Kirkuk Journal of Science Vol. 20, Iss. 2, p. 14-32, 2025 doi:10.32894/kujss.2025.159529.1207

Influences of Correcting Ion Pairs and Activity on Classification of Groundwater for Irrigation Purpose in Makhmur Province

Salman Hashm Saheed [1,*], Akram Othman Esmail [1]

[1] Department of Soil and Water Science, College of Agricultural Engineering Sciences, Salahaddin University, Erbil, Iraq.

*Corresponding author : zaneary3@gmail.com

Article Information

Article Type:
Research Article

Keywords:
Groundwater, water classification, ion pair.

History:
Received: 25 April 2025
Revised: 18 June 2025
Accepted: 19 June 2025
Available Online: 30 June 2025

Citation: Salman Hashm Saheed,Akram Othman Esmail, Influences of Correcting Ion Pairs and Activity on Classification of Groundwater for Irrigation Purpose in Makhmur Province, Kirkuk Journal of Science, 20(2), p. 14-32, 2025, https://doi.org/10.32894/kujss.2025.159529.1207

Abstract

This study was done during the dry and wet seasons of 2024, which included water chemical analysis for 36 wells in Makhmur province is located between the longitude (43° 58'34" E and 43°37, 82" E latitude 35°26'70" N and 35° 15' 56" N), then classified depending on some international classification systems before and after correcting ion pairs and activity. The main results were as follow:

Depending on Electrical conductivity and sodium adsorption ratio values of water samples the water for (9, 1, 22 and 4) wells had (C_3S_1, C_3S_2, C_4S_1 and C_4S_2) classes before correcting ion pairs and activity respectively; while after correction, the water for (9, 1, 16, 8, 1 and 1) wells had (C_3S_1, C_3S_2, C_4S_1, C_4S_2, C_4S_3 and C_4S_4) classes. Relying on water salinity potential (SP) values, before correcting ion pair and activity the water for (9, 3 and 24) wells had good, moderate, and bad category. It means correcting ion pairs and activity caused conversion the water for (4) wells from bad to moderate class. On the other hand, relying on sodium adsorption ratio values water for (14, 17 and 5) wells had non-restriction, slight to moderate and severe restriction of use respectively before correction. While after correcting ion pair and activity the water for (12, 19 and 5) wells had non-restriction, slight to moderate and severe restriction of use respectively that caused change the water for two wells from class one to class two. While depending on bicarbonate concentration the water for two wells changed from slightly-moderate class to non-severe restriction of use after correcting ion pairs plus activity. In general, in most cases correcting ion pair and activity causes decrease in risk of saline water for irrigation due to conversion the water classes towards the better classes. The main results explained the role of ion pairs and activity in conversion the water from class to another then decrease the salinity risk for irrigation use in most cases.

1. Introduction:

Water quality in Iraqi Kurdistan region varies from location to another depending on the geological formation of the study area, type of aquifer, the chemical reaction between water and aquifer, environmental conditions, depth of wells... etc. [1].

The area of ground water is very large in Kurdistan region, its area in Erbil governorate is which equal to (5000 km2) and the number of drilled wells is (9805) [1]. In Makhmur province the ground water is the main source of irrigation due to low rainfall, absenting irrigation projects. [2] The numerous water quality studies were conducted in Kurdistan region from 1955 to 2024. The first study was done by Parsons and Ralph Engineering Company (1955) at Alton-copri basin and the last one was done by Hamad (2024). Ion pairs means the approach of soluble cation and anion in water to a distance less than 5 Angstrom by columbic force and both of them keep its hydration shell this phenomenon called ion pairing [3].

The charger of ion pairs equal to the difference between the valence of the contributed cation and anion in ion pairs, for example the charge of ($CaSO_4$)0 and ($MgSO_4$) o equal to zero, while the charge of (KSO_4)- and ($CaHCO_3$)+ equal to -1 and +1 respectively [3].

Electrical conductivity had the same values depending on concentration (before correcting ion pairs and activity) and activities (after correction ion pairs and activity) of cations and anions, because ion pairs are non-conductance to electrical current [2]. Correcting ion pairs and activity causes increase in SAR and decrease in salinity potential (SP) and residual sodium carbonate (RSC) due to high contributing of Ca and Mg and low contributing of Na in ion pairs [2] and [3]. On the other way, the decrease in salinity potential (SP) and negative values of residual sodium carbonate (RSC) causes shifting the water quality to the better category and via versa for SAR [4] and [5].

This may be due to the differing in participation of main cations and anions in ion-pairing and they are differing in activity coefficient that had either positive or negative influences on the mentioned parameters [3], [4] and [5]. In general correcting ion pairs and activity causes decrease in salinity potential (SP) and residual sodium carbonate which are causing decrease in risk of using saline water for irrigation [2]. The residual sodium carbonate (RSC)value for most of groundwater had negative value due to high calcium and magnesium concentration in comparing with concentration of carbonate and bicarbonate ions [6] and [7].

The groundwater for 25 wells in Kaniqirzhala district, Erbil was classified by [8] depending on EC and SAR values, the results indicated that the water for (24 and 1) wells had C_2S_1 and C_3S_1 classes respectively. On the other hand, depending on residual sodium carbonate (RSC) the water for all wells had safe probably class since their RSC values less than 1.25 meq L^{-1}. [9] Studied the water quality for 62 wells in Erbil-Pirmam area, the results showed that the water for (59 and 3) wells had C_1S_1 and C_3S_1 classes respectively since their SAR values less than 2 and their EC values ranged between 0.33-1.18 dS m^{-1}. In Dohuk governorate the water 30 water samples were classified by [10], the results explained that their water classes were ranged between Excellent to bad classes.

The influences of correcting ion pairs and activity was used to focuses on their role in conversion the water classes of 155 wells in Erbil governorate, the results indicated to conversion the water of 40 wells towards the better classes [2]. Since there are no studies in Makhmur province about the role of correcting ion pair and activity in conversion the water from class to another and decrease the salinity risk for irrigation purpose depending on some classical international systems. For above reasons the goals of this investigation are:

1. Classify the groundwater of Makhmur province for irrigation purpose using some international classification systems.

2. Studying the role of correcting ion pairs and activity in decrease the risk of salinity for irrigation.

2. Material and Methods:

2.1 Study area:

The study area was conducted during the wet and dry season of 2024, the area is located between the longitude (43° 58’34” E and 43°37, 82” E latitude (35°26’70” N and 35° 15’ 56” N. The area of the studied locations is 2690 km^2. The elevation ranges between 190-394 meter above sea level Figure 1.

The climate of Center Makhmur and Qaraj is aired with the mean of rainfall less than 250 mm $year^{-1}$, while the climate of Dibaga and Gwre is semi- arid with the average of rainfall of 250-500 mm per year [11].

2.2 Water sampling:

The water samples were taken from 15^{th} of May, and 15^{th} of October ,2024 from 36 wells in agricultural lands of Makhmur province. The samples were collected in aplastic bottle of 2500 ml, then kept in the refrigerator at (4 ◦C) then sent to the laboratory for analysis. The water was classified according to the mean of two seasons.

2.3 Water Analyses:

The water properties were determined according to the standard methods which included (EC, pH, concentration of Ca^{+2}, Cl^-, $HCO_3{}^-$, K^+, Mg^{2+}, Na^+, $NO_3{}^-$ and $SO_4{}^{-2}$) [12].

