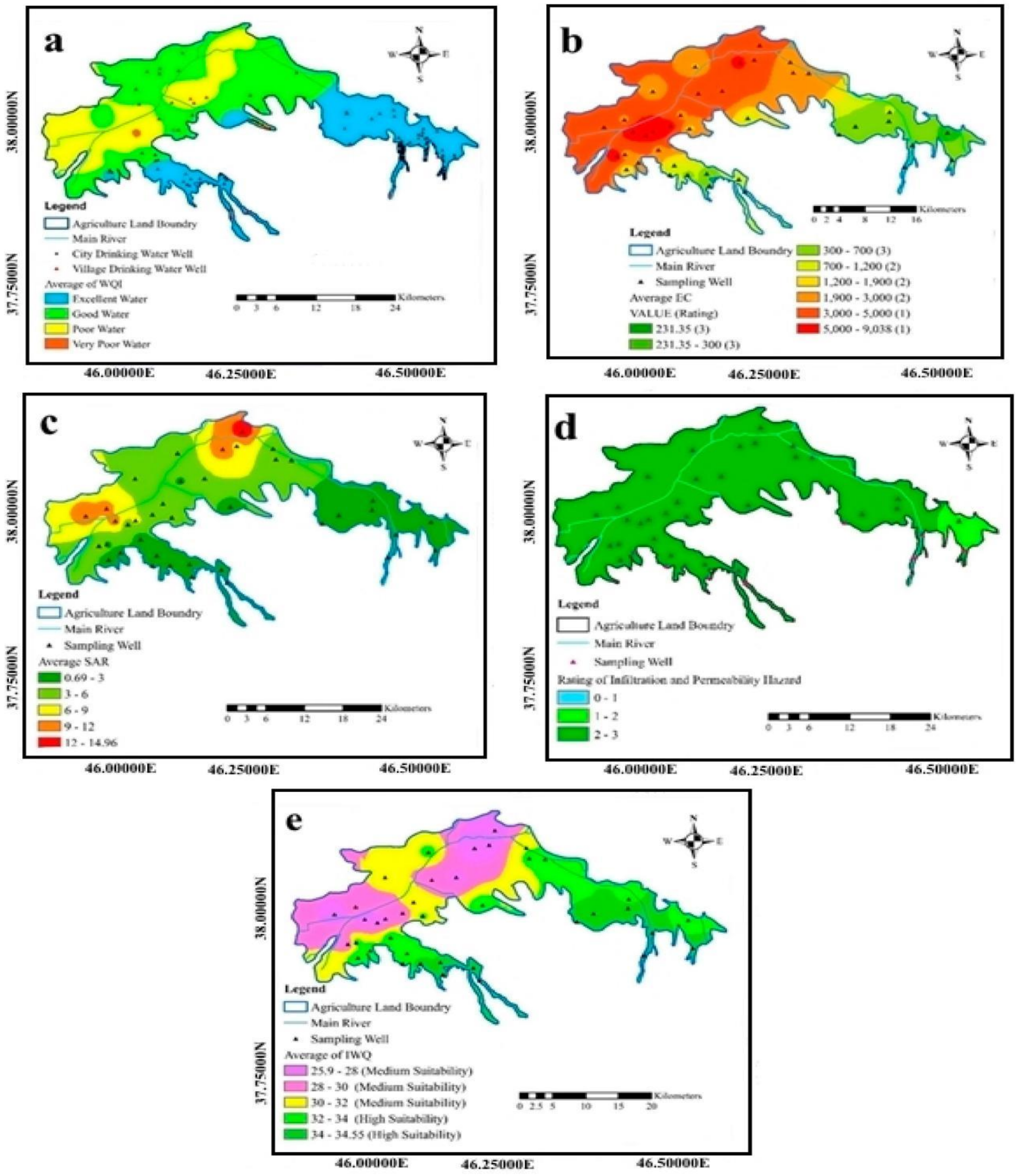

Figure 3. Geographical distribution of studied parameters in the study area ((**a**): WQI, (**b**): EC, (**c**): SAR, (**d**): infiltration and permability hazard and (**e**): IWQ).

