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Groundwater Quality Assessment and Its Suitability for Agricultural Use in Al-Shirqat Area, Salahaldin Governorate

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ABSTRACT

The study aims to investigate the assessment of groundwater quality and its suitability for agricultural use in the Al-Shirqat area in Salahaldin Governorate. The selected (23) wells are distributed over the study area at two different locations. The first location includes 12 wells and is located within the sedimentary soil unit, while the second site includes 11 wells and is located within the calcareous soil unit. Well water samples are analyzed to measure the positive and negative dissolved ions (Ca, Mg, Na, K, HCO_3, Cl, and SO_4). The irrigation water quality criteria (SAR, Na% %, ESP, PS, Mg% % and TDS) are calculated, and spatial distribution maps are prepared. The results show that the concentrations of calcium and chloride ions exceed the permissible limits needed for irrigation, while the concentration of sodium ions is within the permissible limits according to FAO standards. The values of EC range between 3-10 dSm-1 and a low exchangeable sodium absorption ratio SAR (less than 4.48) under the S1C4 group.

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تقييم نوعية المياه الجوفية وملاءمتها للاستخدام الزراعي في منطقة الشرقاط، محافظة صلاح الدين

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الملخص

تهدف الدراسة الى تقييم نوعية المياه الجوفية وملاءمتها للاستخدام الزراعي في منطقة الشرقاط في محافظة صلاح الدين. اختير (23) اثنان وعشرون بئراً موزعة على منطقة الدراسة ومن موقعين مختلفين. اما الموقع الأول فاشتمل على 12 بئراً ويقع ضمن وحدة الترب الرسوبية، اما الموقع الثاني فاشتمل على 11 بئراً ويقع ضمن وحدة الترب الكلسية. تم جلب نماذج مياه الآبار الى المختبر لقياس وتقدير الايونات الموجبة والسالبة الذائبة فيها طبقا للطرق القياسية المتبعة في مختبرات قسم علوم التربة في جامعة تكريت. تم حساب بعض المعايير والمؤشرات وهي SAR, Mg%, ESP، Na%، PS، TDS وتم اعداد خرائط توزيعها المكاني. أظهرت النتائج ان تراكيز ايوني الكالسيوم والكلوريد تجاوزت الحدود المسموح بها وفقا لمواصفة FAO، في حين كان تركيز ايون الصوديوم ضمن الحدود المسموح بها. أظهرت النتائج بان الايصالية الكهربائية كانت بين 3- 10 ديسيمنز م-1 ومنخفضة نسبة الصوديوم المتبادل SAR اذ كانت اقل من 4.48 وصنفت مياه الري ضمن (عالية الملوحة وقليلة الصوديوم S1C4).

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Introduction

Mismanagement of water for irrigation purposes leads to soil degradation and reduced agricultural production through the toxicity of nutrients, especially in arid and semi-arid areas, if it is improperly managed and exploited (Al-Hadidi, 2009; Berhe et al., 2015; Salcedo et. al., 2021). Treder (2005) confirmed that the presence of calcium and magnesium ions in irrigation water results in high accumulation in the soil under the drip irrigation system. Herrero and Perez-Coveta (2005) studied soil salinity variations over 24 years in a Mediterranean irrigated area and explained that soil degradation from salt accumulation is a threat in irrigated regions, and salinization has often been evaluated from changing cropping types, and often the trends in the salinization process have not been quantified. The quality of groundwater is of great importance in determining its suitability for various uses, as water is considered the secret of life and existence. The extraction of groundwater is of primary importance to the people who want to use their agricultural lands, which have been affected by land degradation due to drought. This is a part of the practices of land management in arid and semi-arid regions (Ma et al., 2017, 2018; Periasamy and Ravi, 2020). The impact of salinity is not limited to agricultural production, but it has negative repercussions on the environment and direct or indirect effects on the life of society (Zhang et al., 2022). Hence, groundwater needs to be evaluated for its quality, and this requires identifying the most important specifications that must be available in this water to determine its suitability for a specific use. Some limits must be met in water to determine its suitability for agricultural use. Many studies have been conducted to evaluate water quality and its suitability for irrigation in different regions of the world (Kovda et al., 1973; Liu et al., 2015; Kaba and Majar, 2020; Dimple et al., 2022; Mohammed et. al., 2023). Locally, Abbas (2010) studied the hydrogeochemistry of groundwater in Ummordomah in western Iraq and confirmed the possibility of using water for irrigation purposes. Ibrahim and Kashmola (2011) studied the quality properties of some wells water and the Lower Zab River. According to the American Salinity Laboratory classification, it is between (S1-C3) and (S3-C1). The dominant cations and anions were sodium, calcium, chloride, and sulphate. Therefore, it is worth paying attention to studying the quality of groundwater, the possibility of exploiting it agriculturally, and the extent of its potential impact on soil degradation. Several worldwide studies have used the SAR, EC, Cl, and TDS in the assessment of water quality (Presley et al., 2004; Meireles et al., 2010; Al-Rifaee and Al-Rubay, 2017; Abbasnia et al., 2018; Mostafa et al., 2020; Ekhmaj et al., 2021; Mahmood et al., 2022). These studies focused on evaluating the quality of water for irrigation, which is an important aspect of agricultural land management and raising its production efficiency.

The main goal of the present study is to evaluate the groundwater quality and its suitability for agricultural use in the Al-Shirqat area of Salahaldin Governorate based on the International Food and Agriculture Standards.