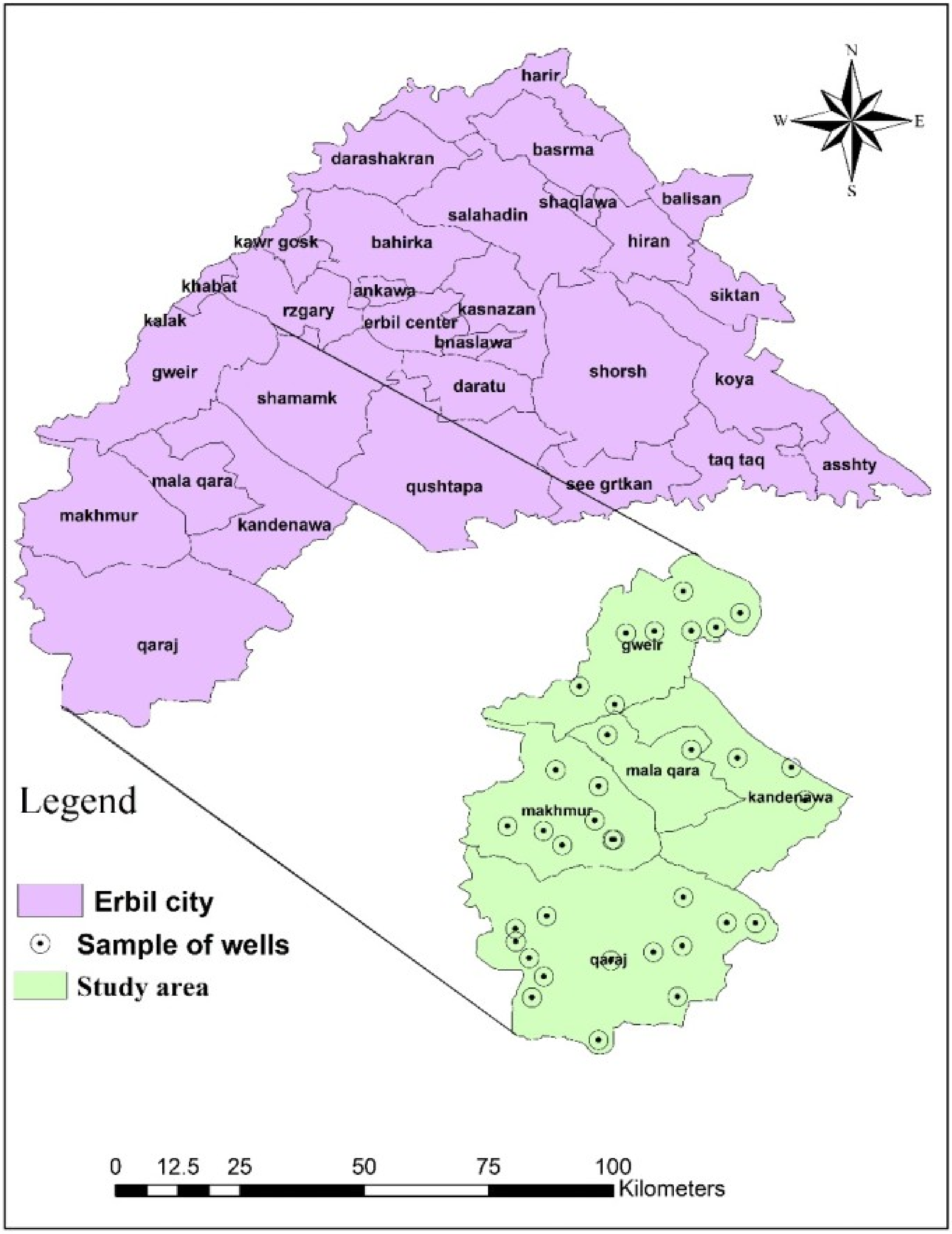

Figure 1. Shows the area and the locations of the study wells.

2.4 Ion pairs and activity were determined according to special program prepared by [2], that depended on models which summarized as follow:

Ionic strength

$$(\mu) = 1/2\Sigma CiZi^2 \quad (1)$$

Where: Ci = actual molar concentration of each ion in the water (mmol L^{-1}).

Zi = valence of ions.

In the program the activity coefficient of ions was calculated using Debye–Huckle equation as follows:

$$-Log\ \gamma = AZi^2\sqrt{\mu} + Bdi\sqrt{\mu} \quad (2)$$

Where: γ = Activity coefficient, μ = Ion strength (mol L^{-1}). A is water constant that equal to 0.509 at 25 C, Zi = charge of ions, B is constant which = 0.3285 and di = Ion size parameter.

$$a = \gamma * c \quad (3)$$

Where: a = Ionic activity, γ = Activity coefficient, c = concentration in mmol L^{-1}. The parameters were determined as follow:

1. Sodium Adsorption Ratio (SAR) [13].

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (4)$$

Concentration of Na, Ca and Mg in meq L^{-1} = mmolec L^{-1}

2. Salinity Potential (SP) as Represented by [14].

$$SP = (Cl^- + SO^4_{2-}) \quad (5)$$

Concentration of Cl^-, and $SO_4{}^{2-}$ in meq L^{-1} = mmole CL^{-1}

3. Residual Sodium Carbonate (RSC) as mentioned by [12].

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (6)$$

Concentration of $CO_3{}^{2-}$, $HCO_3{}^{-}$, Ca^{2+} and Mg meq L^{-1} = mmole CL^{-1}

4. The type of ion pairs, number of ions contributed in ion paring, activity of ions, SAR, SP and RSC were determined from raw data using the unit of mmole L^{-1} [2].

2.5 Classification of irrigation water:

There are numerous international systems for irrigation water classification, some of them were selected in this investigation, because they are affecting by ion pairs and activity of ions, which are:

1- Richard's classification:

This classification (Richard's classification, 1954) categorized the water into 4 classes depending on EC and SAR separately as shown in below, while the total number of classes are (16) classes from C_1S_1 to C_4S_4. Depending on crossing between C and S as shown from Table 1 [13].

This classification (Richard's classification, 1954) categorized the water into 4 classes depending on EC and SAR separately as shown in below, while the total number of classes are (16) classes from crossing between C and S types such as C_1S_1 to C_4S_4. as shown from Table 1 [13].

2- Donnen classification:

This classification depending on soil permeability and water salinity potential [14] as shown in Table 2 below:

3-Wilcox classification:

[15] This classification depends on Residual sodium carbonate (RSC) value., which classified irrigation water into 3 classes [15] as explained in Table 3 below:

4- Ayers and Westcot classification (1994):

They classified the water depending on numerous parameters and only three of them were selected since they had great relation with this study as explained in Table 4 below [16].

3. Results and Discussion:

The properties of the study groundwater or raw data were used in a special program after testing accuracy of data according to the model mentioned by [1] to determine ion pairs, activity, activity coefficient and some parameters Table 5 and 6.

Table 7 Range, mean and standard deviation for the properties of study water samples before and after correcting ion pairs and activity. As shown Table 7.

The values of SAR, SP, RSC, SAR**, SP**, RSC** and the ratio between them were recorded in Table 9 after conversion the raw data to (meq L^{-1}). The results indicated that correcting ion pair and activity caused (1.1 to 2.1) times increase in SAR**values. This may be due to high contributing of Ca and Mg in ion pairing and their low activity coefficients and via

Table 1. Water classes according to EC.

EC (dS m^{-1} at 25 ^{o}C)	Water class	SAR Value	class	Classes and properties
$\leq$ 0.25	C1	<10	S_1	C_1S_1 = Excellent with Low salinity
0.25 - 0.75	C2	10 - 18	S_2	C_2S_2 = Good with Medium salinity
0.75- 2.25	C3	18 -26	S_3	C_3S_13 = Fair with High salinity
> 2.25	C4	>26	S_4	C_4S_4 = Poor with Very high salinity

Table 2. Water categories depending on Donnen,s classification [14].

	Positional of salinity (SP) SP = (Cl^- + 1/2 SO_4^{2-}) mmolc L^{-1}.		
Water Category	Soil permeability		
	High	Moderate	Low
Good	Less than 7	Less than 5	Less than3
Moderate	7 to 15	5 to 10	3 to 5
Bad	More than 15	More than 10	More than 5

Table 3. Wilcox classification depending on Residual sodium carbonate (RSC) value.

Water classes of irrigation water	RSC (mmolc L^{-1})
Probably safe	Less than 1.25
Marginal	1.25 to 2.5
GUnsuitable	More than 2.5

versa for Na (Table 8 and 10).

The ratio between SP**/SP was ranged between 0.58-0.94, this may be due high contributing of SO_4^{2-} and low activity coefficient of it Table 8. The mentioned correction caused 0.19.-1.17 times increase in RSC** /RSC due to high contributing of Ca, Mg and HCO_{3-} in ion pairs and their low activity coefficients (Table 8 and 10).

Finally, the above corrections lead to decrease in negative values of RSC** and increase in its positive value. The water RSC values for all wells had negative value except the water for well number 1 which had positive value. These results agree with [1] and disagree with [16], [17] and [18] due to differing in the location of study area and their geological formation.

