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Impact of seasonal changes on groundwater quality for irrigation purposes in Al-Sharqat, Iraq: A GIS and IWQI approach

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Abstract: This study aims to develop an Irrigation Water Quality Index (IWQI) and Geographic Information Systems (GIS) to evaluate the groundwater quality of several wells in the Al-Sharqat district, Iraq, for irrigation purposes. The results of IWQI in the summer season showed that 8% of studied wells were categorized as a low-restriction range, while the other wells were within the range of moderate restriction. On the other hand, 75% of the IWQ index in the winter season was in the moderate restriction range, whereas 25% of others were classified as a high restriction. The GIS maps illustrated that the groundwater quality of wells along the Tigris River was suitable for irrigation. Whereas the others located far from the river are almost unsuitable because they have high salinity concentrations. Generally, the groundwater quality in the study area improved during the summer because of the increase in the Tigris River's water level, leading to the dilution of the aquafers.

Keywords: *GIS, Groundwater, Iraq, IWQI, Sharqat city, Sustainable water management.*

1. Introduction

Water quality and scarcity have become a serious problem, especially in arid and semiarid regions. As a result, many countries are trying to find alternative resources of water to meet the increasing demands of all purposes, such as agricultural, domestic, and industrial uses (Belhassan 2021)(Nyangi and Leonard 2024). Many factors have contributed to the depletion of groundwater quantity and quality, such as the difference between water demand and supply and increased global pollution (Batarseh et al. 2021).

In addition, rainfall scarcity, quick growth of industrial and agricultural activities, and high evaporation rates have added additional pressure on groundwater availability and quality in arid and semiarid regions (Aziane et al. 2020). Recently, groundwater monitoring has become an important system that uses many effective tools to assess and understand groundwater quality and hydro-chemical characteristics (Adimalla and Taloor 2020)(Sabir et al. 2022)(Francis et al. 2024). These tools include contaminants indexes, Water Quality Index (WQI), Geographical Information System (GIS) techniques, statistical approaches, and geochemical modeling (Taloor et al. 2020)(Yetis et al. 2021). Furthermore, there are numerous physical and chemical parameters are used to calculate the contamination indices and groundwater quality (Al-Aizari et al. 2024). Because the Al-Sharqat district is surrounded by farms and agricultural lands, groundwater has been exploited extensively in this area for a long time in irrigated agricultural developments. As a result, continuous evaluation and monitoring of irrigation water quality in the Al-Sharqat district is necessary to understand the effects of human activities on the quality of soil and crop production, composition of geological, and declining water levels.

Thus, this study is important in understanding the status of groundwater quality and how to ensure its preservation using the Irrigation Water Quality Index (IWQI), which provides an assessment of groundwater quality. Moreover, this study used GIS zoning maps to illustrate the spatial and temporal variation in groundwater quality during the summer 2023 and winter 2024 seasons in Al-Sharqat district, Iraq.

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2. Methods and Materials

2.1. Study area

The study area covers the Al-Sharqat district, located in the northern part of Salah Aladdin province, Iraq, between GPS coordinates of latitudes (35°28′20″N) and longitudes (43°16′40″E), as shown in figure (1). The Al-Sharqat district is divided by the Tigris River into two parts. Some of the agricultural lands in the study area depend on the Tigris River while the other far lands depend on rainfall and groundwater for irrigation.

2.2. Sample Collection and Analysis of Physio-Chemical Parameters

Fifteen groundwater samples, including three river samples, were collected in polyethylene bottles from the Al Sharqat district, as shown in Fig. 1 and Table 1, during the winter and summer of 2024.