Materials and Methods

Study Area

Al-Shirqat is a district in Salahaddin Governorate in northern Iraq; its center is the city of Shirqat. It is located 115 km south of Nineveh Governorate, 125 km north of Tikrit, and 135 km west of Kirkuk Governorate. The total area of Al-Shirqat District is approximately 1,568 km^2, in which two locations are identified to evaluate the quality of groundwater in agricultural lands. The first site is located between longitudes (43°18'15.229" E and 43°19'17.511" E) and latitudes (35°23'32.155" N and 35°23'55.828" N). Twelve wells are selected within the physiographic unit of the alluvial plain affected by the sediments of the Tigris River, characterized by the cultivation of wheat, barley, and corn crops (Fig. 1). The second site is located between longitudes (43°24'59.756"E and 43°28'37.361"E) and two latitudes (35°26'1.696"N and 35°25'14.314" N). Eleven wells are selected that are distributed over the area of the study; this site is characterized by lands cultivated with wheat and maize crops. The study area is located within the arid and semi-arid areas with high temperatures in summer, which reach about 50°C, leading to burning of field crops due to the high concentration of salts in the soil resulting from the quality of well water with high temperature.

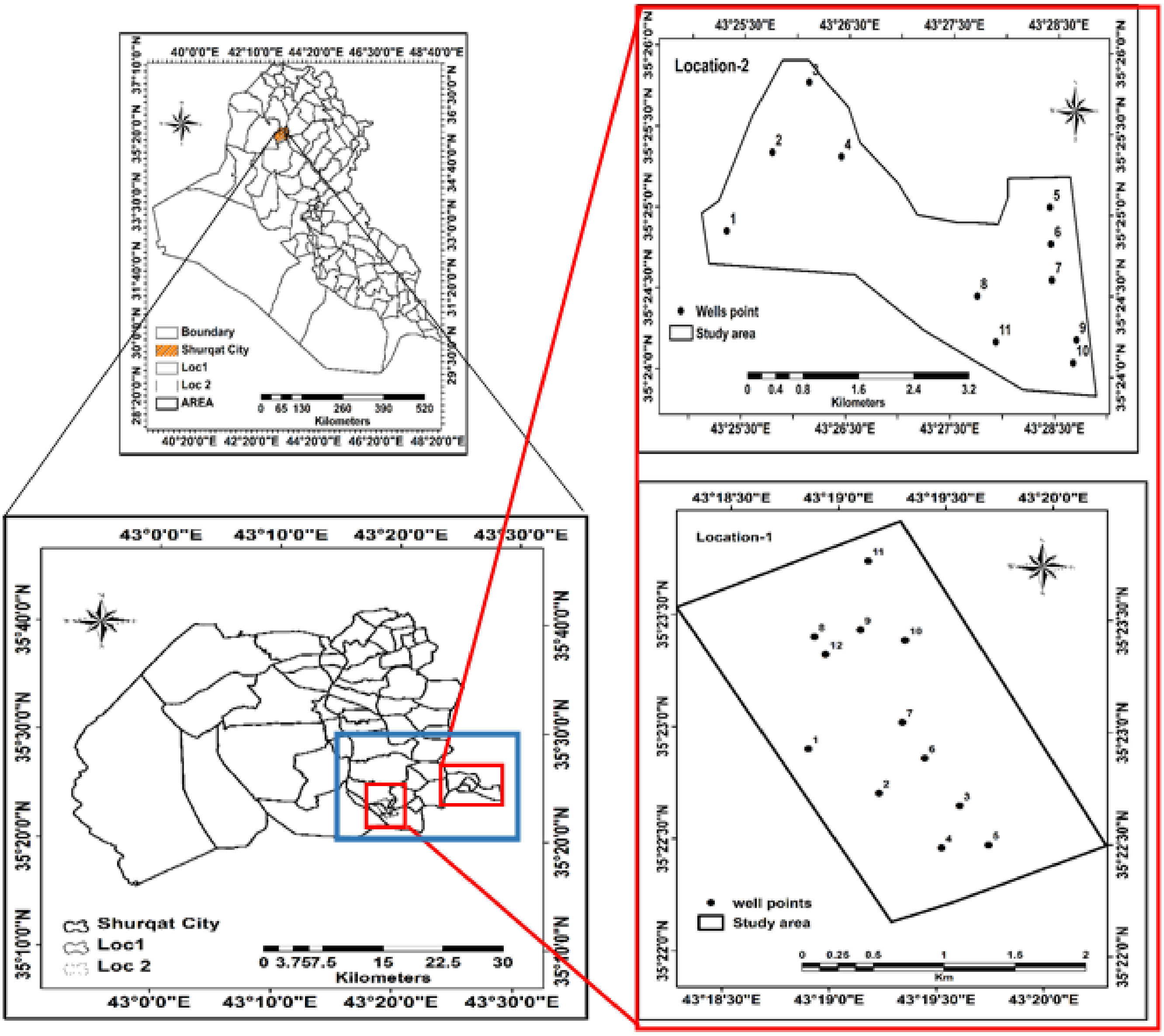


Fig. 1. Maps of study locations.

Laboratory work

Water samples were collected on October 5, 2023, and their geographic coordinates were recorded using GPS. The laboratory work includes measuring the EC and pH according to the method described by Page et al. (1982). The dissolved positive ions, calcium and magnesium, are determined by titration with EDTA (Jackson, 1969). Sodium and potassium ions are estimated using the flame photometer. Chloride is determined by precipitation with silver nitrate, while bicarbonate and carbonate are determined by titration with 0.01 M sulfuric acid (Jackson, 1969). Ayers and Westcot's (1985) classification is used in the assessment of irrigation water quality (Table 1).

Table 1: Irrigation water quality criteria according to Ayers and Westcot (1985).