SAR, SP and RSC = their values (meq L^{-1}) depending on concentration or before correction SAR**, SP** and RSC = their values (meq L^{-1}) depending on ion pair and activity or after correction. The focus was on types of ion pairs and their concentrations that determined from raw data using special program Table 10. The series of ion pairs depending on their mean were as follow:

$(CaSO_4)^o > (MgSO_4)^o > (CaHCO_3)^+ > (NaSO_4)^- > (MgHCO_3)^+ > (NaHCO_3)^o > KSO_4)^-$.

These results disagree with those obtained by [3] due to differing in chemical composition of the water samples of the mentioned studies. The concentration of ion pairs is differing depending on chemical composition and EC of the study groundwater samples, increase in EC value causes increase in ion pairs formation.

The amount of ions which contributed in ion pairs are documented in Table 10. These were calculated from different ion pairs. Sum of cations contributed in ion pairs = sum of anions, this indicates to the accuracy of program applied in this study. The series for the mean of ions contributed in ion paring were as follow: $Ca^{+2} > Mg^{+2} > Na^+ > K^+ > SO_4{}^{-2} > HCO_3{}^-$. Water classification: The study waters were classified according to some classifications which are affecting by correcting ion pairs and activity as explained below:

1- Richard classification [12]:

The results of classification depending on EC and SAR values in Table 9 were summarized in Table 11. The results indicated that before correcting ion pairs and activity the water of (9, 1, 22 and 4) wells had C_3S_1, C_3S_2, C_3S_1 and C_4S_2 classes respectively , while after correcting ion pair and activity the water quality for (9, 1, 16, 8, 1 and 1) wells had C_3S_1, C_3S_2, C_4S_1, C_2S_4 and C_4S_3) respectively Table 12.

Table 4. Ayers and Westcot classification (1994) depending on some selected parameters.

Potential irrigation	Unite	Degree of restriction of use (classes)		
	Salinity (EC)	Ds m^{-1}	None	Slight to moderate Severe
Salinity (EC)		< 0.7	0.7 – 3.0	> 3.0
SAR		< 3	3 – 9	> 9
Bicarbonate (HCO_{3-}) mmolcL $^{-1}$ < 1.5	1.5 -8.5	> 8.5		

It means that correcting ion pair and activity caused conversion the water class of some wells to bad class for example the water of (4, 1 and 1) wells or the water for wells number (7, 12, 17, 19 and 22) were changed from C_4S_1 to C_4S_2 and water for well number 18 changed from C_4S_2 to C_3S_3 respectively. This may be due to high initial SAR values of water for the mentioned wells mentioned wells Table 9. The high contributing of calcium and magnesium in ion paring and their low activity coefficients, with low sodium contribution in ion pairs and its high activity coefficients were caused increase in SAR values. These results agree with [5], and disagree with those recorded [2] since the initial SAR value of water samples of her study is very low which ranged between (1.5 -2.75).

Figure (2, 3 and 4) explains spatial distribution of the water for the study wells depending on their EC, SAR and SAR** receptively. Depending on EC the water for 26 wells had C4 category before and after correction since the ion pairs and activity are not affecting on EC value as mentioned before. The area of orange color means high EC value than is greater than green color (low EC value). Table 9 explains that 72.22% of wells had high saline water which ranged from 2.25 to 18.50 dS m^{-1}.

Figure 3 The spatial distribution of the studied water samples depending on sodium adsorption ratio values (SAR) before correcting ion pairs and activity. The green, yellow and red colors are represented S1, S2 and S3 water classes depending on SAR values. The mentioned colors represent the water of 31,4 and 1 wells that had S1,S2 and S3 categories respectively. The green, yellow and red colors is equal to (86.11, 11.11 and.2.8) % of the study water samples of the study area. These results disagree with the results of most of the studies conducted in Kurdistan region since due to their low SAR values less than 10 or (S1 class). The high waters SAR values in this study of may be due to existing spots of halite in the study area [17] and [19].

Figure 4 Refers to spatial distribution of SAR** after correcting ion pairs and activity which caused increase in SAR** values in comparing with SAR before correcting. The correctios caused 1.1-2.1 times increase in SAR values (Table 10 which caused creating new water class such as S_3 and S_4. The water of 26, 8, 1 and 1) wells had S_1, S_2, S_3, and S4 classes respectively. This may be due to increase in SAR values due to the reasons mentioned before. The green, yellow, orange and pink colors represent (72.22, 22.22. 2.78 and 2.78) % of the studied water which differing from Figure 3 due to the role of ion pairs and activity in increasing SAR** values [2].

2- Doneen classification (1945) of groundwater depending on salinity potential before and after correcting ion pairs and activity:

Correcting ion pair and activity caused decrease in (SP**) values due to high contributing of $SO_4{}^{2-}$ (0.09-10.22) mmole L^{-1} in ion pairs and its low activity coefficient (051-0.73) (Table 9 and 7). As shown from Table 12 and depending on SP and SP** values in Table 9 the water of (9, 3 and 24) wells had good, moderate and bad quality respectively for high permeable soils, while after correction the water for (9, 7 and 20) wells had good moderate and bad quality respectively. It means correction of ion pair and activity resulted shifting the water of 4 wells from bad to moderate class.

For moderate soil permeability the water for 2 wells changed from bad to moderate Table 11 While for low soil permeability the water of (0, 6 and 30) wells had (good, moderate and bad) quality respectively before ion pair and activity correction, the results also depend on soil permeability. In general correcting ion pair and activity caused shifting the water towards the better classes. These may be due to high contribution of SO_4 in ion pairs and low activity coefficient of it as mentioned before. Similar results were observed by [4].

Figure 5 Classified the water of the study area into 3 classes or 3 colors depending on the results of classification. The green, yellow and turquoise colors represent (66.67,25 and 8.33) % of the study waters represents the bad, moderate and good water for irrigation due to high salinity potential. This may be due to differing in geological formation of the study area (High gypsum and spots of halite) [17], [18], [19] and [20]. Correcting ion pairs and activity caused change the of 4 well from bad to moderate quality due to the reasons mentioned before.

3- Ayers and Westcot classification:

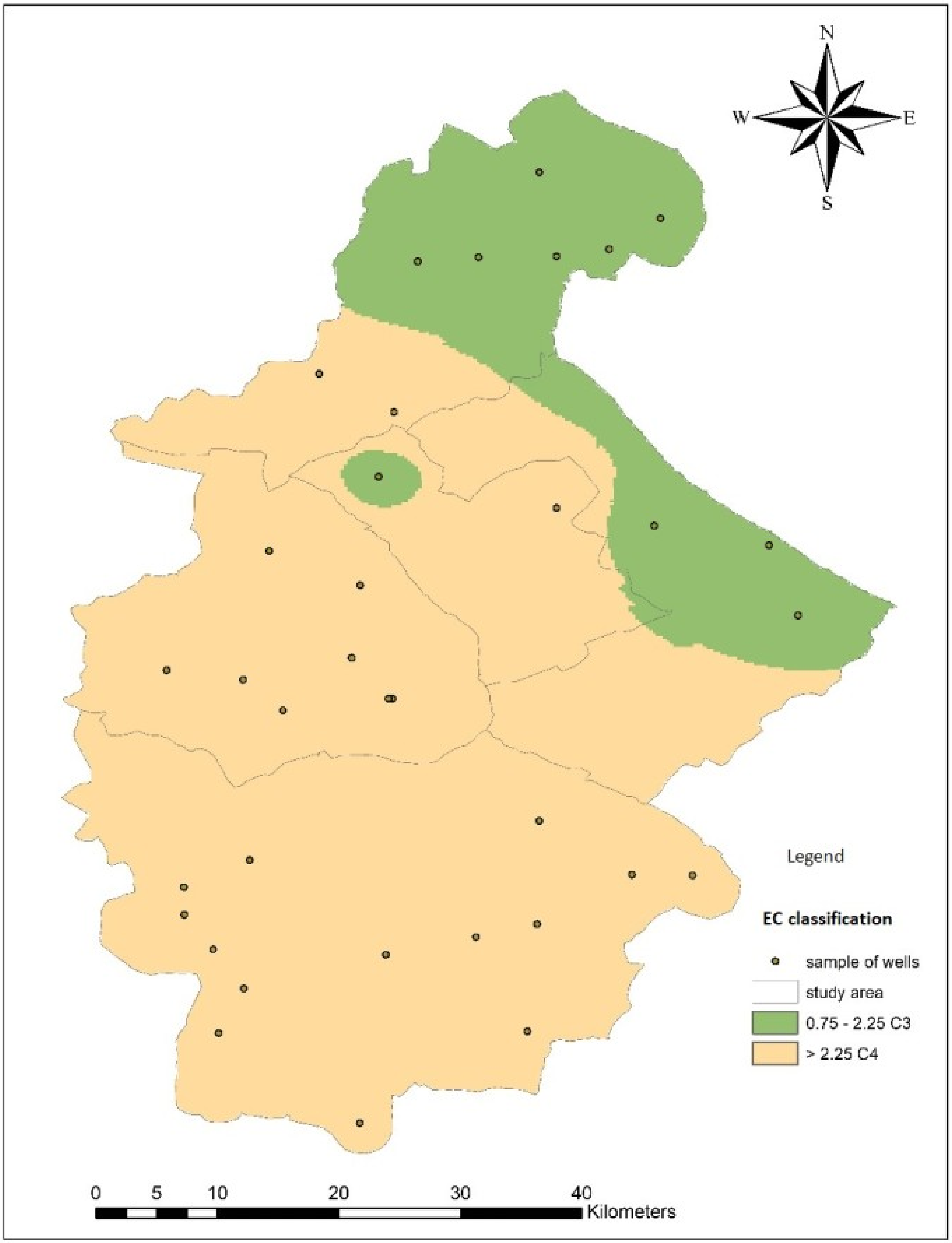

Figure 2. Shows the area and the locations of the study wells.

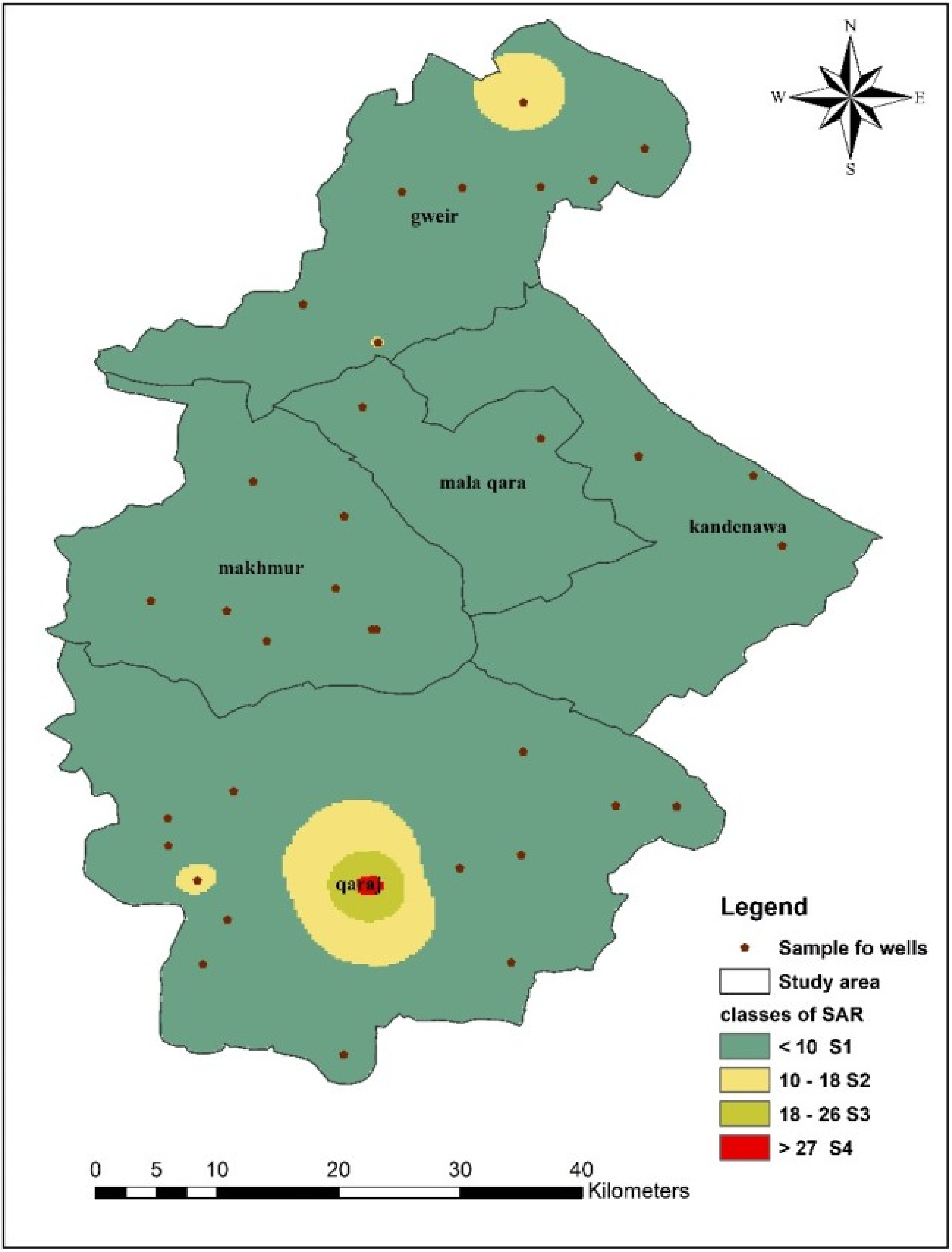

Figure 3. Shows the area and the locations of the study wells.