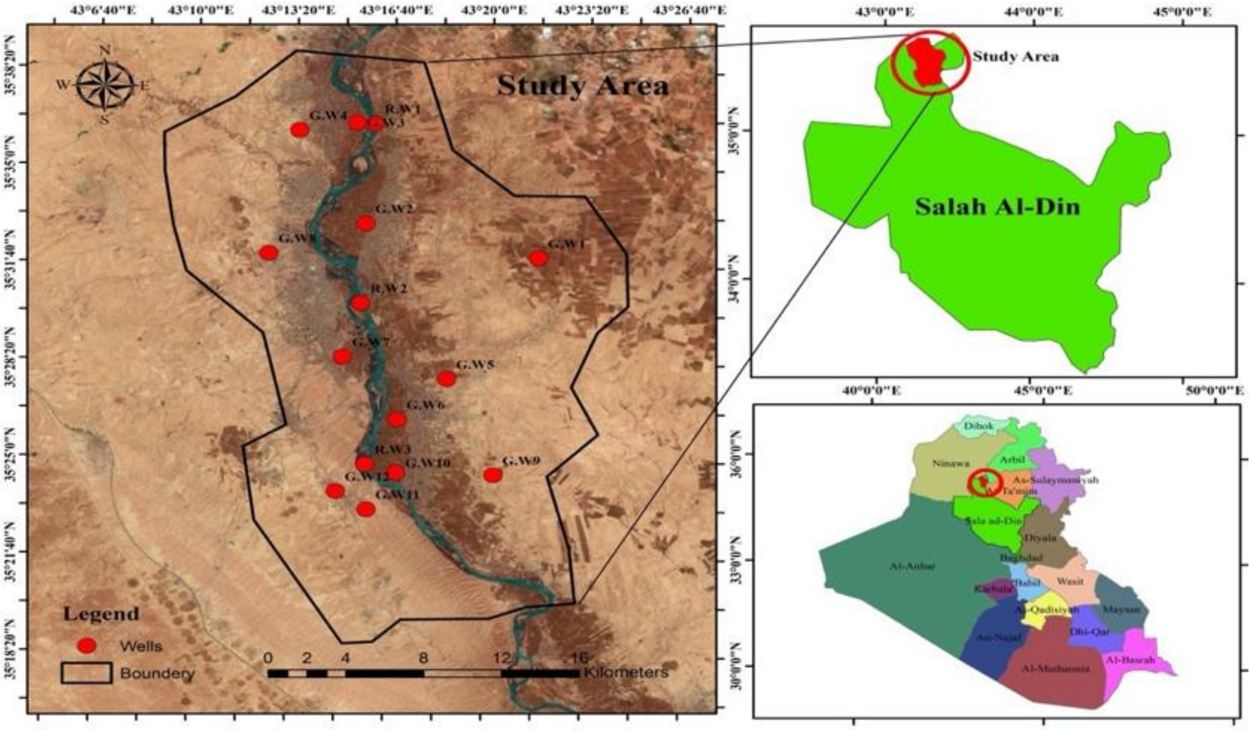
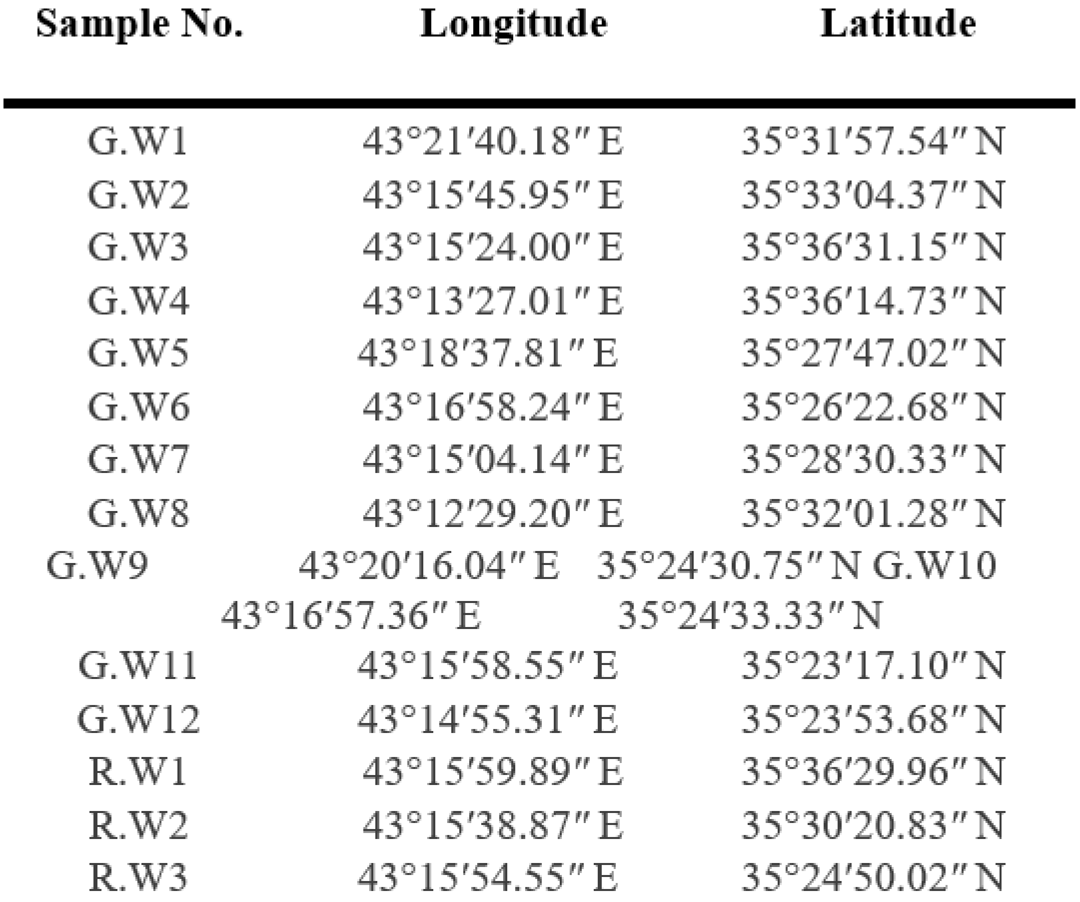


Figure 1:
Sampling locations in the Al-Sharqat plain.

Table 1:
Locations of investigated wells and river sectors.



Sample No.	Longitude	Latitude
G.W1	43°21′40.18″ E	35°31′57.54″ N
G.W2	43°15′45.95″ E	35°33′04.37″ N
G.W3	43°15′24.00″ E	35°36′31.15″ N
G.W4	43°13′27.01″ E	35°36′14.73″ N
G.W5	43°18′37.81″ E	35°27′47.02″ N
G.W6	43°16′58.24″ E	35°26′22.68″ N
G.W7	43°15′04.14″ E	35°28′30.33″ N
G.W8	43°12′29.20″ E	35°32′01.28″ N
G.W9	43°20′16.04″ E	35°24′30.75″ N
G.W10	43°16′57.36″ E	35°24′33.33″ N
G.W11	43°15′58.55″ E	35°23′17.10″ N
G.W12	43°14′55.31″ E	35°23′53.68″ N
R.W1	43°15′59.89″ E	35°36′29.96″ N
R.W2	43°15′38.87″ E	35°30′20.83″ N
R.W3	43°15′54.55″ E	35°24′50.02″ N

All the wells were pumped continuously before sampling to ensure that all groundwater samples represented the aquifer (Bridgewater et al. 2017). All the water samples were preserved by adding an appropriate reagent after filling them. Then, these samples were kept in a dark box maintained at 4°C and sent to the laboratory of Baiji's Refinery to measure their physical and chemical characteristics, as shown in Table 2.

The obtained data were tested in triplicate, and then the average value was calculated for each test.

Table 2:
Water quality parameters, units, and analytical methods used for Tigris River (Bridgewater et al. 2017).