Properties	EC dSm^{-1}	pH	TDS $mg\ l^{-1}$	SAR	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$	HCO_3^{-}
					meq/l						
Critical	3	6.5-8.4	2000	15	20	5	9	2	10	20	10

Ayers and Westcot (1989, 1994): https://www.fao.org/4/t0234e/T0234E01.htm#tab2; Islam et al., 2016)

Water Quality Criteria

Several indices are used in this study as follows:

1 – Total Dissolved Salts (TDS): It is calculated after knowing the degree of electrical conductivity, and expressed as in the following equation (Thorne and Thorne, 1954).

$$TDS(mg/L) = EC(dS\ m^{-1}) \times 640 \quad .... 1$$

2 - Sodium Hazard (Na%): It is calculated according to Todd (1980) (Table 2).

$$Na\% = \frac{Na+K}{Ca+Mg+Na+K} \times 100 \quad .... \ 2$$

3- Sodium Adsorption Ratio (SAR): It is an expressive value of the concentration of sodium to the (calcium and magnesium concentration) in milliequivalents of charge per liter using the following equation (Richards, 1954) (Fig. 2; Table 2).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad ....3$$

4- Exchangeable Sodium Percentage of water (ESP): It refers to the proportion of exchange sites occupied by sodium ion and calculated by the following formula (Richards, 1954).

$$ESP = \frac{100 \times (-0.0126 + 0.01475\ SAR)}{1 + (-0.0126 + 0.01475\ SAR)} \ldots \ldots \ldots \ldots 4$$

5- Potential Salinity (PS). It is calculated according to the following equation suggested by Doneen (1971), who considered its values in the range of (5-20) for good soil permeability, (15-3) for moderate soil permeability, and (7-3) meq/l is suitable for low permeable soils (after Al-Zubaidi, 1989) (Table 2).

$$\boldsymbol{PS}(\boldsymbol{meq\ l}^{-1}) = \boldsymbol{Cl} + \frac{\mathbf{1}}{\mathbf{2}} \times SO_4 \ldots\ldots\ldots\ldots 5$$

6- Magnesium Hazard (Mg%): When its value exceeds 50%, it is considered unsuitable for irrigation (Kovda et al., 1973). It is calculated by the following formula (Table 2).

$$\boldsymbol{Mg}\% = \frac{\boldsymbol{Mg}}{\boldsymbol{Ca} + \boldsymbol{Mg}} \times \mathbf{100} \ldots \ldots \ldots \ldots \mathbf{6}$$

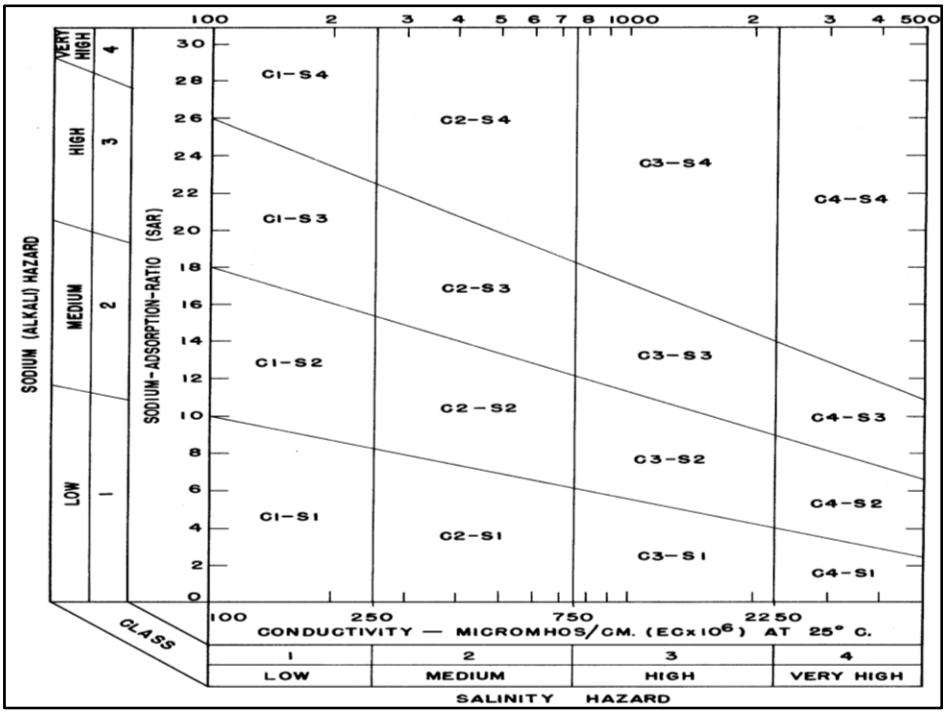


Fig. 2. Classification of irrigation waters.

Table 2: Irrigation water quality criteria for assessing groundwater in the study area.

Indicator	Class	Range	Quality	Reference
EC (dSm^{-1})	1	<0.7	High	Ayers and Westcot (1985)
	2	0.7-2.25	Moderate	
	3	2.25-5.00	Low	
	4	>5.00	Very low	
SAR	1	<3	Very High	Ayers and Westcot (1985) * Reprinted 1989, 1994)
	2	3-6	High	
	3	6-12	Moderate	
	4	12-20	Low	
	5	20-40	Very low	
TDS	1	< 450	Non	Ayers and Westcot (1985)
	2	450-2000	Slightly to Moderate	
	3	> 2000	Sever	
Na %	1	60	Excellent to good	Doneen (1954)
	2	60 - 75	Good to injurious	
	3	>75	Injurious to unsatisfactory	
PS	1	<3	Suitable	Awad et al. (2022)
	2	>3	Unsuitable	
Mg %	1	<50%	Suitable	Kovda et al. (1973)
	2	>50%	Unsuitable	

