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Assessment of Groundwater Quality for Sustainable Drinking Water and Irrigation Practices

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Abstract: This study evaluates the groundwater quality in [specific location or region], focusing on its suitability for sustainable drinking water supply and agricultural irrigation. Groundwater is a vital resource, particularly in areas where surface water is limited, but its quality is often compromised by various anthropogenic and natural factors. The research involves systematic sampling and analysis of groundwater from multiple sources to assess key parameters such as pH, electrical conductivity, total dissolved solids (TDS), heavy metals, and microbial contamination.

The findings indicate that while some groundwater sources meet the standards for safe drinking water as per [relevant guidelines, e.g., WHO or local standards], others exhibit elevated levels of contaminants that pose health risks to consumers and agricultural users. Additionally, the study highlights the impact of agricultural practices, industrial discharges, and urbanization on groundwater quality.

Through spatial analysis and comparison with established water quality criteria, the research provides a comprehensive overview of groundwater conditions, identifying areas requiring immediate intervention and management. Recommendations for sustainable groundwater management practices are proposed, including regular monitoring, pollution mitigation strategies, and public awareness initiatives. This study contributes valuable insights into the importance of safeguarding groundwater resources, ensuring their availability and safety for both human consumption and agricultural productivity.

1. Introduction

Groundwater serves as a critical resource for drinking water and irrigation, especially in regions facing water scarcity and limited surface water availability. As the global population continues to rise and climate change exacerbates water stress, ensuring the sustainability and safety of groundwater resources has become increasingly important. The quality of groundwater directly affects public health, agricultural productivity, and overall ecosystem balance.

The significance of groundwater quality is underscored by its role in supporting agricultural activities, which rely heavily on irrigation in arid and semi-arid regions. Poor groundwater quality can lead to adverse effects on crop yields, soil health, and ultimately food security. Contaminants such as heavy metals, nitrates, and pathogens can infiltrate aquifers from various sources, including agricultural runoff, industrial discharges, and inadequate waste management practices.

In this study, we focus on the evaluation of groundwater quality in [specific location or region], aiming to assess its suitability for both drinking and irrigation purposes. The investigation involves the collection and analysis of groundwater samples from various wells and boreholes, with a focus on key physicochemical and biological parameters that influence water quality.

This research is crucial for understanding the current state of groundwater resources, identifying potential contamination sources, and determining the necessary actions for sustainable management. By establishing a baseline for groundwater quality, we can provide valuable information for policymakers, water resource managers, and local communities to implement effective strategies for safeguarding this essential resource. Ultimately, this study seeks to contribute to the broader goal of promoting sustainable water use practices that ensure safe drinking water and support agricultural needs while protecting the environment.

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:

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

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.

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

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

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

$$Wi=\frac{w}{\sum_{i=1}^{n} w} \quad (4)$$

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:

$$q_i=\frac{C_i}{S_i}\times 100. \quad (5)$$

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:

$$WQI=\sum_{i=1}^{n} Wiqi. \quad (6)$$

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.

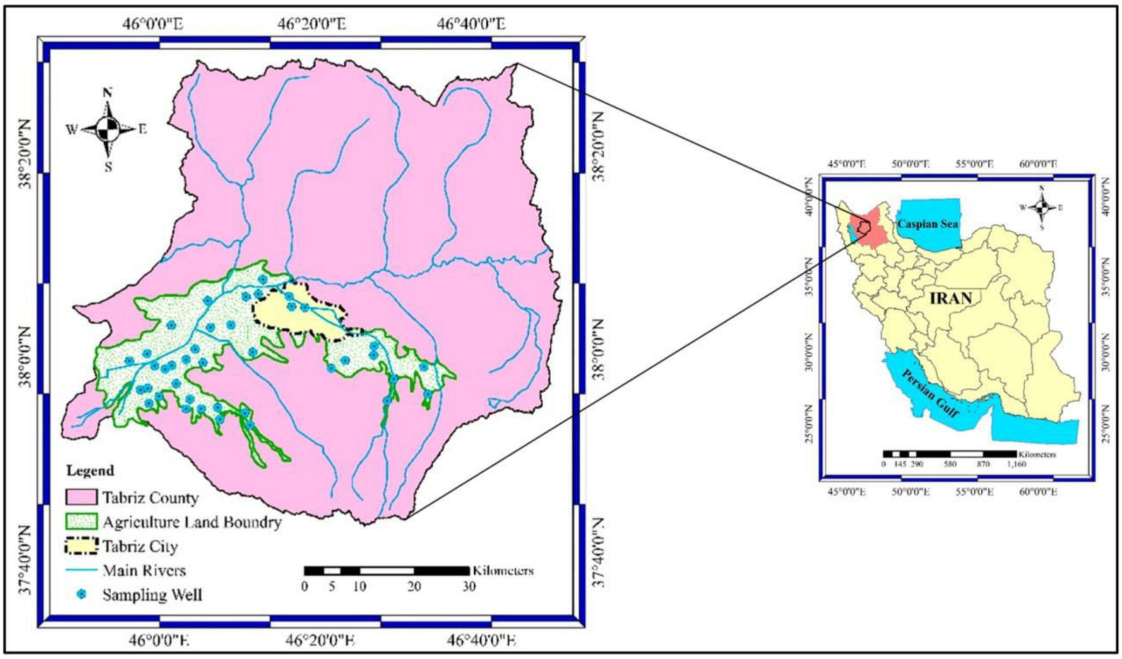

Figure 1. The geographical position of the study area with sites of sampled wells.