Parameter	Unit	Methods
Electrical		
Conductivity	µS/cm	(APHA:AWWA:WEF,1998)part(2510B)
Bicarbonate	mg/L as $CaCO_3$	(APHA:AWWA:WEF,1998)part(2320B1)
Calcium	mg/L	APHA:AWWA:WEF,1998)part(3500-Ca B)
Chloride	mg/L	(APHA:AWWA:WEF,1998)part(4500-Cl-B)
Magnesium	mg/L	APHA:AWWA:WEF,1998)part(3500-Mg B)
Sodium	mg/L	(APHA:AWWA:WEF,1998)part(3111B)

2.3. Irrigation Water Quality Index (IWQI)

In this study, five water quality parameters: Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Sodium ion concentration (Na^+), Chloride ion concentration (Cl^-), and Bicarbonate ion concentration (HCO_3^-) were used to calculate the final values of irrigation water quality index (IWQI) (Batarseh et al. 2021).

After obtaining the analysis results, the units of all concentrations, except EC, were changed to be [m_{eq}/L] depending on the conversion factor (Lesch and Suarez 2009). Consequently, the first step to obtain the IWQI is to calculate the sub-index values (q_i) and the accumulated weights Wi for each parameter. All the IWQI parameters and their suggested limiting values were summarized in Table 3 (Abbasnia et al. 2018).

Table 3:
Limiting values of (qi) calculations (Ayers and Westcot 1985).

	Qi	**EC (µs/cm)**	**(meq/lNa+)**	**(HCOmeq/l3)**	**Cl–**	**(meq/lSAR) 0.5**	
							85
to 100							200
			(meq/l)				
to 750	2 to 3	1 to 1.5	< 4	< 3			
	60 to 85	750 to 1500	3 to 6	1.5 to 4.5	4 to 7	3 to 6	
	35 to 60	1500 to 3000	6 to 9	4.5 to 8.5	7 to 10	6 to 12	
	0 to 35	200 <	2 <	1 <	> 10	> 12	
		> 3000	> 9	> 8.5			

The values of (q_{EC}, q_{SAR}, q_{Na+}, q_{Cl-}, and q_{HCO3-}) were determined using eq. (4) below. The higher limits of the water quality parameters' range mentioned in Table 4 were used as the highest value of the observed samples to evaluate x_{imap}.

q!= q"#$ $%\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_&$!"' $$#"-!#$)× +!%&' ,% (4)

where :

q_{max} : the upper value of the corresponding class of qi,

X_{ij} : the data points of the parameters, Table 4, (Observed value of each parameter), X_{inf} : the lower limit value of the class to which the observed parameter belongs, q_{imap} : the class amplitude for qi classes, x_{imap} : the class amplitude to which the parameter belongs.

Table 4:
Weights for the IWQI parameters (Meireles et al. 2010).

Parameters	**(*Wi*)**
EC (us/cm)	0.211
Na^+ (meq/l)	0.204
HCO_3^- (meq/l)	0.202
Cl^- (meq/l)	0.194
SAR	0.189

The last step is to determine the IWQI by using eq. 5:

IWQI=∑/ q! w! (5)

where:

n: number of parameters,

The values of q_i, calculated by eq.4, will be multiplied by W_i, listed in Table 5, for each parameter according to (Meireles et al. 2010).

2.4. GIS Database Generation and Analysis

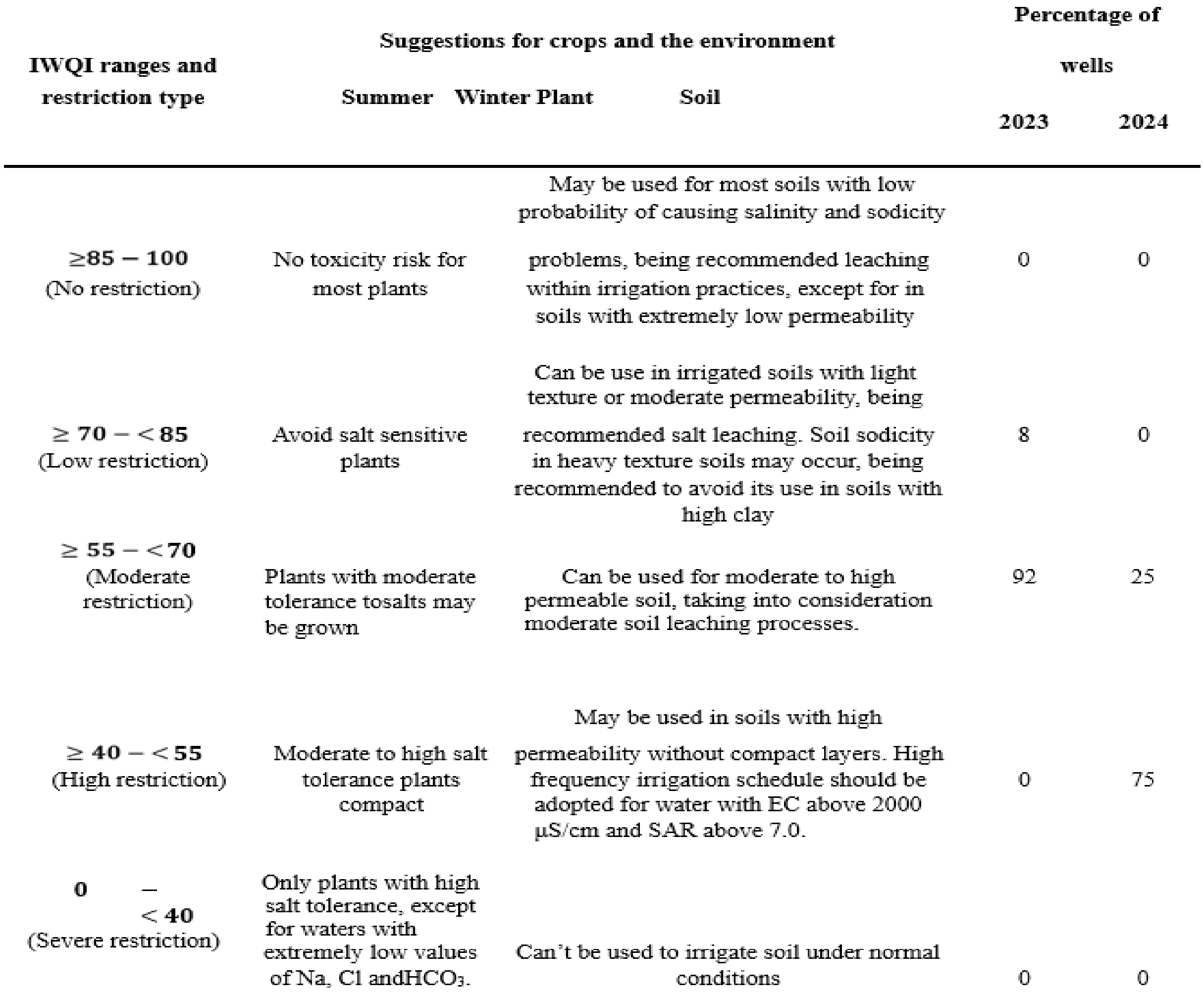
The chemical examination findings from the water specimens were combined with a geographic information system (GIS) setting to create an accurate water quality record for the research region. Panels 2–10 demonstrate the location charts for all the parameters created with ArcGIS 10.1 programs, utilizing the geographical analysis extensions and inverted distance weighting (IDW) interpolated techniques.