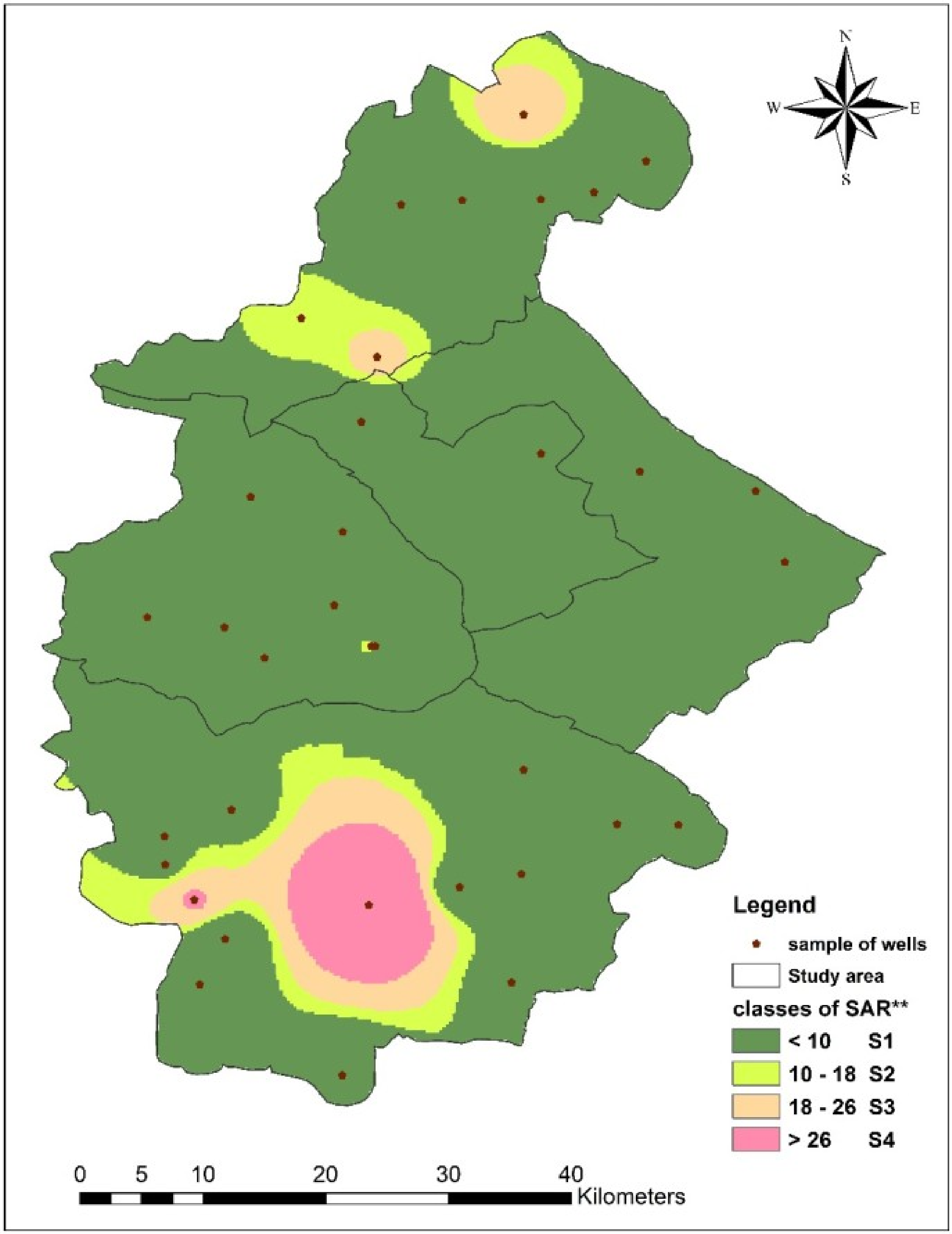

Figure 4. Shows the area and the locations of the study wells.

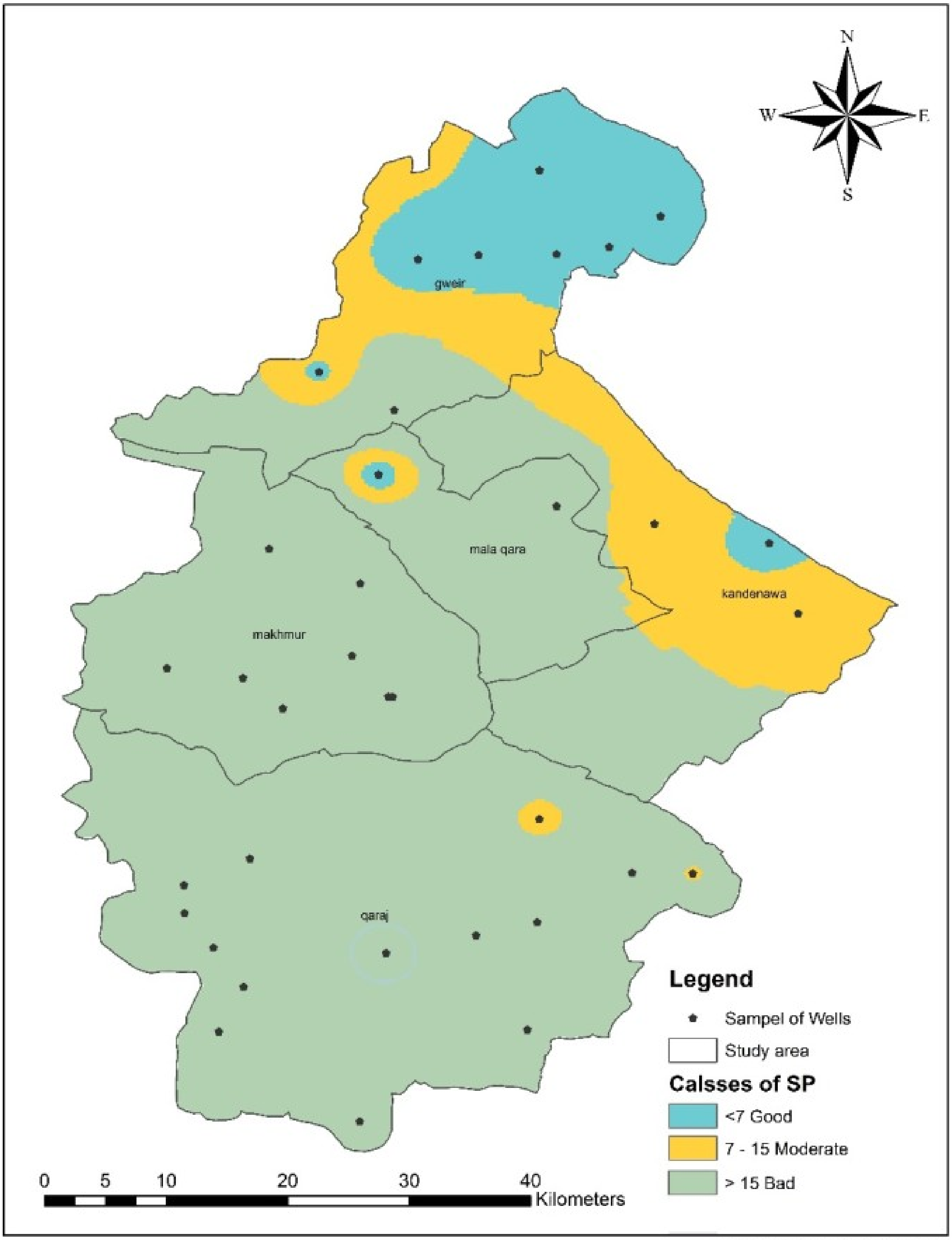

Figure 5. Shows the area and the locations of the study wells.

In Ayers and Westcot classification the focusing is on both SAR and HCO_3 [15], because only these two parameters were affecting by correcting ion pair and activity Table 12. Depending on EC value the water of (13 and 23) wells had slight to sever and sever restriction of use respectively before and after correcting ion pairs and activity since the ion pairs are non-conductive to electrical current [2].

While according to bicarbonate the water of (2 and 34) wells had non and sight to moderate restriction of use before correction, while the water of (4 and 32) wells had non and sight to moderate restriction of use after correction, it means the water of (2) wells changed from sight - moderate class to non-restriction of use class or changed towards the better water quality for irrigation. This may be due to contribution of 0.03 -034 mmole L^{-1} of bicarbonate in ion pairing and its low activity coefficient (0.33 - 0.77) which were decreased their risk for plants, since ion pairs cannot absorb by plants and not contributes in chemical reactions in water and soil solution [6].

As shown from table 12 correcting ion pairs and activity caused conversion the water of 2 wells from non-restriction of use to slight-moderate restriction of use. Figures (3 and 4) indicates to difference between the SAR value before and beyond correcting ion pairing and activity, that caused increase in SAR values then changing the water of some wells to the worse class.

4. Conclusion:

The groundwater in the study area is slightly saline to saline water, it means most of them not suitable in case of using drip and sprinkler irrigation method. While for surface irrigation and tolerance and semi tolerance plants are suitable depending on amount of ions contributing in ion pairs since ion pairs are not absorb by plant. It means this phenomenon had positive effects on classification saline water especially if the dominate ions are magnesium, calcium bicarbonate and sulphate.

5. Recommendations:

Depending on the obtained results the recommendations were summarized as follow:

1. Most of the study waters had low or no risk for irrigation purpose due to contributing high concentration of ions in ion pairs that caused decrease in the risk of their using for irrigation.

2. Increase in water electrical conductivity causes increase in contributing ions in ion pairs then decrease its risk for irrigation.

3. Cultivation of tolerance and semi tolerance plants in some locations of the study area depending on the salinity of water.