Maps and Descriptive Statistics Analysis

ArcGIS program tools are used in preparing of mapping of the soluble ions and water quality indices using Inverse Distance Weighting (IDW). Descriptive statistics values (mean, SD, minimum, maximum, and coefficient of variation, CV%) are calculated using the Excel program.

$$\boldsymbol{Mean = \frac{\sum xi}{n}} \quad \ldots\ldots\ldots \quad 7$$

$$\boldsymbol{Standard\ deviation\ (SD) = \sqrt{\frac{\sum (xi - \bar{x})^2}{n-1}}} \ldots\ldots\ldots \mathbf{8}$$

$$Coefficient\ of\ Variance\ (\boldsymbol{CV}\%) = \frac{\boldsymbol{SD}}{\bar{\boldsymbol{x}}} \times \mathbf{100} \ldots\ldots\ldots\ldots \mathbf{9}$$

Results and Discussion

EC, TDS, and pH

Table 3 indicates the variation of well water in the degree of electrical conductivity. Through the results of descriptive statistics, the well water values for the first site range between 3.80-10 dSm^{-1} with a mean of 6.27; the standard deviation value is 2.13, and the coefficient of variance (CV) is 34.04%. While in the second site, it ranges between 4.20-7.70 dSm^{-1} with a mean of 5.70; the value of the standard deviation is 1.10, and the coefficient of variance (CV) of 19.22%. Compared to the standard specifications, the well water exceeds the permissible limits for irrigation water, which is 3 dS.m^{-1} EC. The electrical conductivity causes an increase in the osmotic pressure of the liquid soil phase to affect the ability of plants to absorb water and nutrient elements, which can decrease productivity in the long term. It is the most important parameter in determining the suitability of water for irrigation, and is generally measured as the electrical conductivity (EC) of water or the concentration of total dissolved salts (TDS). The results of Fig. 3 show that the total dissolved salts (TDS) in the first site range from 2432.0 to 6400.0 mg/l, with a CV of 34.04 %. As for the second site, they range between 2688.00 and 4928.00 mg l^{-1}, with a CV of 19.22%. According to the FAO classification, they are severe. Table 3) exhibits the pH values for the first site, ranging between 6.60 and 7.20 with an average of 7.01, and the standard deviation is 0.19, with a coefficient of variance of 2.70%. While the second site, the degree of interaction ranges between 6.20 and 6.90 with an average of 6.60, with a standard deviation value of 0.21, and the CV% is 3.25%.

Table 3: Descriptive Statistics of pH, EC, TDS, and soluble ions of well water.

Statistics	pH	EC	TDS	Ca^{+2}	Mg^{+2}	Na^{+1}	K^{+1}	HCO_3^{-1}	Cl^{-1}	SO_4^{-2}
		dSm^{-1}	mg l^{-1}	meq/l						
Site-1										
Min	6.60	3.80	2432.00	22.50	7.50	9.70	0.06	2.30	6.75	26.57
Max	7.20	10.00	6400.00	67.50	28.00	23.39	0.27	8.20	33.00	64.03
Mean	7.01	6.27	4010.67	35.38	14.92	14.35	0.17	5.43	18.33	41.05
SD	0.19	2.13	1365.39	13.65	6.55	4.74	0.07	1.79	7.80	13.02
CV %	2.70	34.04	34.04	38.59	43.86	33.04	42.48	32.97	42.56	31.72
Site-2										
Min	6.20	4.20	2688.00	19.00	8.00	9.43	0.11	2.10	8.25	30.60
Max	6.90	7.70	4928.00	43.00	21.00	15.78	0.22	7.50	25.50	45.18
Mean	6.60	5.70	3648.00	32.25	12.68	12.58	0.15	5.18	16.91	35.56
SD	0.21	1.10	701.08	7.41	4.39	1.99	0.04	1.90	6.31	4.40
CV%	3.25	19.22	19.22	22.98	34.61	15.83	25.02	36.74	37.29	12.36