Agricultural water quality index is most affected by salinity, permeability, and infiltration hazard weights of 5 and 4, respectively. It should be noted that the weights provided are based on WHO guidelines and norms. Figure 3b depicts the geographical distribution of the average electrical conductivity as determined from 39 wells. The research area's south and east, which are mostly aquifer feeding regions, have the lowest levels of EC, and as one gets closer to the study area's centre, the EC values rise (Figure 3b). According to research by Mosaedi et al., the eastern and central sections of the Tabriz plain are both low in salinity. More so than in the locations where the aquifer is fed, the quality of the subsurface water is less ideal in the centre of the Tabriz plain.

Additionally, 34% (268 km2) of the entire land has an EC between 700 and 3000 (s/cm), 48% of the territory has more EC than 3000 (s/cm), and 18% of the region has an EC amount between 700 and 3000 (s/cm).

The greatest and lowest average SAR values are 0.69 and 14.96, respectively (Figure 3c). The amount of SAR is modest in both the EC and the aquifer feed zone and rises as one gets closer to the north and west of the aquifer.

According to studies, the Tabriz plain's aquifer feeding regions have superior groundwater quality than the rest of this plain.

According to the infiltration and permeability criteria, the research region is deemed hazardous (Figure 3d). The negative impacts of each parameter can be offset by increasing EC and SAR levels in a location. As a result, the infiltration and permeability dangers in the central, northern, and western sections of the research area are minimal due to the high concentrations of EC and SAR in these locations. Figure 3d shows that, on average, 4.21 percent of the area (33 km2) was evaluated as a 1 to 2, while 95.79 percent of the area (758 km2) was ranked as a 2 to 3. In actuality, infiltration and permeability problems in this region are not constrained by agricultural water.

In the study, the IWQ index was derived for the 24 observations between May and September of 2003 and 2014. The minimum and highest IWQ index values were 21 and 35, respectively. Based on the area of Thiessen polygons corresponding to each of the wells, the average area IWQ index was derived. Figure 2b displays the IWQ index change trend over time. The IWQ index is acceptable over time in terms of climate adaptability for farming in the area, according to this figure. A very slight negative IWQ indicator over time demonstrates the viability of the research area's groundwater quality for agricultural use. The required actions must be made to terminate the downward trend in the IWQ index and subsequently advance to a positive trend in order to retain the aquifer's quality. For the whole region, IWQ values range from 25.9 to 34.55 (Figure 3e). The results of IWQ in Figure 3e show that roughly 37 percent (296 km2) of the research area's groundwater has a high compatibility and the remaining 63 percent (495 km2) has a moderate adaption for agricultural uses based on the aforementioned ranges. The findings also indicate that groundwater in 2227 agricultural wells is somewhat suitable and that groundwater in 1657 agricultural wells is very suitable.

4. Conclusions

In order to preserve the freshwater resources in arid and semi-arid areas, which are crucial for sustainable development, it is critical to identify and manage the groundwater quality. Local legislators and water resource managers can distribute resources for either drinking water or agricultural use depending on the quality of the groundwater in different places. In the Tabriz aquifer, which is situated in the province of East Azerbaijan, northwest Iran, this study intends to pinpoint appropriate sites for water pumping for drinking and agricultural harvest. Indicators were employed in this study to assess the quality of groundwater. The WQI and IWQ indices provide ideal locations for collecting agricultural and drinking water, respectively. These indices are also used to measure the acceptability of water drawn from wells in the research region based on the kind of application. The findings demonstrated that the majority of urban and rural water wells were rated as having "excellent water" and "good water" consistency. There is no low suitability region in the research area's agricultural water compatibility zoning map and the area contains high and medium adaptability groundwater. The study area's WQI and IWQ index variations over time reveal a decline in the quality of the groundwater for drinking and agricultural, respectively. Limiting natural runoff from farms and urban land use can reduce water pollution.

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