Table 5. properties of the studied waters before correcting ion pairs and activity.

no.	Location	pH	EC	Ca^{2+}	Mg^{2+}	K+	Na^{+}	Cl^{-}	SO^{42-}	CO^{32-}	HCO^{3-}
			dS m^{-1}	Concentration (mmole L^{-1})							
1	Kawr	8.2	1.24	0.40	0.20	0.10	11.00	5.10	1.45	0.00	2.60
2	Tarjan	7.4	1.02	1.60	1.05	0.10	4.80	1.90	2.45	0.00	2.80
3	Shamamar	7.1	1.23	1.75	1.90	0.20	4.90	3.30	1.50	0.00	3.90
4	Zhiba	7.2	1.55	2.40	2.60	0.30	5.20	3.80	3.05	0.00	3.40
5	Shamshula	7.2	1.39	1.80	1.60	0.10	7.00	4.30	1.90	0.00	3.30
6	Abu sheta	7.2	1.33	1.70	1.05	0.20	7.70	2.90	1.95	0.00	74.60
7	Zmaray jasm	7.4	3.04	2.90	2.20	0.10	20.20	14.00	7.10	0.00	3.40
8	Darmanawa	7.2	6.08	7.50	5.00	0.10	35.70	27.90	12.60	0.00	3.60
9	Makhmur	7.1	2.60	6.00	4.30	0.10	5.60	11.70	5.10	0.00	2.90
10	Dugirdkan	7.4	3.35	5.80	1.95	0.10	17.90	10.70	8.50	0.00	3.00
11	Garasor	7.3	3.98	12.25	2.10	0.10	11.20	4.50	16.35	0.00	1.50
12	Sirma	7.2	12.35	18.65	18.80	0.20	44.50	51.80	30.10	0.00	3.70
13	Grabasha	7.3	5.39	5.63	3.03	0.10	9.55	14.45	5.15	0.00	0.95
14	Hawarghal	7.5	4.40	9.20	6.40	0.20	12.70	29.30	4.90	0.00	1.90
15	Khalidiya	7.2	4.53	7.60	3.907	0.20	22.10	19.30	7.80	0.00	2.00
16	Adla	7.2	6.59	15.85	8.75	0.20	16.50	34.20	11.70	0.00	3.20
17	Hasarok	7.5	7.99	11.70	8.70	0.20	38.90	60.60	5.60	0.00	2.80
18	Shendr	7.2	9.63	13.85	7.65	0.30	53.00	53.40	15.50	0.00	73.20
19	Ankawa	7.3	6.80	10.50	6.40	0.20	33.90	36.00	10.20	0.00	2.80
20	chwar goman	7.1	4.86	11.45	8.40	0.20	8.70	6.40	718.35	0.00	2.20
21	Kalashkhan	7.6	3.21	8.75	5.05	0.40	7.00	11.80	3.35	0.00	2.90
22	Dinkawa	7.0	11.91	22.74	14.91	0.30	43.59	35.49	35.94	0.00	3.81
23	Qalata soran	7.3	2.717	6.90	4.10	0.10	5.10	8.30	3.85	0.00	2.80
24	Grda rasha	7.3	5.06	10.90	10.36	0.20	7.80	13.00	16.06	0.00	3.00
25	Ruala	7.2	18.50	8.65	15.80	0.20	135.89	79.90	48.85	0.00	3.20
26	Grdachal	7.1	8.02	17.50	8.76	0.30	27.40	38.20	15.86	0.00	2.00
27	Hushtraluk	6.8	8.55	16.96	9.86	0.40	31.50	41.70	16.90	0.00	2.20
28	Qabr said	6.9	9.25	20.16	16.14	0.21	20.40	45.30	717.49	0.00	3.30
29	Doma azez	6.6	6.75	15.00	9.10	0.20	12.30	29.00	11.26	0.00	2.70
30	Malakagha	6.8	2.66	6.70	4.00	0.20	5.00	4.80	8.70	0.00	2.40
31	Jana	8.0	0.89	1.60	1.30	0.20	3.10	3.30	1.55	0.00	1.90
32	Shorija	7.8	1.67	2.75	2.55	0.10	6.00	3.60	4.90	0.00	2.00
33	Milihorti	7.6	1.04	1.60	1.45	0.10	4.10	1.60	2.70	0.00	2.30
34	Dibagah	7.4	0.96	1.60	1.65	0.10	3.00	1.60	2.80	0.00	2.00
35	Talamira	8.9	6.24	4.90	7.75	3.10	36.40	25.20	17.20	0.00	1.00
36	Majd malaqara	8.0	4.02	9.25	5.70	0.20	10.00	8.50	14.70	0.00	1.00

Table 6. Physiochemical properties of the studied waters after correcting ion pairs and activity.

Wells number	pH	EC	Ca^{+2**}	Mg^{+2**}	K^{+**}	Na^{+**}	Cl^{-**}	SO^{-2**}	CO_3^{-2**}	HCO_3^{-**}
		dS m^{-1}				Activity of ions (mmole L^{-1})$^{-}$				
1	8.2	1.24	0.23	0.12	0.09	9.76	5.10	0.85	0.00	2.30
2	7.4	1.02	0.87	0.59	0.09	4.25	1.90	1.30	0.00	2.44
3	7.1	1.23	0.98	1.11	0.18	4.32	3.30	0.74	0.00	3.35
4	7.2	1.55	1.21	1.38	0.26	4.51	3.80	1.37	0.00	2.86
5	7.2	1.39	0.98	0.91	0.09	6.14	4.30	0.93	0.00	2.82
6	7.2	1.33	0.91	0.59	0.17	6.77	2.90	1.00	0.00	3.96
7	7.4	3.04	1.15	0.94	0.08	16.73	14.00	2.82	0.00	2.75
8	7.2	6.08	2.49	1.82	0.08	28.17	27.90	3.69	0.00	2.69
9	7.1	2.60	2.64	2.02	0.08	4.69	11.70	1.77	0.00	2.29
10	7.4	3.35	2.23	0.81	0.08	14.75	10.70	3.11	0.00	2.38
11	7.3	3.98	5.03	0.92	0.08	9.47	4.50	6.62	0.00	1.23
12	7.2	12.35	6.07	6.72	0.15	35.00	51.80	7.98	0.00	2.71
13	7.3	5.39	2.49	1.43	0.08	8.00	14.45	1.86	0.00	0.76
14	7.5	4.40	3.81	2.87	0.16	10.29	29.30	1.37	0.00	1.41
15	7.2	4.53	2.95	1.64	0.16	17.95	19.30	2.45	0.00	1.53
16	7.2	6.59	6.71	3.97	0.16	13.62	34.20	3.73	0.00	2.47
17	7.5	7.99	5.22	4.17	0.16	31.92	60.60	1.78	0.00	2.15
18	7.2	9.63	5.29	3.17	0.24	42.77	53.40	4.85	0.00	2.44
19	7.3	6.80	4.53	2.95	0.16	28.10	36.00	3.59	0.00	2.21
20	7.1	4.86	4.54	3.56	0.16	7.28	6.40	6.72	0.00	1.76
21	7.6	3.21	3.99	2.46	0.33	5.82	11.80	1.01	0.00	2.21
22	7.0	11.91	8.09	5.74	0.24	35.36	35.49	11.49	0.00	2.92
23	7.3	2.71	3.21	2.02	0.08	4.29	8.30	1.31	0.00	2.20
24	7.3	5.06	4.46	4.52	0.16	6.52	13.00	5.68	0.00	2.38
25	7.2	18.50	2.23	2.26	0.08	117.00	79.90	35.90	0.00	1.19
26	7.1	8.02	6. 90	3.72	0.24	22.34	38.20	4.87	0.00	1.52
27	6.8	8.55	6.53	4.11	0.32	25.56	41.70	5.11	0.00	1.67
28	6.9	9.25	8.64	7.41	0.16	16.91	45.30	5.66	0.00	2.56
29	6.6	6.75	5.76	4.94	0.11	11.28	29.00	3.78	0.00	1.71
30	6.8	2.66	2.67	1.71	0.16	4.17	4.80	3.07	0.00	71.90
31	8.0	0.89	0.94	0.79	0.18	2.77	3.30	0.82	0.00	1.66
32	7.8	1.67	1.28	1.25	0.08	5.16	3.60	2.16	0.00	1.67
33	7.6	1.04	0.86	0.81	0.09	3.63	1.60	1.40	0.00	1.99
34	7.4	0.96	0.86	0.92	0.09	2.66	1.60	1.45	0.00	1.73
35	8.9	6.24	1.50	2.61	2.61	28.45	25.20	4.98	0.00	0.75
36	8.0	4.02	3.13	2.09	0.16	8.07	8.50	4.52	0.00	0.76

Table 7. Range, mean and standard devition.