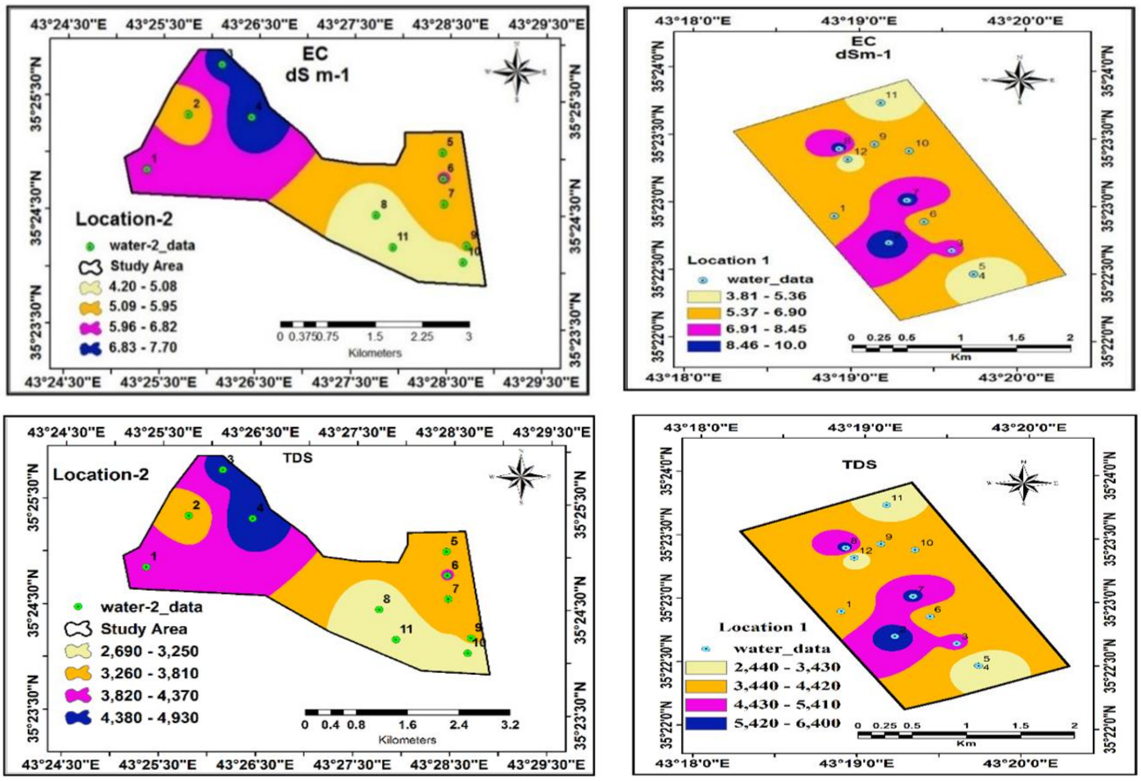


Fig. 3 Maps of electrical conductivity in the study area.

Cations

The calcium ion concentrations in the first site range from 22.50 to 67.50 meq/l with a mean of 35.38 meq/l, a standard deviation value of 13.65, with a dispersion coefficient of 38.59%. The calcium concentrations in the second site range between 19.00 and 43.00 with a mean of 32.25 meq/l, with a standard deviation of 7.41, and a coefficient of variance of 19.22%. According to the classification of Ayers and Westcot (1985) the concentration of calcium is considered unacceptable for irrigation purposes (20 meq/l or 400 mg/l) (Fig. 4). The magnesium ion concentration ranged between 7.50 and 28.00, with an average of 14.92 meq/l; the value of the standard deviation was 6.55, with a coefficient of 43.68%. The concentration of magnesium in the second site ranged between 8.00 and 21.00, with an average of 12.58, a standard deviation of 4.39, and a coefficient of variance of 34.61%. It was noted that the wells of the study sites fell within the impermissible limits of 5 meq/l. The concentration of Ca and Mg in groundwater is derived from weathering of calcite or dolomite. The ions Calcium and Magnesium, and bicarbonate originate primarily from calcite and dolomite minerals (Avaci et al., 2018) (Fig. 4; Table 3).

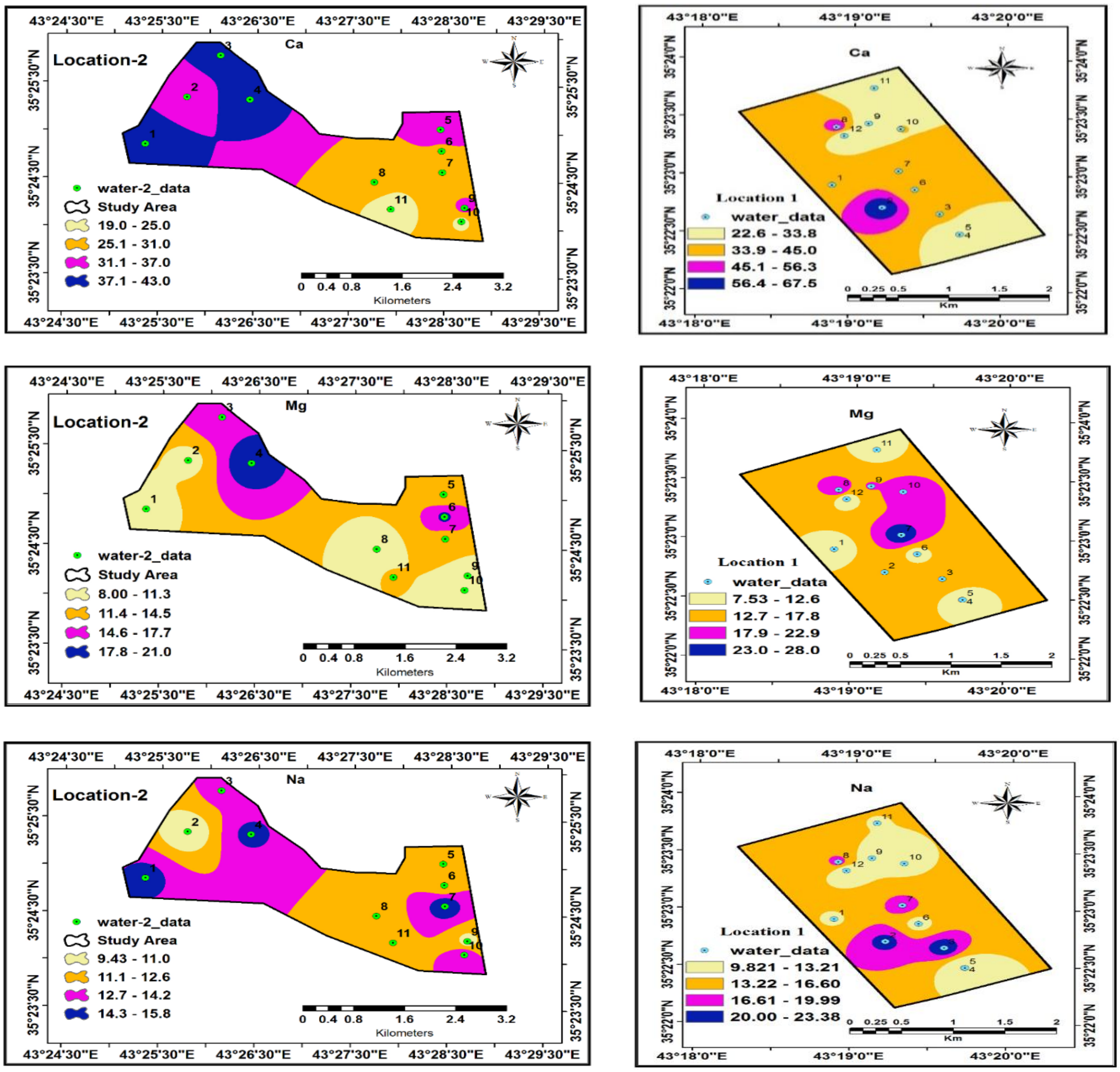


Fig. 4 Spatial distribution of positive soluble ions concentration in well water.

