

Role of ion pairs and activity in classification of groundwater for irrigation in Makhmur district

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ABSTRACT

This investigation was performed during the dry and wet seasons of 2024, which included water chemical analysis for 36 wells in Makhmur District, then classified depending on the mean of chemical analysis for both seasons using some international such as USDA classification (1954), Wilcox (1954) and Ayres and Westcot classification (1994) relying on ions concentrations and their activities. Depending on EC and SAR values the water for (25, 2.70, 61.11 and 11.11) % of wells had (C_3S_1 , C_3S_2 , C_4S_1 and C_4S_2) classes before correcting ion pairs and activities respectively; while depending on activity of ions, the water for (25, 2.70, 44.44, 22.22, 2.70 and 2.70) of wells had (C_3S_1 , C_3S_2 , C_4S_1 , C_4S_2 , C_4S_3 and C_4S_4) classes. Relying on salinity potential (SP), before correcting ion pairs and activities the water for (9, 3 and 24) wells had good, moderate, and poor categories, after correcting ion pair and activities the water for (4) wells changed from bad to moderate class. On the other hand, referring to Ayers and Westcot (1994) and relying on sodium adsorption ratio values the water for (14, 17 and 5) wells had no restriction, slight to moderate restriction and severe restriction of use respectively before ion pair and activities correction. While after correcting ion pairs and activities the water for (12, 19 and 5) wells had no restriction, slight to moderate restriction and severe restriction of use respectively that caused change two wells to change from class one to class two. Depending on bicarbonate concentration the water for two wells changed from slightly to moderate class to no restriction of use after correcting ion pairs plus activities. Decrease in risk of saline water for irrigation due to converting the water classes towards the better categories. The main results explained the role of ion pairs and activities in conversion the water from class to another then decrease the salinity risk for irrigation use.

Keywords: Groundwater, Water classification, Ion pairs, Activity, Makhmur district

پوخته

ئەم لېكۆلېنە وەهە لە وەرزی وشكە سالی و تەری سالی ۲۰۲۴ ئەنجامدراوه، كه شیکاری کیمیایی ئاوی بۆ ۳۶ بېر له قەزای مەخمور لەخۆگرتبوو، پاشان پۆلینکرا بەپێی مامناوەندی شیکاری کیمیایی بۆ هەردوو وەرزه که به بهکارهێنانی هەندیک پۆلینکردنی نیوده و له تی وهک پۆلینکردنی (USDA ۱۹۵۴)، ویلکۆکس (۱۹۵۴) و پۆلینکردنی ئایرېس و ویستکۆت (۱۹۹۴) به پشتبەستن به چرپی ئایۆن و چالاکیهه کانیا. به پێی به هاکانی EC و SAR ئاوی بۆ (۱۱.۱۱ و ۲۵.۲۷۰، ۶۱.۱۱) % بېره كان پۆله كانی (C3S1, C3S2, C4S1 و C4S2) یان هه بووه پېش راستکردنه وهی جووته ئایۆنه كان و چالاکیهه كان به رېكکهوت؛ له کاتیکدا که پشت به چالاکیهی ئایۆنه كان ده به ستیت، ئاوی بۆ (۲۵.۲۷۰، ۴۴.۴۴، ۲۲.۲۲، ۲.۷۰ و ۲.۷۰) بېره كان پۆله كانی (C3S1, C3S2, C4S1, C4S2, C4S3 و C4S4) ی هه بووه. به پشتبەستن به توانای شووتی (SP)، پېش راستکردنه وهی جووته ئایۆنه كان و چالاکیهه كان ئاوی بۆ (۳، ۹ و ۲۴) بېره كان پۆلی باش، مامناوهند و خراپی هه بوو، دواي راستکردنه وهی جووته ئایۆنه كان و چالاکیهه كان ئاوی بۆ (۴) بېره كان له پۆلی خراپه وه بۆ مامناوهند گۆرا. له لایه کی دیکه وه، به ئاماژه دان به Ayers و Westcot (1994) و پشت به ستن به به هاکانی رېژه ی مژینی سۆدیۆم ئاوی بۆ (۱۷، ۱۴ و ۵) بېره كان هېچ سنووردارکردنی نه بوو، سنووردارکردنی که م بۆ مامناوهند و سنووردارکردنی توندی به کارهێنان به رېكکهوت پېش جووته ئایۆنه كان و راستکردنه وهی چالاکیهه كان. له کاتیکدا دواي راستکردنه وهی جووته ئایۆنه كان و چالاکیهه كان ئاوی بۆ (۱۹، ۱۲ و ۵) بېره كان هېچ سنووردارکردنی نه بوو، سنووردارکردنی که م بۆ مامناوهند و سنووردارکردنی توندی به کارهێنان به رېكکهوت که بووه هۆی گۆرپینی دوو بېر له پۆلی یه که مه وه بۆ پۆلی دووهم. به پێی چرپی بیکاربۆنات ئاوی بۆ دوو بېر له پۆلیکی که مه وه بۆ پۆلی مامناوهند گۆرا بۆ بئ سنووردارکردنی به کارهێنان دواي راستکردنه وهی جووته ئایۆنه كان له گه ل چالاکیهه كان. که مه و نه وهی مه ترسی ئاوی خوئ بۆ ئاودېری به هۆی گۆرپینی پۆله كانی ئاوی به ره و پۆله باشتره كان. ئەنجامه سه ره کیهه كان رۆلی جووته ئایۆنه كان و چالاکیهه کانیا. روونکرده وه له گۆرپینی ئاوه که له پۆلیکه وه بۆ پۆلیکی تر پاشان که مکرده وهی مه ترسی شووتی بۆ به کارهێنانی ئاودېری.