Water properties	Unit	Before correcting ion pairs and activity			After correcting ion pairs and activity			Activity coefficient		
		Range mmolc L^{-1}	Mean	S D	Range mmolc $^{-1}$ *	Mean	S D	Range	Mean	S D
EC	dS m^{-1}	18.50-0.89	4.21	3.92	18.5-0.89	4.21	3.92	-	-	-
Ph		8.90-6.60	7.26	0.42	8.90-6.60	7.26	0.42	-	-	-
Ca^{2+}		45.50-0.75	16.26	12.19	17.29-0.46	5.61	4.61	0.61-.0.38	0.427	0.08
Mg^{2+}	mmol L^{-1}	37.59-0.38	10.04	9.48	14.82-0.24	4.04	3.60	70.63-0.39	0.46	0.09
K^{+}		3.10-0.10	0.16	0.49	2.61-0.09	0.17	0.37	0.90-0.84	0.81	0.09
Na^{+}		135.87-3.00	11.75	24.16	117.0-2.77	10.03	13.80	0.92-0.0.86	0.83	0.03
Cl^{-}		79.90-1.60	12.36	19.93	79.90-1.60	12.36	19.93	1.00 – 1.00	1.00	-
SO_4^{-2}		97.70-2.90	17.20	20.56	71.80-1.47	5.66	4.81	0.73-0.51	0.55	0.10
HCO_3^{-}		4.60-0.95	2.78	0.81	3.96-0.75	2.21	1.75	0.86-0.78	0.79	0.09

Table 8. Influence of correcting ion pairs and activity on some water parameters and their ratios.

NO.	EC	SAR	SAR**	SAR**/	SP	SP**	SP**/SP	RSC	RSC**	RSC**/
	(dS m-1)	(mmolc L-1)$^{0.5}$		SAR	(mmolc L^{-1})			mmolc L^{-1}		RSC
1	1.24	14.60	16.60	1.10	6.51	5.92	0.91	1.49	1.60	1.08
2	1.02	3.00	3.52	1.20	4.36	3.20	0.73	-2.46	-0.48	0.20
3	1.23	2.60	2.99	1.20	4.84	4.06	0.84	-3.37	-0.82	0.24
4	1.55	2.30	2.81	1.20	6.83	5.15	0.75	-6.58	-2.31	0.35
5	1.39	3.80	4.48	1.20	6.22	5.27	0.85	-3.59	-0.94	0.26
6	1.33	4.60	5.52	1.20	4.83	3.87	0.80	-0.82	0.96	1.17
7	3.04	9.00	11.58	1.30	21.09	16.83	0.80	-6.69	-1.42	0.21
8	6.08	10.10	13.57	1.30	40.49	31.59	0.78	-21.39	-5.92	0.28
9	2.60	1.70	2.17	1.20	16.76	13.43	0.80	-17.69	-7.04	0.40
10	3.35	6.40	8.46	1.30	19.21	13.84	0.72	-12.55	-3.69	0.29
11	3.98	3.00	4.59	1.50	20.82	11.09	0.53	-27.09	-10.39	0.38
12	12.35	7.30	12.44	1.70	81.94	59.82	0.73	-71.12	-21.90	0.31
13	5.39	4.60	9.65	2.10	39.15	30.74	0.78	-32.69	-5.93	0.18
14	4.40	3.20	3.98	1.20	34.17	30.65	0.90	-29.29	-11.94	0.41
15	4.53	6.50	8.38	1.30	27.09	21.73	0.80	-21.02	-7.64	0.36
16	6.59	3.30	5.05	1.50	45.92	37.92	0.83	-45.99	-18.17	0.40
17	7.99	8.60	12.69	1.50	66.21	62.37	0.94	-38.02	-15.98	0.42
18	9.63	11.40	18.22	1.60	68.96	58.29	0.85	-39.76	-13.73	0.35
19	6.80	8.20	12.40	1.50	46.24	39.62	0.86	-31.06	-12.15	0.39
20	4.86	2.00	3.06	1.60	24.74	13.11	0.53	-37.55	-14.02	0.37
21	3.21	1.90	2.29	1.20	15.10	12.78	0.85	-24.67	-10.70	0.43
22	11.91	7.10	11.72	1.60	71.40	46.95	0.66	-71.49	-23.87	0.33
23	2.71	1.50	1.88	1.20	12.11	9.56	0.79	-19.13	-8.26	0.43
24	5.06	1.70	2.60	1.50	29.00	18.64	0.64	-39.47	-14.96	0.38
25	18.50	27.50	52.88	1.90	128.77	82.76	0.64	-45.65	-8.60	0.19
26	8.02	5.30	8.41	1.60	54.01	43.04	0.80	-50.54	-19.23	0.38
27	8.55	6.10	9.66	1.60	58.59	46.83	0.80	-51.45	-19.08	0.37
28	9.25	3.40	5.09	1.50	62.80	50.96	0.81	-69.33	-28.81	0.42
29	6.75	2.50	3.76	1.50	40.30	32.81	0.81	-45.51	-14.80	0.33
30	2.66	1.50	1.99	1.30	13.48	7.83	0.58	-19.00	-6.84	0.36
31	0.89	1.80	2.11	1.20	4.84	4.09	0.85	-3.87	-1.79	0.46
32	1.67	2.60	3.25	1.20	8.52	5.79	0.68	-8.53	-3.38	0.40
33	1.04	2.30	2.81	1.20	4.29	2.99	0.70	-3.86	-1.34	0.35
34	0.96	1.70	1.99	1.20	4.35	3.00	0.69	-4.48	-1.83	0.41
35	6.24	10.20	14.05	1.40	42.42	30.21	0.71	-24.35	-7.46	0.31
36	4.02	2.60	3.53	1.40	23.19	13.00	0.56	-28.87	-9.68	0.34

Table 9. Type of ion pairs and amount of ions contributed in ion paring.

Ion pairs and ions	Unit	Range	Mean	S. D
		mmol L^{-1}		
$(CaSO_4)^o$	$mmol\ L^{-1}$	5.91 - 0.04	1.26	1.38
$(CaHCO_3)^+$		0.16 - 0.01	0.09	0.04
$(MgSO_4)^o$		4.56 - 0.02	0.65	1.03
$(MgHCO_3)^+$		0.13 - 0.001	0.05	0.03
$(NaSO_4)^-$		0.59 - 0.01	0.08	0.17
$(NaHCO_3)^o$		0.04 - 0.001	0.01	0.01
$(KSO_4)^-$		0.11 - 0.001	0.00	0.02
Ca^{+2}		6.05 - 0.05	1.34	1.40
Mg^{+2}		4.70 - 0.02	0.71	1.05
Na^+		0.61 - 0.01	0.09	0.18
K^+		0.11 - 0.01	0.01	0.02
$HCO_3)^-$		0.31- 0.03	0.14	0.07
$SO_4)^{-2}$		10.22 - 0.09	2.09	2.46

Table 10. Influence of correcting ion pairs and activity on some water parameters and their ratios.

Water class before correcting ion pair and activity	No. of wells	Water class after correcting	No. of wells	Change in water classes
C_3S_1	9	C_3S_1	9	0 No change
C_3S_2	1	C_3S_2	1	0 No change
C_4S_1	22	C_4S_2	16	-6 Decrease
C_4S_2	4	C_4S_2	8	+5 increase
0	0	C_4S_3	1	+1 increase

Table 11. Classification the water of study wells depending on (SP) [14].

Water	Class Before correcting ion pairs and activity (SP)			After correcting ion pairs and activity (SP**)		
	Soil permeability			Soil permeability		
	High	Moderate	Low	High	Moderate	Low
Good	9	6	0	9	6	0
Moderate	3	4	6	7	6	6
Bad	24	26	30	20	24	30

Table 12. Effects of correcting ion pairs and activity on water classes.

Parameters	Water classes before correction			Water classes after correctios			Change in water classes
	Number of wells						
	Non- restriction	Slight-moderate restriction	Severe	Non- restriction	Slight to moderate restriction	Severe	
EC	13	23	0	13	23	0	0
HCO_3^-	2	34	0	4	32	0	2
SAR	14	17	5	12	19	5	2

Funding: None.

Data Availability Statement: All of the data supporting the findings of the presented study are available from corresponding author on request.

Declarations:
Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: This research did not include any human subjects or animals, and as such, it was not necessary to obtain ethical approval.

Author Contributions: Salman Hashim Saheed was responsible for sample collection, analysis, data interpretation, manuscript writing, and review. Akram Othman Esmail conceived the research, supervised the research, and read the manuscript.

