Evaluation of Groundwater Quality South of Mosul for Irrigation Purposes and Its Contribution to Food Security

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Abstract

This study was conducted to assess the suitability of groundwater for irrigation purposes in agricultural areas south of Mosul, located in the Nineveh Governorate, using the Water Quality Index (WQI) as an effective tool for estimating the suitability of water for irrigation. The study involved collecting samples from ten wells distributed throughout the area, with one sample per month from each well for six consecutive months. These samples underwent physical and chemical analyses, including measurement of pH, electrical conductivity at 25 °C (EC25), and bicarbonate and chloride concentrations. A set of parameters used in assessing irrigation water quality was also calculated, including sodium percentage (%Na), sodium absorption ratio (SAR), Kelly ratio (KR), magnesium absorption ratio (MAR), residual sodium carbonate (RSC), permeability index (PI), and potential salinity (PS). The results showed that the PS index exceeded the standard limits allowed for irrigation, which is attributed to the passage of water through geological formations containing evaporitic rocks rich in sulfate ions. The EC25 values also exceeded the standard limits allowed for irrigation, and this increase in salinity is attributed to the geological characteristics of the area, particularly the abundance of gypsum, anhydrite, and dolomite rocks, as well as evaporite salts within the local geological formations. The water quality index (WQI) ranged between 90.59 and 143.5, indicating that all water samples studied fall within the "poor" water category, with the exception of well No. 1, which was classified as "good" according to the approved classification for irrigation water.

Keywords: Water quality index, water quality standards, groundwater in Mosul, food security

Introduction

Groundwater is one of the main water resources in Iraq, especially in areas where surface water sources are not available. Water plays a prominent role in the lives of the population through its use for domestic, irrigation, industrial, and other purposes. Groundwater in Iraq is found at various depths ranging from the surface to more than 700 meters below the surface in different aquifer systems, and part of this water naturally emerges to the surface through springs (1)

In semi-arid environments and due to climate change, groundwater is the primary resource for meeting the needs of population growth and urban development, given the limited surface resources. This water is extremely important in supporting social and economic aspects, especially in the agricultural sector, where its quality is directly affected by human and agricultural activities(2) . Salinity is one of the most significant challenges facing groundwater in Iraq, as a result of its exposure to geological strata and geochemical interactions, as well as the possibility of contamination by agricultural fertilizer residues and domestic and industrial waste that may seep through permeable layers into the aquifer, negatively affecting its usability.(3) Accordingly, there is a need to adopt modern irrigation techniques and apply advanced methods of water quality assessment, such as the use of mathematical models that rely on collecting water quality data over different time periods and locations, and then converting them into a unified index that reflects the environmental status of the area during A specific period(4) . The province of Nineveh has been the subject of a number of studies on irrigation water quality, including a study (5)(6). which analyzed well water in the district of Al-Kask in northeastern Iraq. The results of the analyses showed high electrical conductivity values due to the water containing significant concentrations of calcium, sulfate, and sodium ions, which negatively affected water quality and its suitability for irrigation. In a study(7) that evaluated well water in the village of Abu Maria in the Tal Afar district, the results showed that the water quality index was classified as “poor” for irrigation purposes, due to high electrical conductivity values and concentrations of calcium and sulfate ions. In a study (8), the quality of well water in the Mahaliba area northwest of Mosul was assessed. The data showed high concentrations in the qualitative characteristics of the water studied, particularly total dissolved salts and calcium and sulfate ions, The values ranged from 3390 mg/L for dissolved salts to 673–2271 mg/L for calcium and sulphate, which had a negative impact on irrigation water quality indicators in that area.

The current study aims to identify the qualitative characteristics of groundwater in agricultural villages south of Mosul and analyze the results in order to assess the environmental status of water resources. This is done by applying a specialized mathematical model to estimate the suitability of groundwater for agricultural uses, irrigation purposes, and food security.