The sodium ion concentrations range from 9.70 to 23.39 with a mean of 14.92 meq/l, and the standard deviation value is 4.74, with a dispersion coefficient is 33.04%. As for the second site, the sodium concentrations range between 9.43 and 15.78 with a mean of 12.58, with a standard deviation of 1.99, and a coefficient of variance of 15.83% (Table 3; Fig. 4). The results of table (3) show that the potassium ion concentrations in the first location range between 0.06 to 0.27 meq/l, and according to the dispersion coefficient, it is observed that the well water had a dispersion coefficient of 42.48%, with a standard deviation of 0.07. This is due to the variation occurring like the rock material and geological formations, which are the main storehouse of nutrients and their quantity dissolved in water. As for the second location, the potassium ion concentrations range between 0.11 and 0.22 meq/l, according to the dispersion coefficient, it is noted that the well water had a dispersion coefficient of 25.02, with a standard deviation of 0.04.

Anions

Fig. (5) shows that the chloride content in the first location range between 6.75 to 33.00 meq/l, and the value of the dispersion coefficient is 42.56%, with a standard deviation of 7.80. In the second site, the chloride contents range between 8.25 and 25.50, and the dispersion coefficient value is 37.29, with a standard deviation of 6.31 (Table 3). Most of the samples in the study area are within the limits that are not permissible for irrigation purpose. Table (3) and Fig. (5) show that the sulfate contents in the first site range from 26.57 to 64.03 meq/l, and the value of the dispersion coefficient reached 31.72%, with a standard deviation of 13.02. As for the site second, sulphates range between 30.6 and 45.18 meq/l, and the dispersion coefficient value reaches 12.36, with a standard deviation of 4.40. Therefore, compared to the classification standards, most of the samples in the study area are within the impermissible limits. The results of Table 3 show that the bicarbonate (HCO_3) concentrations in the first site range between 2.30 and 8.2 with a mean of 5.43 meq/l, and the value of the dispersion coefficient is 32.97%, with a standard deviation of 1.7. In the second site, the bicarbonate concentrations range between 2.10 and 7.50 meq/l, and CV reaches 36.74%, with a standard deviation of 1.90. Compared with Table 1, both sites are within the permissible limits. The HCO_3 is unstable at high temperature (100 C°), and sometimes converted to H_2O and CO_2 (Avaci et al., 2018).