3. Results and Discussion

3.1. Salinity Hazard

Figure 2 presents the spatial and temporal distribution of EC measured in samples of the twelve wells and the three sections on the Tigris River collected in the summer 2023 and winter 2024 seasons.

Table 5:
Irrigation Water Quality Index Characteristics (Meireles et al. 2010).



IWQI ranges and restriction type	Suggestions for crops and the environment		Percentage of wells	
	Summer Winter Plant	Soil	2023	2024
≥85 – 100 (No restriction)	No toxicity risk for most plants	May be used for most soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability	0	0
≥ 70 – < 85 (Low restriction)	Avoid salt sensitive plants	Can be use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay	8	0
≥ 55 – < 70 (Moderate restriction)	Plants with moderate tolerance tosalts may be grown	Can be used for moderate to high permeable soil, taking into consideration moderate soil leaching processes.	92	25
≥ 40 – < 55 (High restriction)	Moderate to high salt tolerance plants compact	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS/cm and SAR above 7.0.	0	75
0 – < 40 (Severe restriction)	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl andHCO_3.	Can't be used to irrigate soil under normal conditions	0	0

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In summer, the highest value of EC was observed at GW5 (9300 µS/cm), while the lowest EC value was measured at GW12 (3140 µS/cm). Depending on the summer results, it's noticed that the region located in the southwest part of the study area has good-quality groundwater for irrigation. The eastern region of the study area has high EC values because of the geological formation of land and aquifer (gypsum and calcite). Previous studies about this area mentioned that the EC values were also recorded high because of the agricultural drainage infiltrating toward groundwater aquifers (Alobaidy 2021). In winter, the highest EC value was observed at GW5 (7500 µS/cm), while the lowest was at GW12 (3000 µS/cm). It's easy to notice that the EC values decreased during this season, leading to improved groundwater quality for irrigation purposes in most measured wells. This improvement was due to the diluting of aquifers due to falling rain and an increase in the water level of the Tigris River during this season (Alattar 2024).

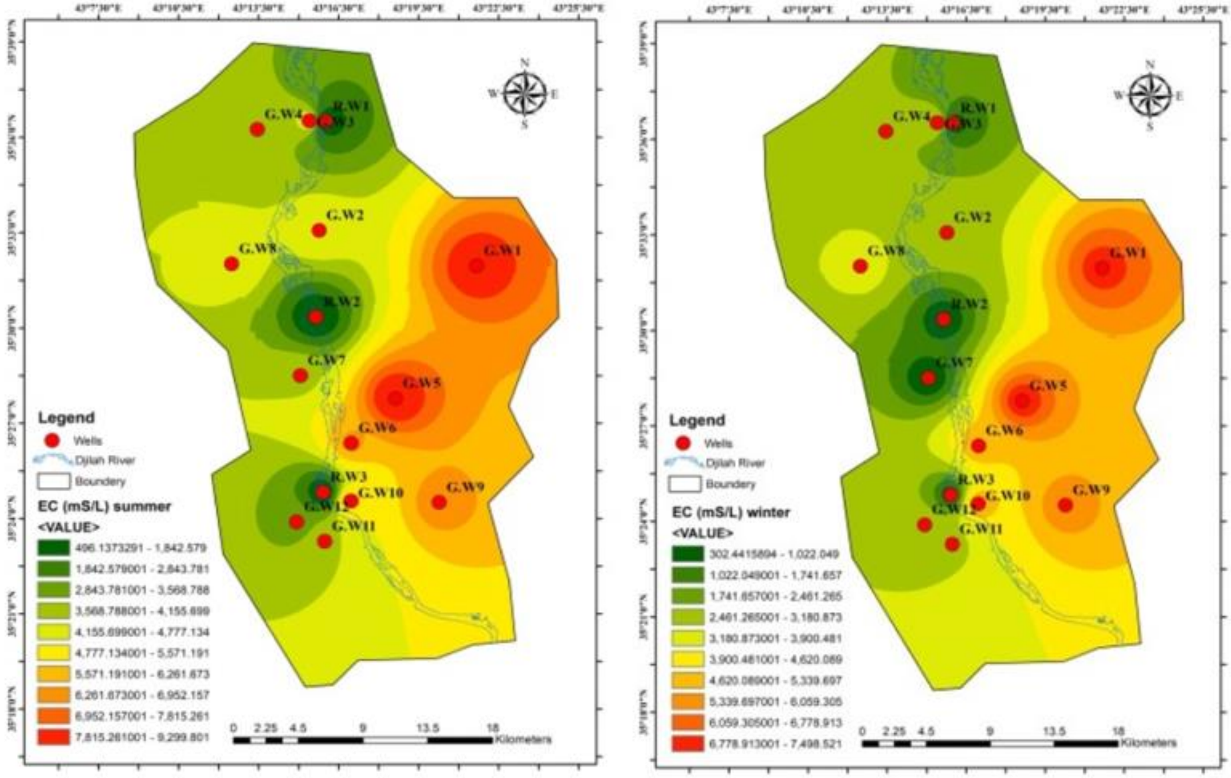

Figure 2:
Electrical conductivity distribution in Sharqat district during summer 2023 and winter 2024.