Study area

The study area is located south of Mosul, covering a total area of 850 square kilometers, stretching from the village of Sananik to the Al-Houd area. The ten well sites were carefully selected after surveying the entire area and taking into account the opinions of the local population regarding the wells that had been neglected within the geographical area of the study. The selected wells had water at different depths ranging from 18 meters to 163 meters. The locations of the wells were accurately determined using GPS and Google Earth. (1) shows the locations of the wells on the aerial map, while Table (1) shows the coordinates of the wells in relation to longitude and latitude, as well as their elevation above sea level.

Figure (1): Aerial map showing the locations of the wells as viewed through Google Earth.

Table (1): Shows the coordinates in the UTM system and the characteristics of the wells studied.

Uses	(m)	Elevation (m)	Latitude lines	Longitude	Region	Al-Abar
For agricultural purposes	30	198	3983054.11N	350409.08E	ship	1
For agricultural purposes	10	192	3969372.85N	346012.66E	Hood	2
For agricultural purposes	40	199	3975234.15N	347699.98E	Talul Nasser	3
For agricultural purposes	18	187	3969880.74N	345686.93E	Hood1	4
For agricultural purposes	107	335	4002663.26N	328443.76E	Sanik	5
For agricultural purposes	163	339	4002114.23N	328393.18E	Sanik1	6
For agricultural purposes	24	190	3981679.95N	349318.86E	ship1	7
For agricultural purposes	17	194	3989018.75N	351191.06E	Nimrod	8

For agricultural purposes	51	284	3998910.16N	337187.25E	Kharar	9
For agricultural purposes	55	283	3999485.29N	336840.14E	Kharar1	10

Materials and methods

Sample collection

Water samples were carefully collected to represent the same water quality in the aquifer from November (2024) to April (2025) by pumping well water for five minutes before collecting it in polyethylene bottles. The bottles were washed with sample water for the purpose of homogenization, as indicated by (9) . Field measurements were carried out on selected well water samples, including pH and electrical conductivity (EC), while other analyses were carried out in the laboratories of the Environmental Research Center at the University of Mosul, using internationally approved standard methods for collecting and analyzing groundwater samples. (10)

Laboratory tests included determining the concentrations of chloride (Cl^{-} 1), bicarbonate (HCO_3 $^{-}$ 1), and sulfate (SO4-2) ions, as well as positive ions such as sodium, potassium, calcium, and magnesium. A set of indicators specific to irrigation water quality were also calculated, such as the percentage of sodium (Na%), sodium absorption ratio (SAR), Kelly index (KI), magnesium absorption ratio (MAR), residual carbonate (RSC), and permeability index (PI). (11)

According to the following equations

$$\%Na = \frac{\text{Na}}{\text{Na} + K + Mg + Ca} x100$$

$$\text{P.S (meq /L)} = \text{Cl} + \frac{1}{2}\,SO_4$$

$$\text{RSC (meq. l}^{-}\text{)} = [HCO_3^{-} + CO_3^{-2} - (Ca^{+2} + Mg^{+2})]$$

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

$$\frac{\text{Na}}{\text{Ca+Mg}} = \text{KI}$$

$PI = Na [(HCO3)^{1/2} / (Ca + Mg + Na)]$

$$MAR = \frac{Mg \times 100}{Ca + Mg}$$

Finding a Water Quality Index (WQI)

Given the large number of measurements associated with water quality, accurately analyzing this data requires specialized quantitative models. Therefore, it has become necessary to reduce water quality data to representative numerical values that express its quality. Among the methods used to achieve this, the “Sub Index Model” system stands out as an effective tool in managing and assessing the quality of the water under study(11)

In this context, the weighted index system for irrigation water is used to assess water quality, with 11 key variables included in the analysis, including: pH, electrical conductivity at 25°C (EC25), chloride ions (Cl^-), bicarbonate (HCO_3^-), sodium percentage (%Na), sodium adsorption ratio (SAR), Kelly index (KI), magnesium adsorption ratio (MAR), residual carbonate (RSC), potential salinity (PS), and permeability index (PI). The relative weight of each of these indices (Wi) was calculated using an equation based on the relative importance of each element in the assessment process (12).