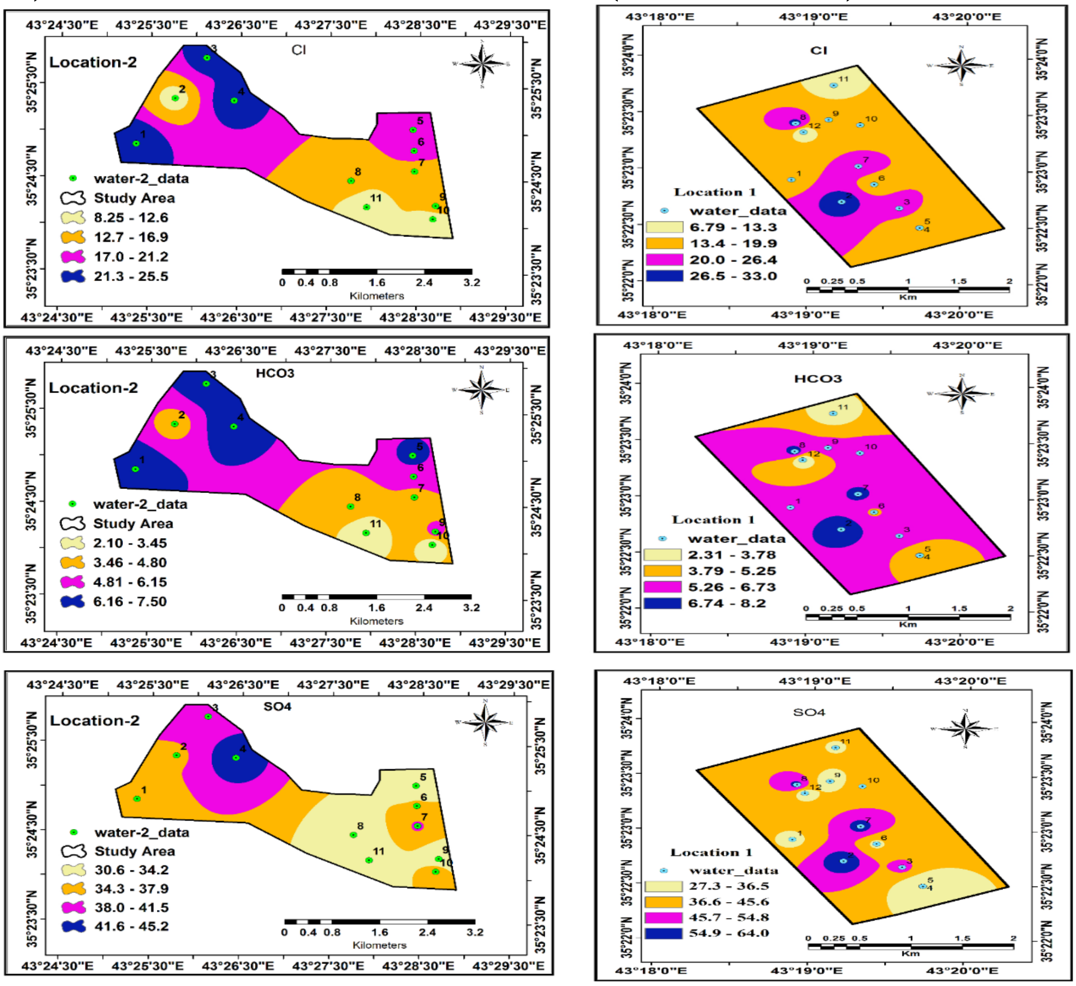


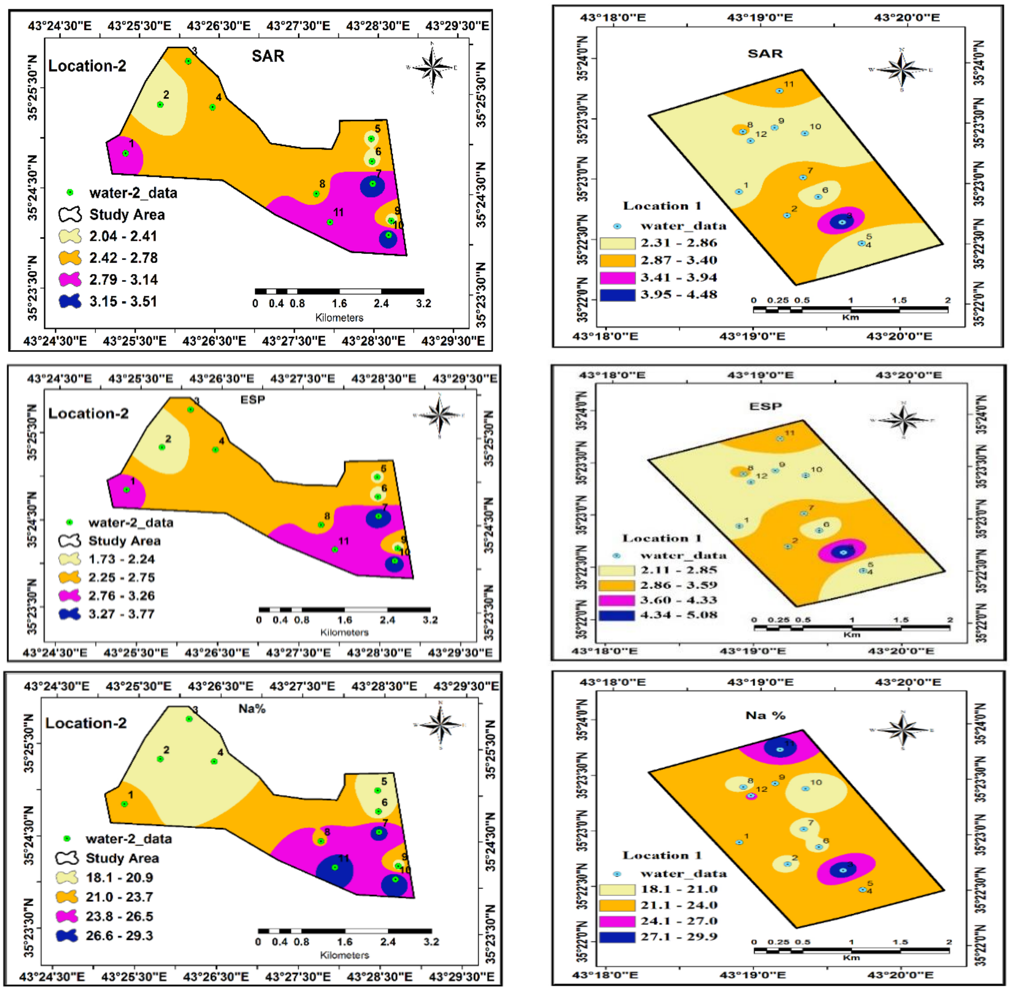
Fig. 5. Maps of negative soluble ions concentration in the study area.

SAR, ESP, and Na%

Table (4) and Fig. (6) display the variation in the sodium adsorption rate, which represents the degree of saturation of the irrigation water solution with the sodium concentration at the expense of the concentration of magnesium and calcium ions. In the first location, it ranges from 2.31 to 4.48, and according to the standards of descriptive statistics and CV of 21.95% compared with Fig. 2, all study sites are located within S1 (sodium is low) and C4 (EC is high). As for the second site, the sodium adsorption rate ranges between 2.04 and 3.51, with a CV of 18.00%. The well water of both study sites fell within the permissible limits. The results of Table 4 and Fig. 6 indicate that the percentage of exchangeable sodium percentage (ESP) in the first site ranges from 2.11 to 5.08, and the value of the dispersion coefficient is 30.10% with a standard deviation of 0.86. In the second site, the ESP ranges between 1.73 and 3.77, and the value of the CV reaches 25.64%, with a standard deviation of 0.68. Table 4 shows that the Na% in the first site ranges from approximately 18 to 30%, and the value of the standard deviation reaches 3.62, and the dispersion coefficient is 16.14%. As for the second site, the percentage of sodium hazard ranges between 18.10 and 29.31, with a dispersion coefficient of 19.75%, and the value of the standard deviation reaches 4.39. SAR is one of the valuable parameters for evaluating the suitability of groundwater for irrigation because it is responsible for the sodium hazard. Because SAR is concerned with salt absorption on the soil surface, it provides a good foundation for evaluating the sodium damage degree in irrigation water. Moreover, sodium from irrigation water reaches the soil and replaces the absorbed calcium and magnesium, resulting in a reduction in permeability and poor drainage in the soil (Alaya et al., 2013).