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 + 23.677	0.47	36	WQI = ¯3.5949t + 128.41	0.90
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.

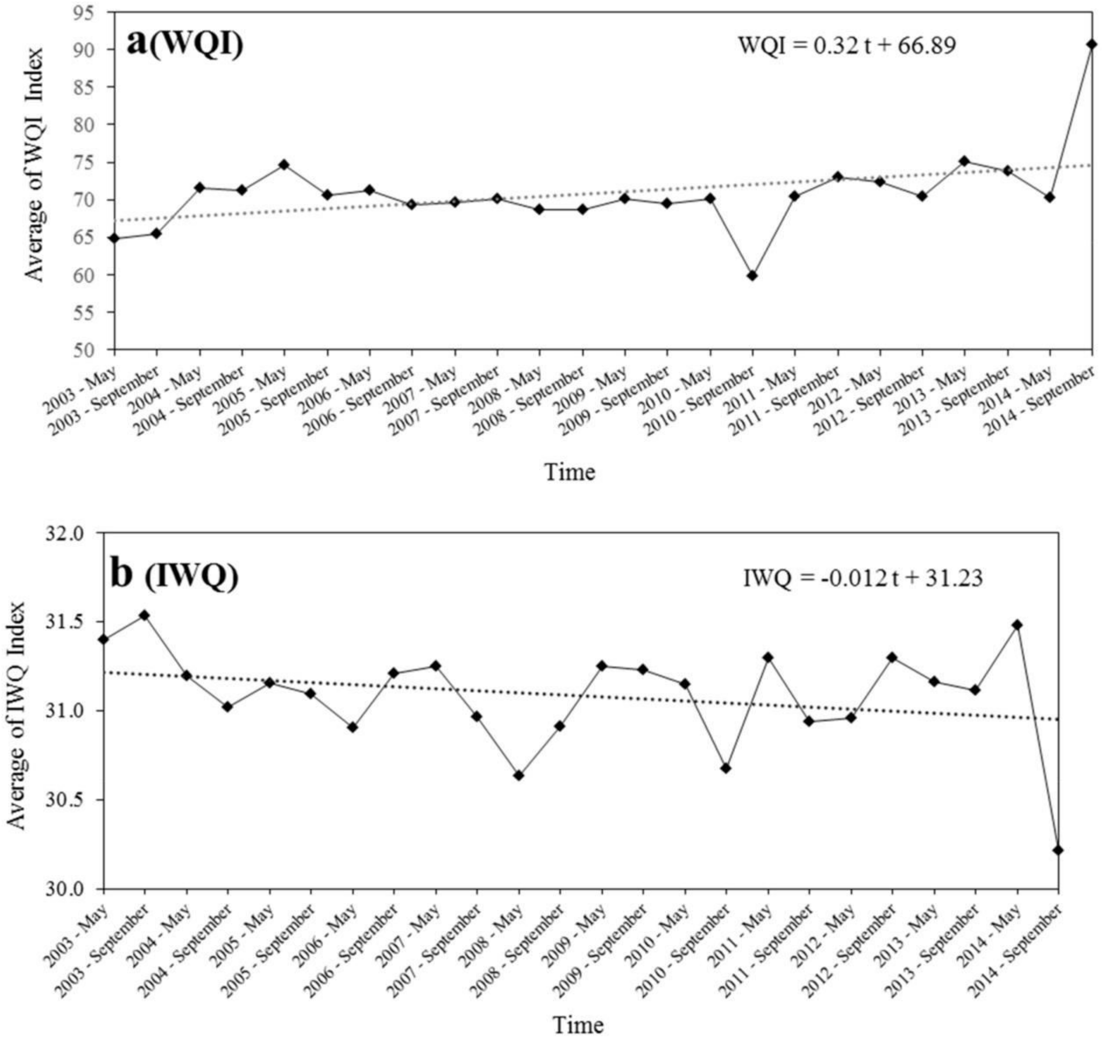

Figure 2. Moderate, and gradual changes in the WQI (**a**) and IWQ (**b**) indexes in the entire study area.

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.