The first step is to calculate the water quality index by assigning a weight (wi) to each measured parameter on a scale of 1 to 5. The weight assigned to a particular parameter depends on its relative importance in terms of its impact on overall water quality.

The second step is to calculate the relative weights (Rwi) using the following equation:

$$RWi = \frac{wi}{\sum_{i=1}{}^{n} wi}$$

Where: Rwi is the relative weight, wi is the weight of each parameter, and n is the number of parameters.

Step 3: The quality index (Qi) for each parameter is calculated by dividing by the permissible limit value and multiplying the result by 100 according to the following equation:

where (Ci) represents the measured value of the attribute, and (Si) represents the standard concentration of the attribute.

$$Q_i = \frac{C_{i \times 100}}{S_i}$$

Step 4: Calculate the values of the subindex Sli as in the following equation:

Sli = Wi x qi

Step 5: Find the WQI value as in the following equation:

WQI = ∑Sli

Water quality is classified based on the WQI value into five main categories, as shown in Table (3), according to the values obtained.

Table (2): Shows the standard limits, attribute weights, and relative weights used to calculate the WQI for irrigation (13)

W_i	w_i	$^*S_i$	Adjective
0.0930	4	7.5	pH
0.1163	5	2000	EC_{25}
0.0698	3	10	CI
0.0698	3	8.5	HCO_3
0.0465	2	2.25	RSC
0.1163	5	75	PI
0.0930	4	60	NA%
0.1163	5	18	SAR
0.0930	4	50	MAR
0.1163	5	7	P. S
0.0698	3	1	KI
1	43	Total	

Table (3): Classification of water quality according to WQI values(14)

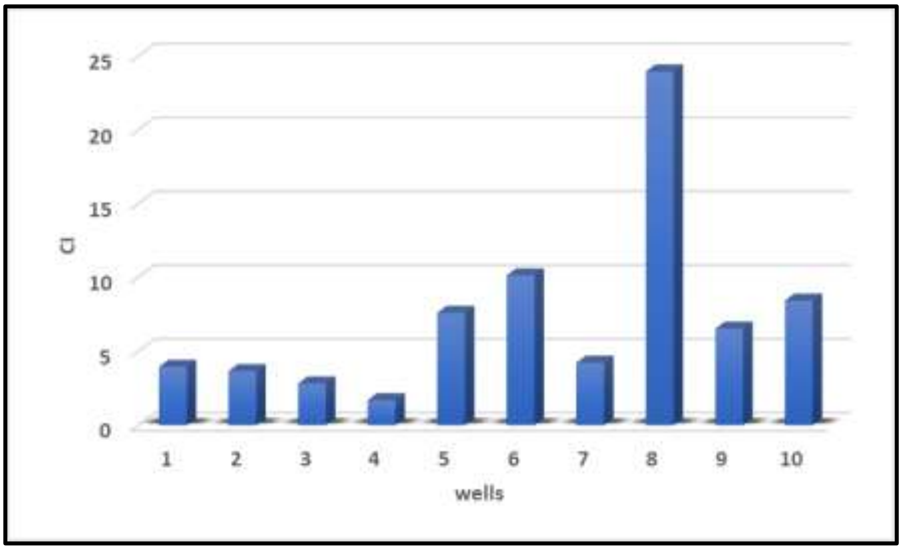
Water quality	WQI
Excellent	50 >
Good	100-50
Poor	200-100
Very Poor	300-200
Unsuitable	300 <

Results and Discussion

The results in Figure 2 show that the pH values of the wells located within the study area ranged between 6.5 and 7.38. This variation reflects the ability of the bicarbonate-containing aquifer to regulate pH. Rock components, such as calcite and dolomite, also contribute to pH modification through their interaction with water, leading to reduced changes in pH values (5,15).