Table 4: Criteria for evaluating the quality of well water at the study sites.

Stat.	PS	SAR	Na%	ESP	(MH)	Group
			Site-1			
Min	17.74	2.31	18.07	2.11	18.60	C4-S1
Max	40.22	4.48	29.96	5.08	43.90	C4-S1
Mean	25.95	2.86	22.44	2.87	29.64	C4-S1
SD	7.99	0.63	3.62	0.86	7.94	C4-S1
CV%	30.79	21.95	16.14	30.10	26.78	C4-S1
			Site-2			
Min	18.37	2.04	18.10	1.73	18.10	C4-S1
Max	29.89	3.51	29.31	3.77	37.99	C4-S1
Mean	22.96	2.69	22.25	2.63	28.24	C4-S1
SD	3.33	0.48	4.39	0.68	6.98	C4-S1
CV%	14.51	18.00	19.75	25.64	24.71	C4-S1



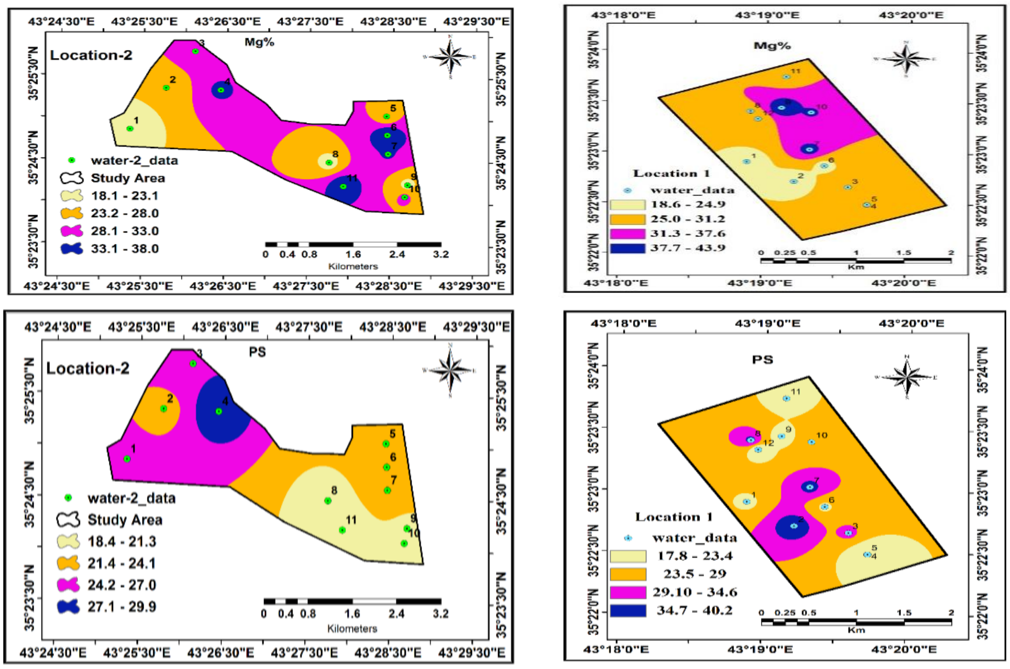


Fig. 6. Maps of SAR, ESP, Na%, and MH in the study area.

PS and Mg %

The results of Table 4 and Fig. 6 show that the PS values in the first site range from 17.74, as the lowest effect of the magnesium hazard ratio, to approximately 40, as the highest PS ratio. The value of the dispersion coefficient reaches 30.79 with a standard deviation of approximately 8.00. As for the second location, the PS percentage ranges between 18.37 and 29.89, and the dispersion coefficient value reaches 18.83%, with a standard deviation of 7.28.

A potential salinity is less than 3 meq/l, illustrating that the water can be used for irrigation (Doneen, 1954; Avaci et al., 2018; Awad et al., 2022). The PS values of all collected samples are estimated as high values. The results of Fig. 6 show that the risk percentage of magnesium in the first site ranges from 20.65 to 43.94%, with a standard deviation value of 8.81 and a dispersion coefficient of 28.14%. As for the second site, the risk rate of magnesium ranges between 22.35 and 39.36%, with a dispersion coefficient of 20.54, and the standard deviation value is 6.10. These values are less than 50 meq/l, indicating that all samples are suitable for irrigation and have no effect on crop yield (Zhao et al., 2021).

Conclusion

The results confirm that the electrical conductivity concentration is relatively high in some study areas, while we did not notice an increase in the exchangeable sodium ratio, which is less than 10. The results also confirm that the concentration of total dissolved salts reaches more than 6000 mg/l in some areas, while we note that the other indicators had good results for agricultural use. Research has shown significant differences in water quality even between wells located just a few kilometers apart. Therefore, each well must be studied independently based on its unique characteristics. In general, groundwater in this area is suitable for irrigating crops that are moderately resistant to desertification, such as wheat during the winter season. Groundwater can also be used as a supplementary source of irrigation when rainfall is interrupted for short periods during the agricultural season. However, it is crucial to avoid overusing this water as excessive use, which may lead to salt accumulation in the soil and degrade its quality over time, negatively affecting agricultural productivity and contributing to desertification.

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