3.2. Infiltration Hazard

Figure 3 shows the spatial and temporal distribution of SAR. In the summer season, the highest value of SAR was mainly recorded in the northwest part of the study area, particularly at GW4 (2.311(meq/L)$^{0.5}$). As in the case of EC, the increment in SAR values belongs to the aquifers' chemical formation and the irrigation water's infiltration into groundwater.

While the lowest value was observed at GW10 (1.407(meq/L)$^{0.5}$) in the southeast of the study area. The SAR value of this well was lower than others because it is located close to the Tigris River's west bank, diluting the water of this well. On the other hand, the lowest value of SAR was observed at GW3 (1.5 (meq/L)$^{0.5}$) in the northeast of the study area during the winter season. Infiltrating the rainfall and the Tigris River water into the aquifer led to a rise in the water table, and, as a result, decreasing in SAR values in most of the studied wells (Alattar 2024).

3.3. Specific Ion Toxicity

3.3.1. Sodium Ion Na$^+$:

In this study, a higher concentration of sodium ion Na$^+$ was detected at GW5 and GW9 (205 (mg/L)) together in the summer season, whereas the lower concentration of Na$^+$ was recorded at GW12 (175 (mg/L)). The responsible reason for increasing Na$^+$ ions in these wells is the infiltration of irrigation water into groundwater because the groundwater level in this region is near the surface. On the other hand, Na$^+$ concentration decreased at GW12 because of the dilution of the groundwater by the river's water.

In winter, the Na$^+$ concentrations were ranged between (202 (mg/L)) at GW4 and (145 (mg/L)) at GW3. Most values of the Na$^+$ decreased slightly because of the rainfall and the dilution by river water. Raising the salinity is due to the increasing rate of river water evaporation before infiltrating the aquifer.

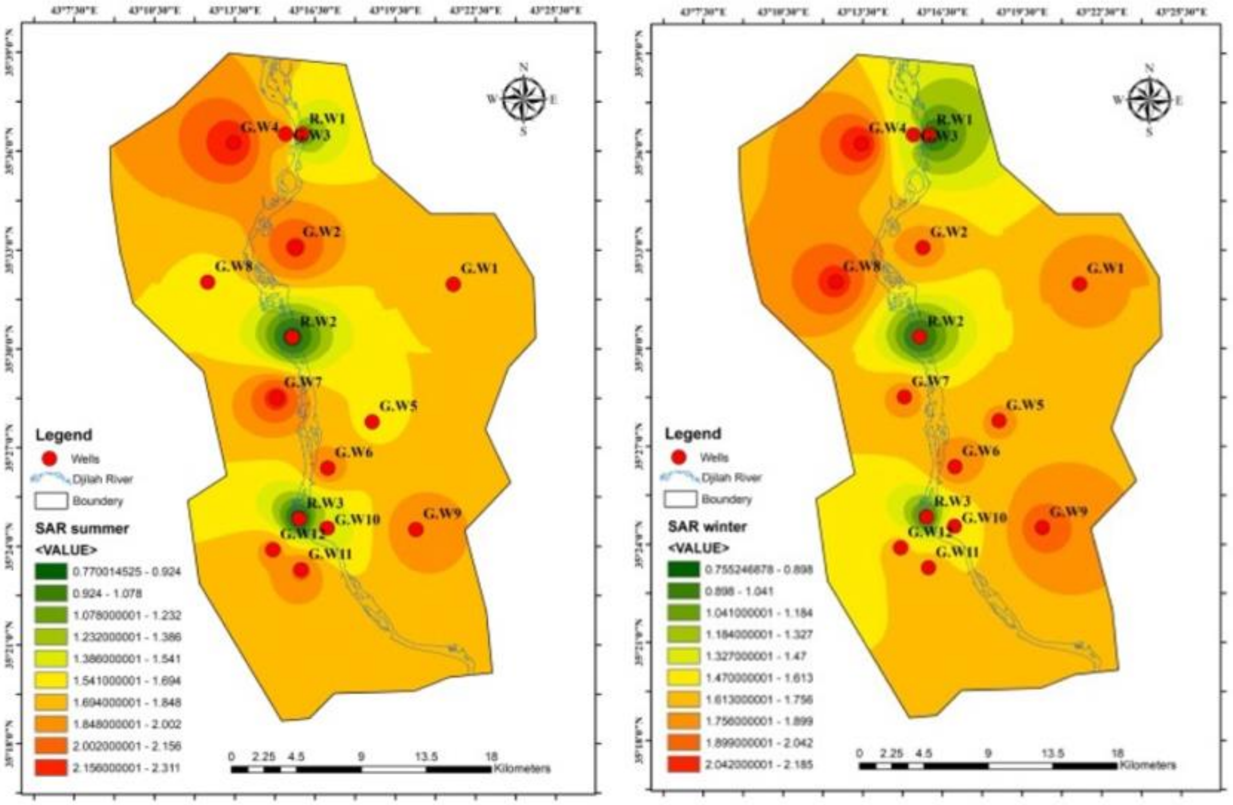

Figure 3:
SAR distribution in Sharqat district during summer 2023 and winter 2024.