Electrical conductivity (EC) values were recorded at 25 °C between 1220 and 4390 μS/cm, as shown in Figure 3, most of which exceed the permissible levels for irrigation. With the exception of well No. 1, this increase in salinity is attributed to the geological characteristics of the area, particularly the abundance of gypsum, anhydrite, and dolomite rocks, as well as evaporite salts within the local geological formations (5).

On the other hand, increased chloride ion concentrations have toxic effects on plants, manifested by leaf tissue desiccation and burning, as well as an increased risk of agricultural soil salinization. (16,17). However, the data shown in Figure 4 indicate that chloride concentrations in groundwater are within acceptable limits, ranging from 1.69 to 23.96 meq/L. The exceptions are wells 5 and 7, where concentrations exceeded the standard limits for irrigation. The data shown in Figure 5 indicate a notable increase in bicarbonate (HCO_3^-) concentrations in the studied well waters, with an average of 5.60–12.80 meq/L. This elevation is mainly attributed to chemical reactions between groundwater and carbon dioxide (CO_2) as it passes through geological formations, forming carbonic acid which reacts with calcium carbonate to produce dissolved calcium bicarbonate. Bicarbonate remains the dominant contributor to total alkalinity, as the pH values of the samples did not exceed 8.3, the threshold at which carbonate ions (CO_3^{2-}) begin to appear in significant concentration [28][29].



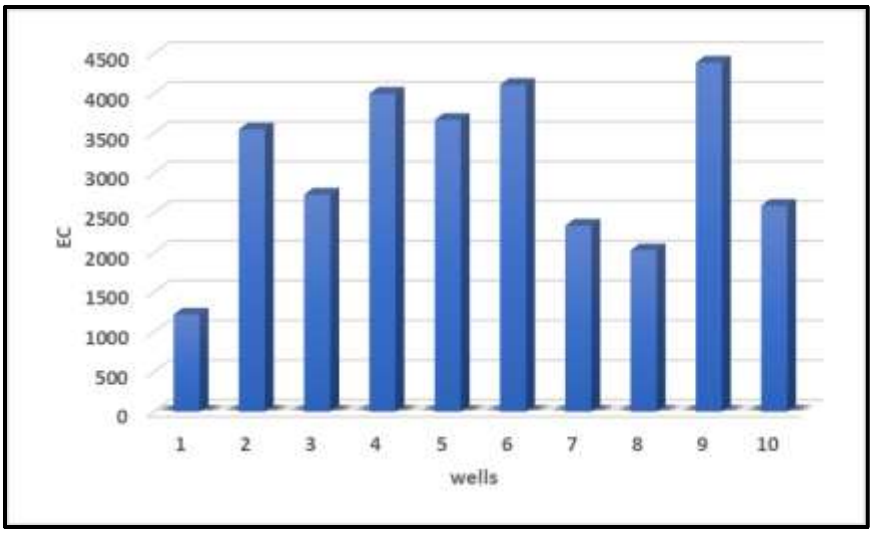


Figure (2): pH averages of the studied wells

Figure (3): The electrical conductivity averages of the studied wells (μS/cm)