References

[1] D. M. D. Sajadi and A. O. Esmail. Comparison between groundwater quality at north east and south west of erbil governorate for irrigation using some global systems and principal component analysis. *Al-Qadisiya Journal for Agriculture Sciences*, 10(2): 308–324, 2020.

[2] A.O. Esmail. *Effect of composition and ion pair in irrigation water on soil and plant*. PhD thesis, College of Agriculture, University of Baghdad, Iraq, 1992.

[3] K. S. Rajab and A. O. Esmail. Influence of ion pairs and activity on the index of irrigation water quality relying on some modern terms in erbil governorate. *Zanco Journal of Pure and Applied Sciences*, 34(2): 118–128, 2022, doi:10.21271/ZJPAS.34.2.9.

[4] A. O. Esmail and H. O. Salih. The role of ion pairs and ion activity in classification of ground waters for irrigation in erbil plain. *Journal of Zankyo Sulaimani*, 16: 177, 2014.

[5] A. S. Alani. . the chemical composition of irrigation water and it is effect on ion pairing, some chemical properties of soil and plant growth, erbil-kurdistan region-iraq. Master's thesis, College of Agri. Salahaddin University. Iraq, 2015.

[6] B.M. Salam. Identifying water suitability for different uses in rania district. Master's thesis, College of Agri. Univ. of Salahaddin, Erbil Kurdistan-Iraq, 2019.

[7] K. Rajab and A. Esmail. Role of ion pairs and activity in estimation of ionic strength from electrical conductivity of irrigation water. *Iraqi Journal of Agricultural Sciences*, 54: 755–767, 2023, doi:10.36103/ijas.v54i3.

[8] M.H. Hamad, J.J. Toma, K. Karimkhanm, and A. M. Hanna. Application of geographical information system –water quality index techniques for evaluating the groundwater quality in kaniqirzhala landfill, kurdistan region, iraq. *Iraqi Geological Journal*, 57(2C): 296–315, 2024, doi:10.46717/igj.57.2C.20ms-2024-9-28.

[9] S. Esmael and Sh. Seeyan. Hadrochemical investigation and quality of groundwater in erbil-pirmam area, kurdistan region, iraq. *Iraqi Geological Journal*, 56(1A), 2023.

[10] A. O. Esmail, V. I. Barwari, and O. A. Rekani. Limiting irrigation water quality indices of several rivers, wells and springs in dohuk governorate. *Zico Journal of Pure and Applied Sciences*, 34(4), 2022.

[11] S.Z. Jassim and J.C. Goff. Geology of iraq. *distributed by Geological Society of London*, 2006.

[12] American Public Health Association. *Standard methods for the examination of Waster and water*. A. P. H. A., Washington, 20^{th} edition, 1998.

[13] L.A. Richard. Diagnosis and improvement of saline and alkali soils. us department of agriculture. *US Department of Agriculture. Agricultural Handbook*, 60: 7–53, 1954, doi:10.1097/00010694-195408000-00012.

[14] L.D. Deneen. Salination of soil by salts in the irrigation water. eos, 1954.

[15] L. Wilcox. classification and use of irrigation waters, 1955.

[16] R.S. Ayers and D.W. Westcot. Water quality for agriculture, 1985.

[17] S.O.I. Seeyan. *Hydrogeological and hadrochemical investigations of the Shaqlawa-Harrir Basin*. PhD thesis, College of Sci.Technische Univ. of Berg Akademie Freiberg-Germany, 2015.

[18] A.A. Marif. *Assessment of the water quality for groundwater using iwqi methods and multivariate statistical analysis for irrigation*. PhD thesis, Sulaimani governorate, Kurdistan Region, Iraq, 2023.

[19] AA. Marif and A.O. Esmail. Quality evaluation of water resources for irrigation in sulaimani governorate, iraq. *Applied Ecology and Environmental Research*, 14(2): 189–196, 2009, doi:10.15666/aeer/2103.

[20] A. Sh. Hamad Ali. Groundwater investigation, water uses and suitability for qaladze-sangaserarea, suleimani governorate, ikr. Master's thesis, Salahaddin University-College of Agricultural Engineering Sciences, Soil and Water Department, 2024.

تأثير تصحيح الأزدواج الأيوني و الفعالية الأيونية في تصنيف المياه الجوفية في منطقة مخمور لغرض الري

سلمان هاشم سعيد [1*] ، اكرم عثمان اسماعيل [1]

[1] قسم التربة والمياه ،كلية علوم الهندسة الزراعية، جامعة صلاح الدين، اربيل ، العراق.

* الباحث المسؤول: *zaneary3@gmail.com*

الخلاصة

اجريت هذه الدراسة خلال فترتي الجفاف والرطب لعام 2024 ، والذي شمل التحليل الكيميائي للمياه لـ 36 بئرًا في قضاء مخمور التي شملت مركز مخموروناحية قراج و ديبه كة و كوير، ثم صنفت المياه استنادا الى متوسط نتائج التحليل الكيميائي لكلا الموسمين باستخدام بعض التصنيفات العالمية وكانت النتائج كالاتي: استنادا الئ قيم التوصيل الكهربائي و نسبة امتزاز الصوديوم (*SAR* و *EC*) فإن مياه (9 ، 1 ، 22 و 4) بئرا كانت لها صنف (C_3S_1 ، C_3S_2 ، C_4S_1 و C_4S_2) قبل تصحيح أزواج الأيوني ووالفعالية الايونية على التوالي. بينما بعد تصحيح الازدواج الايوني و الفعالية الأيونيةا، فإن مياه (9 ، 1 ، 16 ، 8 ، 1 و 1) بئرا سجلت صنف (C_3S_1 ، C_3S_2 ، C_4S_1 ، C_4S_2 ، C_4S_3 و C_4S_4) على التوالي . اما اعتمادًا على جهد التملح (*SP*)، وقبل تصحيح أزواج الأيوني والفعالية الايونية ،كانت مياه (9 ، 3 و 24) بئرا ذات نوعية جيدة ومتوسطة ورديئة. ادت تصحيح الازدواج الايوني وافعالية الى تغير نوعية مياه (4) بئرا من رديئة إلى متوسطة. من ناحية أخرى، وبالإشارة إلى قيم نسبة امتصاص الصوديوم فقط فان نوعية المياه لل(14 و 17 و 5) بئرا لها صنف عدم تقييد وتقييد طفيف إلى متوسط وشديد في الاستخدام على التوالي قبل التصحيح. بينما بعد تصحيح الازدواج الأيوني و الفعالية ،كانت مياه (12 و 19 و 5) بئرا لها أصناف سابقة الذكر على التوالي مما تسبب في تغيير مياه بئرين من الدرجة الأولى إلى الدرجة الثانية. بينما اعتمادا على تركيز البيكربونات فأن مياه لبئري تغير من درجة معتدلة قليلاً إلى تقييد غير شديد في الاستخدام بعد التصحيح. بشكل عام، في معظم الحالات ادت تصحيح الأزدواج الأيوناي والفعالية إلى تقليل خطر الملوحة بسبب تحويل نوعية المياه نحو االنوعية الأفضل. وقد أوضحت النتائج الرئيسية دور الأزواج الأيوني والفعالية في معظم الحالات في تحويل المياه من نوعية إلى أخرى ومن ثم تقليل خطر الملوحة للاستخدام في الري.

الكلمات الدالة : المياه الجوفية ، تصنيف المياه، الأزدواج الأيوني، *ionpair* ، *water classification* ، *Groundwater* .

التمويل: لايوجد.

بيان توفر البيانات: جميع البيانات الداعمة لنتائج الدراسة المقدمة يمكن طلبها من المؤلف المسؤول.

اقرارات:

تضارب المصالح: يقر المؤلفون أنه ليس لديهم تضارب في المصالح.

الموافقة الأخلاقية: : لم يتضمن البحث أى تجارب على البشر او الحيوان .بالتالى لم يكن من ضرورى الحصول على الموافقة اخلاقية .

مساهمات المؤلفين: تولى سلمان هاشم سعيد مسؤولية جمع العينات، وإجراء التحليلات، وتفسير البيانات، وكتابة المخطوطة، ومراجعتها. أما اكرم عثمان اسماعيل، فقد تولت فكرة البحث، وأشرفت على البحث، وقرأت المخطوطة.