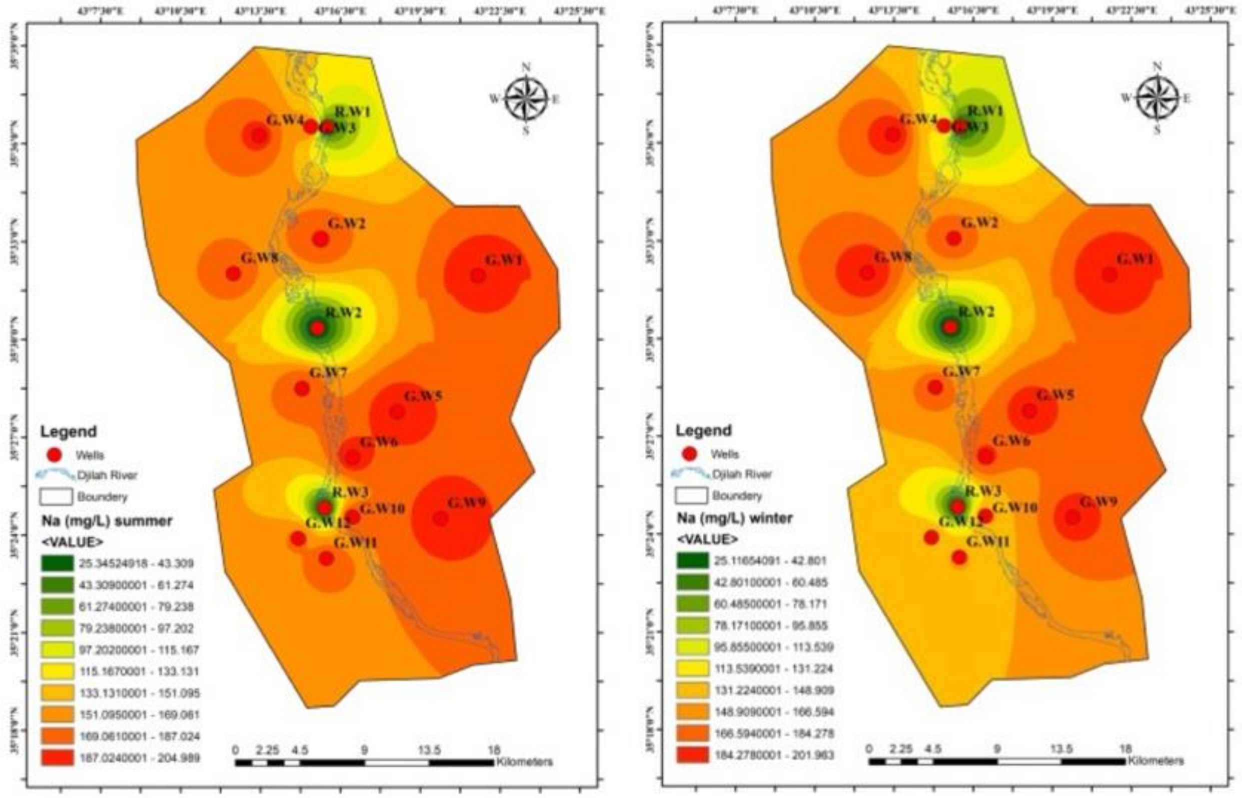

Figure 4:
Sodium ion (Na^+) distribution in Sharqat district during summer 2023 and winter 2024.

3.3.2. Chloride Ion Cl^-

The spatial and temporal distribution of Chloride ion Cl^- are shown in Figure 5. In summer, the higher concentrations of Cl^- (35 mg/L) observed at GW3 as a result of and (15.5 mg/L) at GW10, as shown in Figure 3. Whereas, In winter, the Cl^- concentrations ranged between (35 (mg/L)) at GW5 and (17 (mg/L)) at GW11. As noticed, the concentrations of Cl^- ion were low in all wells because of the nature of geological formation that consists of bicarbonate and sulfur.

Consequently, the concentration of Cl^- was relatively higher in the western part of the study area than in the eastern part in the summer season because of decreasing the water level of the Tigris River. Also, the groundwater of this part contains high values of chloride ions. While, in the winter season, the quality of groundwater improved due to the increasing water level of the Tigris River. On the other hand, the values of Cl^- ion in the eastern part of the study area showed increasing because of the decrease in the water level in the lower Al-Zab tributary.