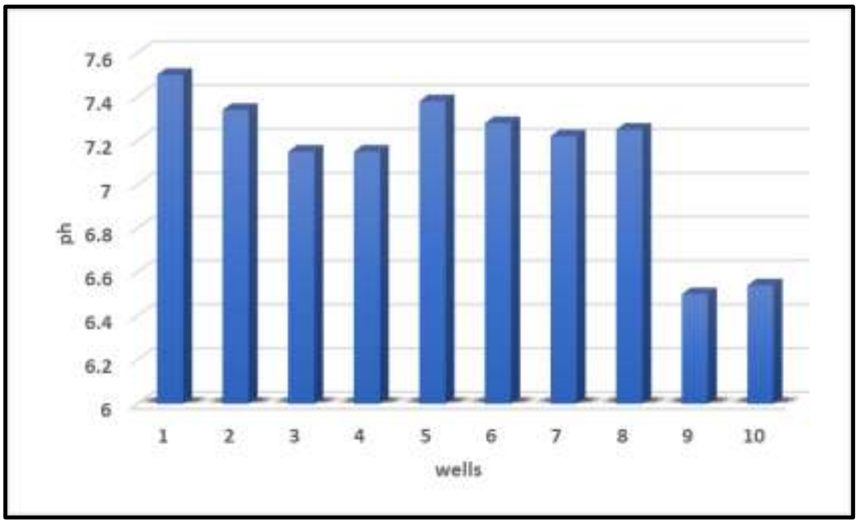
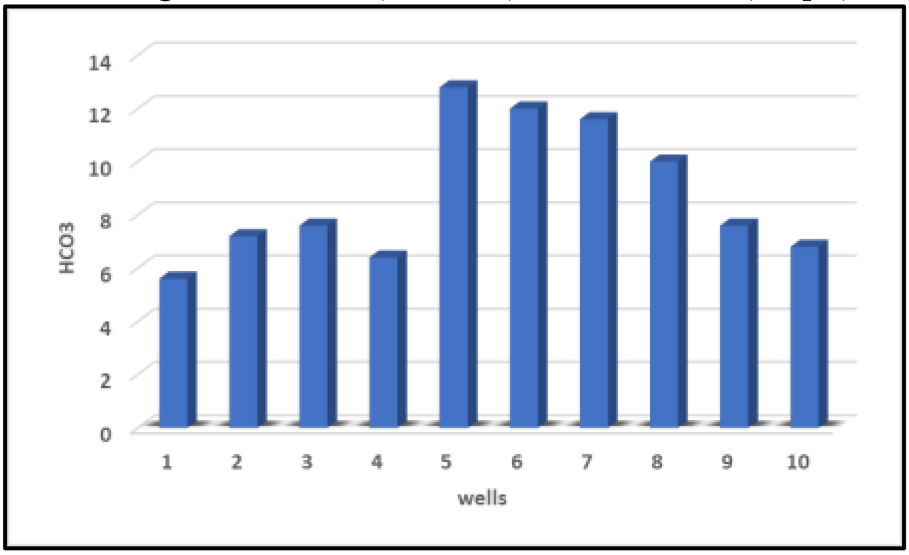


Figure (4): The average chloride (Cl^-) concentrations (meq/L) in the studied wells

Figure (5): The average bicarbonate (HCO_3^-) concentrations (meq/L) in the studied



wells

The sodium absorption ratio (SAR), Kelly ratio (KR), and percentage of sodium (%Na) are key indicators in assessing the suitability of water for agricultural use, as they are directly dependent on the concentration of sodium ions. High sodium levels in irrigation water disrupt the structural composition of soil particles, causing them to harden and reducing their water permeability during drought, which negatively affects soil productivity (18,19). Based on the data in Table 5, the results of the analysis of the studied wells showed that they belong to the low-sodium water category, making them suitable for irrigation in various types of agricultural land. The calculated rates for KR, SAR, and %Na ranged between (0.44-0.04), (0.31–3.35), and (3.53–30.54), respectively.

The results in Table 5 indicate that the residual sodium carbonate (RSC) values were negative, reaching (-41), which indicates the predominance of calcium and magnesium ions in the water, preventing the formation of precipitated sodium carbonate. As a result, all groundwater samples studied were free of residual carbonates, making them suitable for irrigation and various soil types, and contributing to reducing the potential negative effects of sodium ions. (20,21) On the other hand, the increase in potential salinity (PS) values is one of the factors that negatively affect the hormonal balance of plants; it hinders internal transport from the roots to the leaves, causing some acids to accumulate inside the leaves, which leads to the narrowing of stomata openings, and thus reducing water loss (22). The PS values in

the studied samples ranged between 27.07 and 6.61, all of which exceeded the permissible limits for irrigation, with the exception of well No. 4. The increase is attributed to the geological nature of the region's formations, which are rich in evaporitic rocks such as anhydrite and gypsum, which contribute to an increase in the concentration of sulfate ions as a result of the interaction of groundwater with them (23).