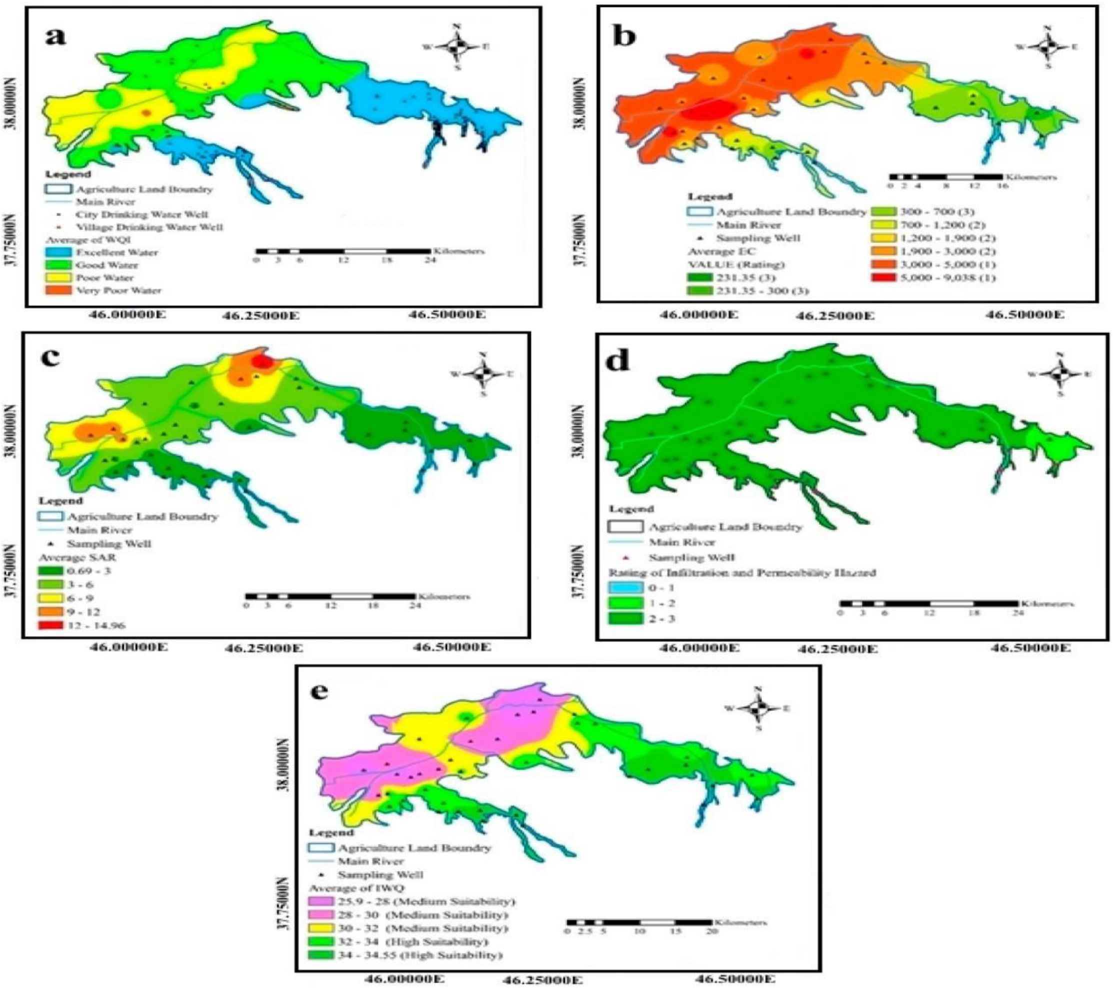

Figure 3. Geographical distribution of studied parameters in the study area ((**a**): WQI, (**b**): EC, (**c**): SAR, (**d**): infiltration and permability hazard and (**e**): IWQ).

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).

4. Conclusions

This study has comprehensively evaluated the groundwater quality in [specific location or region], highlighting its implications for sustainable drinking water supply and irrigation practices. The analysis revealed that while certain groundwater sources meet acceptable standards for drinking water, others exhibit concerning levels of contaminants that pose risks to public health and agricultural productivity.

Key findings indicate that parameters such as pH, electrical conductivity, total dissolved solids (TDS), and the presence of heavy metals and microbial contamination vary significantly across the sampled locations. These variations underscore the influence of local anthropogenic activities, including agricultural practices, industrial discharges, and urbanization, on groundwater quality. Identifying these contamination sources is crucial for implementing targeted interventions and improving water quality.

The study emphasizes the need for regular monitoring and assessment of groundwater resources to ensure their safety for human consumption and agricultural use. Sustainable management practices, such as pollution mitigation strategies and community awareness programs, are essential for preserving groundwater quality and promoting its responsible use.

Furthermore, this research highlights the importance of integrating groundwater management into broader water resource planning frameworks to safeguard this vital resource for future generations. By establishing clear guidelines and best practices, stakeholders can work collaboratively to address water quality issues and enhance the sustainability of groundwater resources.

In conclusion, ensuring the quality of groundwater is paramount for public health, agricultural sustainability, and environmental protection. This study provides a foundation for ongoing research and policy initiatives aimed at promoting sustainable groundwater management and safeguarding this critical resource in [specific location or region]

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