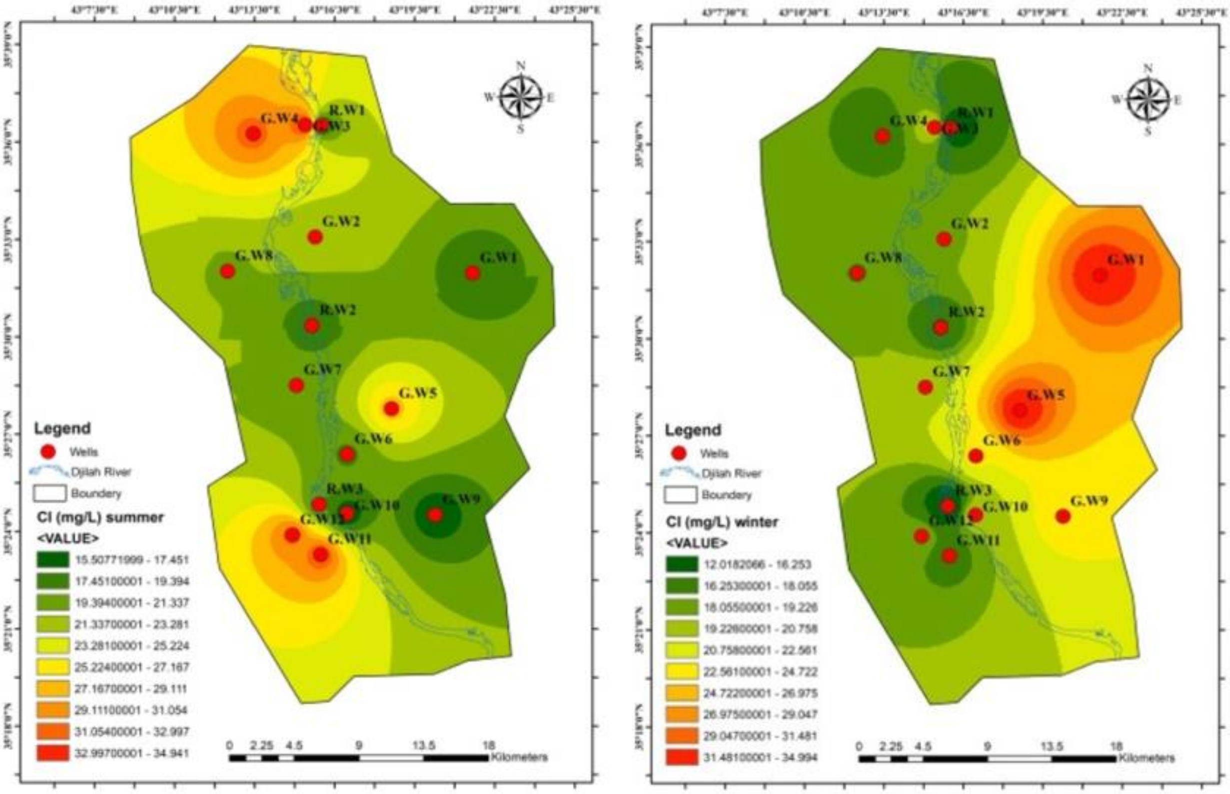

Figure 5:
Chloride ion Cl^- distribution in Sharqat district during summer 2023 and winter 2024.

3.3.3. Miscellaneous Effects

The spatial distributions of bicarbonate ions in the Sharqat district are presented in Figure 6. In this study, the bicarbonate ion concentrations ranged between (450 mg/L as $CaCO_3$) at GW3 and (100 mg/L as $CaCO_3$) at GW1 and GW12 during the summer season. It can be seen from the GIS map that the groundwater quality in the northern part of the study area has bicarbonate values higher than others because the soil and groundwater of this zone are rich in bicarbonate and sulfur (AL-Zubedi 2024).

In winter, the ion concentration decreased in the western part of the study area because the aquifers were diluted by the Tigris River in this season. On the other hand, the eastern part has higher values of bicarbonate ion because of decreasing the flow in the lower Al-Zab water, leading to an increase in the bicarbonate ions in the aquifer. Moreover, the rocks and the soil in the Makhmur area are formed by limestone rocks ($CaCO_3$) which are responsible for increasing the bicarbonate ions in groundwater.

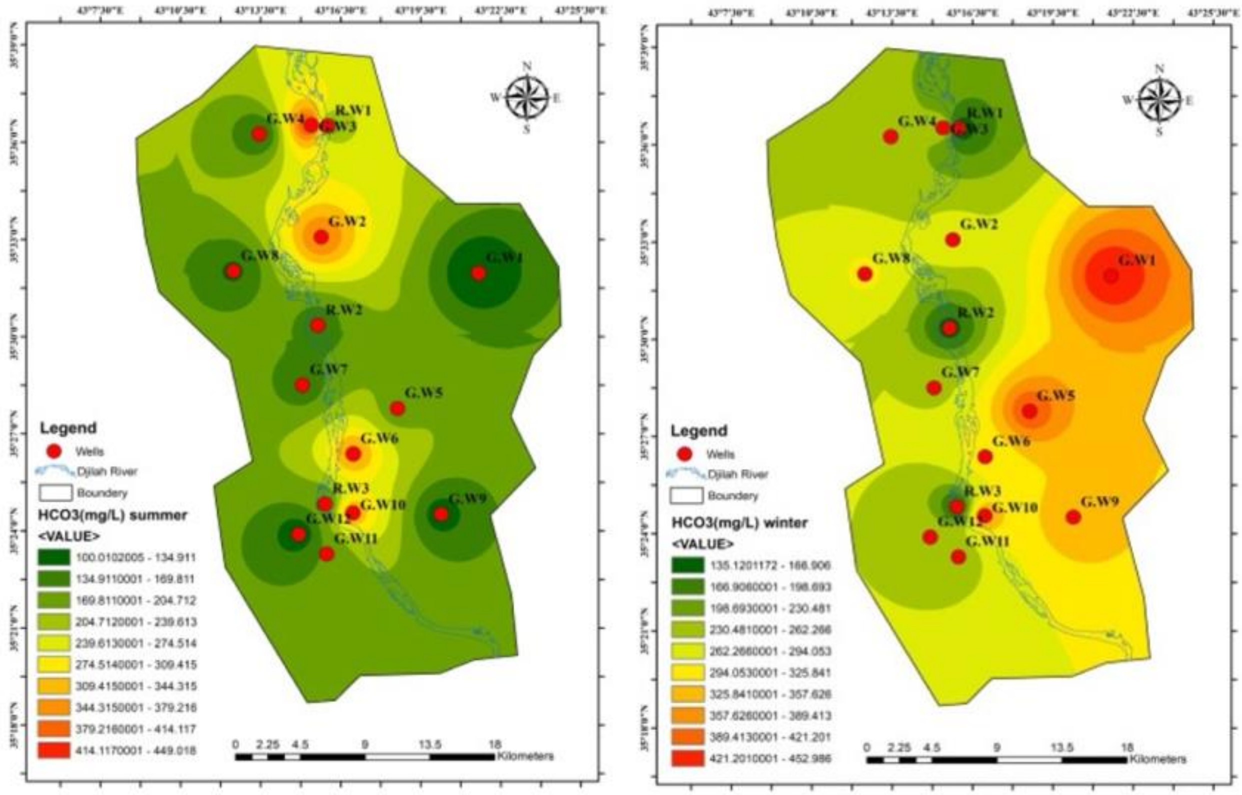

Figure 6:
Bicarbonate ion distribution in Sharqat district during summer 2023 and winter 2024.