As for the permeability index (PI), the results showed its effect when using irrigation water in the long term, as a result of the interaction of various water components such as sodium, calcium, magnesium, and bicarbonate with soil components (24). However, the values showed that all samples were within the appropriate range for irrigation, ranging between (10.26–46.32).

The magnesium activity ratio (MAR), which represents the proportion of magnesium in water, is one of the basic indicators for determining water quality for agricultural use. Although the balance between calcium and magnesium is necessary to maintain the stability of water properties, an increase in magnesium leads to high soil salinity, which may negatively affect crop productivity (25). The results showed that MAR values ranged from 17.85 to 55.50, all of which were within the acceptable limits for irrigation, with the exception of well No. 10.

Table (5): Shows the minimum, maximum, and average irrigation coefficients for the wells studied, in units of millimeters/liter^{-1}.

Wells		P. S	RSC	SAR	Na%	PI	MAR	KI
	Min	7.70	-15.00	0.53	7.91	18.12	27.95	0.05
1	Max	9.12	-13.80	0.68	9.75	21.10	31.15	0.15
	Mean	8.28	-14.30	0.61	8.71	19.31	29.65	0.10
	Min	8.04	-38.40	0.93	8.30	18.10	34.79	0.07
2	Max	10.20	-32.50	1.12	11.10	20.90	38.15	0.16
	Mean	9.24	-34.50	1.02	9.96	19.62	36.69	0.11
	Min	6.26	-26.20	0.60	7.10	14.90	38.30	0.06
3	Max	8.05	-22.91	0.77	8.95	16.90	42.00	0.12
	Mean	7.36	-24.51	0.68	7.85	15.77	40.20	0.09
4	Min	5.71	-39.80	0.45	4.35	9.20	48.10	0.03

	Max	7.61	-36.49	0.61	6.54	11.70	52.10	0.07
	Mean	6.61	-38.49	0.51	5.14	10.49	50.10	0.05
	Min	10.61	-43.67	0.80	6.99	13.15	27.20	0.07
5	Max	13.10	-40.17	1.10	10.12	15.80	31.20	0.12
	Mean	11.81	-41.67	0.97	8.49	14.43	29.20	0.09
	Min	12.57	-40.17	0.97	8.50	15.62	40.60	0.10
6	Max	15.10	-35.27	1.24	11.21	17.60	45.00	0.16
	Mean	13.77	-37.77	1.12	10.00	16.42	42.65	0.11
	Min	7.93	-29.48	0.26	2.83	9.76	16.80	0.02
7	Max	9.16	-26.19	0.36	4.30	11.32	19.00	0.06
	Mean	8.56	-28.48	0.31	3.53	10.26	17.85	0.04
	Min	25.60	-6.10	2.24	28.86	44.80	41.80	0.38
8	Max	28.24	-1.98	2.48	32.88	49.90	44.60	0.50
	Mean	27.07	-4.08	2.36	30.54	46.32	43.20	0.44
	Min	11.86	-41.35	2.58	24.20	28.60	42.30	0.28
9	Max	14.28	-37.84	4.12	27.72	31.20	45.15	0.41
	Mean	12.96	-39.45	3.35	25.61	30.00	43.89	0.34
	Min	11.64	-24.90	1.21	13.60	19.50	53.50	0.15
10	Max	15.18	-22.16	1.58	16.81	24.40	58.10	0.22
	Mean	13.44	-23.76	1.40	15.14	22.40	55.50	0.18

WQI

The Sub-index Model was adopted in assessing the Water Quality Index (WQI), based on 11 criteria for irrigation water quality, as shown in Table (6), where the majority of the wells studied had high values that exceeded the standard limits for irrigation and for some characteristics such as electrical conductivity (EC25) and potential salinity (P.S). These will affect the final result of the water quality index shown in Table (7). The results of the physical and chemical analyses showed that the WQI values ranged between (90.59–143.5). According to the water quality classification based on the WQI, the water from the wells studied was classified as “poor” for irrigation use, with the exception of well No. 1, which was classified as “good” for irrigation.

Table (6): Shows Qi and SLi values for irrigation standards

10	9	8	7	6	5	4	3	2	1	Wells / Parameters	
99.46	100	96.66	96.26	97.06	98.4	95.33	95.33	97.86	100	**Qi**	**Ph**
9.252	9.302	8.992	8.955	9.029	9.153	8.868	8.868	9.103	9.302	**SLi**	
129.5	219.5	101.5	117	205.5	183.5	200	136.5	177.5	61	**Qi**	**EC_{25}**
15.05	25.52	11.80	13.60	23.89	21.33	23.25	15.87	20.63	7.093	**SLi**	
84.40	65.42	239.6	42.28	101.4	76.11	16.91	31.01	50.74	39.46	**Qi**	**CI**
5.888	4.564	16.71	2.950	7.080	5.310	1.180	2.163	3.540	2.753	**SLi**	
80	89.41	117.6	136.4	141.1	150.5	75.29	89.41	84.70	65.88	**Qi**	**HCO3**
5.581	6.238	8.207	9.521	9.849	10.50	5.253	6.238	5.909	4.596	**SLi**	
0	0	0	0	0	0	0	0	0	0	**Qi**	**RSC**
0	0	0	0	0	0	0	0	0	0	**SLi**	
334.8	249.9	161.9	730.8	456.8	519.8	714.9	475.5	382.2	388.3	**Qi**	**PI**
38.93	29.06	18.82	84.97	53.12	60.45	83.13	55.29	44.45	45.16	**SLi**	
25.23	42.68	50.90	5.885	16.66	14.15	8.560	13.08	16.59	14.51	**Qi**	**Na%**
2.347	3.970	4.735	0.547	1.550	1.316	0.796	1.216	1.544	1.350	**SLi**	
7.761	18.58	13.10	1.696	6.244	5.362	2.855	3.798	5.660	3.396	**Qi**	**SAR**
0.902	2.161	1.524	0.197	0.726	0.623	0.331	0.441	0.658	0.391	**SLi**	
110.9	87.77	86.39	35.69	85.30	58.39	100.2	80.39	73.38	59.29	**Qi**	**MAR**
10.32	8.165	8.036	3.320	7.935	5.432	9.321	7.478	6.826	5.515	**SLi**	
191.9	185.1	386.6	122.3	196.6	168.7	94.42	105.1	131.9	118.2	**Qi**	**P. S**
22.32	21.53	44.96	14.22	22.86	19.62	10.98	12.22	15.34	13.75	**SLi**	
17.86	34.48	44.45	3.699	11.17	9.316	5.423	8.531	11.15	9.613	**Qi**	**KI**
1.246	2.406	3.101	0.258	0.779	0.649	0.378	0.595	0.778	0.670	**SLi**	

Table (7): Shows the water quality index (WQI) values and their classification for the wells studied.