4. Irrigation Water Quality Index (IWQI)

After combining all the five parameters according to eq.(5), the IWQ index maps were drawn using the GIS technique, as shown in Figure 7. These maps enabled decision-makers to assess the groundwater quality easily for irrigation purposes and choose the locations of the most suitable wells for extracting water . The GIS maps show the suitability of wells for irrigation purposes depending on the computed IWQI values and their five categories shown in Table 4.

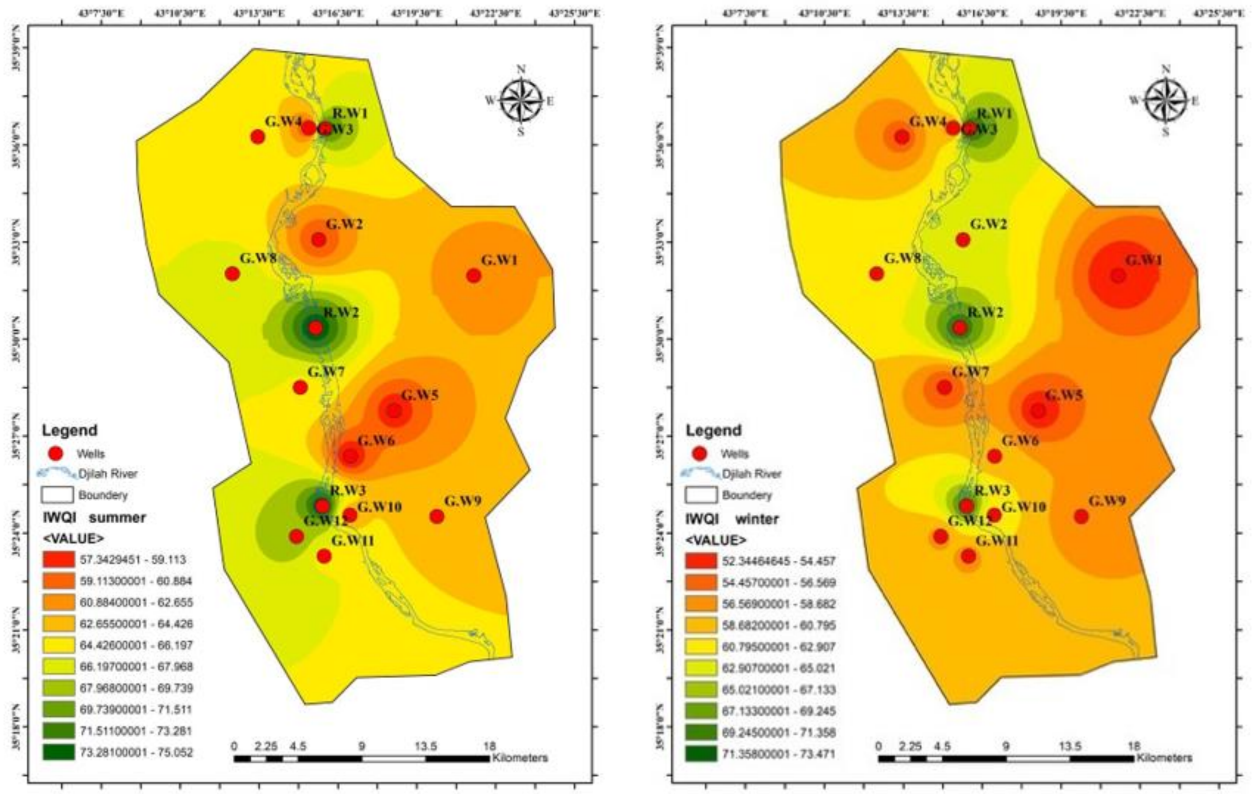

Figure 7:
IWQI Zoning Map of the study area.

Accordingly, the values of irrigation WQI in the summer season were classified as: 8% of wells were in the range of low-restriction, which avoids using the water of these wells for irrigation only to the salt-sensitive plants. However, 92% of other wells were felt in the range of moderate restriction and used for moderate salt tolerance plants in moderate to high permeable soil, considering moderate soil leaching processes. Finally, this study did not record any well-classified within (no, high, and severity) restriction range.

The irrigation WQI values during the winter season were categorized as follows: 75% of studied wells were classified in the moderate restriction range. However, 25% of other wells are classified as a high restriction, which is recommended for irrigating plants of moderate to high salt tolerance. Regarding the type of soil irrigated by groundwater should be permeable without compact layers, considering the high rate of irrigation schedule by water EC > 2,000 μS/cm and SAR >7. Finally, in this season, no wells were recorded in (no, low, severe) restriction.

5. Conclusion

In this study, the Irrigation Water Quality Index (IWQI) and a GIS-integrated tool were used to illustrate temporal and spatial variations in the groundwater quality of several wells in the Al-Sharqat district and evaluate them for irrigation purposes. In the summer season, the IWQ index showed that 8% of studied wells fell in the range of low restriction, but the others placed in the moderate restriction range. On the other hand, the calculated values of the IWQ index in the winter season were classified into two categories: 75% of wells were in the moderate restriction range, whereas 25% of others were classified as high restriction.

The GIS maps simplify to show the spatially and temporally distributed assessment of studied wells' water quality and suitability for irrigation. The GIS distribution maps illustrate that the groundwater

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quality of wells along the Tigris River was suitable for irrigation, but the others located far from the river were almost unsuitable for irrigation.

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