Wells	WQI	Water quality
1	90.59	Good
2	108.7	poor
3	110.3	poor
4	143.5	poor
5	134.4	poor
6	136.8	poor
7	138.5	poor
8	126.9	poor
9	112.9	poor

10	111.8	poor

Groundwater quality and food security

Food security means the ability of people to obtain sufficient, safe, and nutritious food that meets their nutritional needs and preferences, ensuring a healthy and active life. One of its requirements is the availability of water suitable for agriculture and irrigation, which is considered the most important factor for agricultural production in the region. The quality of groundwater in the study area varied depending on the location of the well and the area, with the amount of dissolved salts, as indicated by electrical conductivity, ranging on average between 1220 to 4390 microSiemens/cm, which means that the area can be used to grow various agricultural crops, requiring farmers to have knowledge of the crops suitable for the different well areas. According to the Food and Agriculture Organization of the United Nations (FAO) classification, water with electrical conductivity between (700-1500) microsiemens/cm is classified as low salinity, When electrical conductivity rises to 3000 microSiemens/cm, the water is classified as medium salinity. When electrical conductivity reaches 4500 microS/cm, the water is classified as medium to high salinity. Each of these water salinity classifications can be used to irrigate specific crops, depending on the crop's tolerance to different salinity levels, provided that suitable crops are selected and effective water and irrigation management is implemented. (24). Although this water is not suitable for salt-sensitive crops such as beans, oranges, or grapes, it is suitable for irrigating many salt-tolerant crops, opening up broad prospects for agricultural development in areas suffering from freshwater scarcity. Table 8 shows the classification of water according to salinity and its suitability for growing and irrigating different crops. These crops include barley, sugar beet, spinach, tomatoes (with careful management), white corn, cabbage, and lettuce. Table 9 shows the classification of wells in the study area according to their electrical conductivity values and the selection of suitable agricultural crops and their suitability for irrigation with water from the wells studied.

Table (8): Shows the suitability of agricultural crops based on the electrical conductivity (EC) values of irrigation water according to(25,26)

Crops that can be grown	Agricultural use	Salinity level	Electrical conductivity EC MicroSiemens.cm	Electrical conductivity values for the wells studied by Microsem.cm	Location	Well number
Rice, potatoes, tomatoes	Suitable for most crops	Low	1500-700	1220	The ship	1
Corn, soybeans, okra	Suitable for medium-tolerance crops	Medium	1500 - 3000	2730	Talul Nasser	3
				2340	ship1	7
				2030	Nimrod	8
				2590	Kharar1	10
Barley, sugar beet, spinach, clover, sunflower	Suitable for salt-tolerant crops	Medium to high	3000 - 4500	3559	Al-Houd	2
				4000	Al-Houd1	4
				3670	Sanik	5
				4110	Sanik1	6
				4390	Kharar	9

Affected crops	Extent of agricultural use	Water salinity level	Electrical conductivity value EC microsiemens.cm
Wheat, beans, citrus fruits, grapes	Suitable for all crops	Very low	700 >
Rice, potatoes, tomatoes	Suitable for most crops	low	1500-700
Corn, soybeans, okra	Suitable for medium-tolerance crops	Medium	3000-1500
Barley, sugar beet, spinach, clover, sunflower	Suitable for salt-tolerant crops	Medium to high	4500-3000

Date palms, prickly pears, some fodder	Use with caution for hardy crops only.	high	>4500

Table (9): Shows the classification of different wells according to their conductivity values and their suitability for growing different crops.

Conclusions

The studied well waters were characterized by significantly high electrical conductivity values, in addition to high potential salinity (PS) indices, with values ranging between 1220–4390 microSiemens/cm and 27.07–6.61 milliequivalents/liter-1, respectively. These values are particularly noteworthy, as they exceed the permissible limits for irrigation for most wells, which is clearly reflected in the WQI values. All wells did not exceed the acceptable limits for chloride and sodium ion concentrations, indicating that these elements do not pose a threat to plant growth. Nevertheless, the water is classified as "poor" for irrigation according to this indicator. With the exception of well No. 1, which was classified as "good." Its water can be used for irrigation by applying proper irrigation management, using only the amount of water needed by each type of crop, and selecting crop types suitable for each salinity level based on the concentration of dissolved salts, expressed by electrical conductivity. It is also preferable to reduce electrical conductivity values by reducing the concentrations of salts that cause them to improve water quality and use it in agriculture over large areas.

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