وشه ی سه ره کی: ئاوی ژېرزه وی، پۆلینکردنی ئاوی، جووته ئایۆنه كان، چالاکیهی، قەزای مەخمور

الخلاصة:

اجريت هذه البحث خلال موسمي الجفاف والرطب لعام ۲۰۲۴، والذي شمل التحليل الكيميائي للخواص الرئيسية للمياه لـ ۳۶ بئراً في قضاء مخمور، ثم صنفت المياه استناداً الى متوسط نتائج التحليل الكيميائي لكلا الموسمين باستخدام بعض التصنيفات العالمية مثل تصنيف Richard (1954) و Ayers and Wilcox (1954) Westcot (1994) كانت النتائج كالاتي استناداً الى معدل الصفات للموسمين: حسب قيم التوصيل الكهربائي ونسبة امتزاز الصوديوم (EC و SAR) فإن مياه (11.11 and 25.270, 61.11 and 11.11) % بئراً كانت لها صنف (C3S1, C3S2, C4S1 و C4S2)) قبل تصحيح أزواج الأيونية ووالفعالية الأيونية على التوالي. بينما بعد تصحيح الازدواج الايوني و الفعالية الأيونية، فإن مياه ((2.70 and 22.22, 2.70 and 44.44, 25.270) % بئراً سجلت صنف (C3S1, C3S2, C4S1, C4S2,

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C4S3 و C4S4) على التوالي . اما اعتماداً على جهد التملح (SP)، وقبل تصحيح أزواج الأيونات والفعالية الأيونية ، كانت مياه (٩، ٣ و ٢٤) بئراً ذات نوعية جيدة ومتوسطة وردئية. ادت تصحيح الأزواج الأيونات وفعالية الى تغيير نوعية مياه (٤) بئراً من رديئة إلى متوسطة. من ناحية أخرى، وبالإشارة إلى قيم نسبة امتصاص الصوديوم فقط فان نوعية المياه لل(١٤ و ١٧ و ٥) بئراً لها صنف عدم تقييد وتقييد طفيف إلى متوسط وشديد في الاستخدام على التوالي قبل التصحيح. بينما بعد تصحيح الأزواج الأيونات و الفعالية ، كانت مياه (١٢ و ١٩ و ٥) بئراً لها أصناف سابقة الذكر على التوالي مما تسبب في تغيير مياه بئرين من الدرجة الأولى إلى الدرجة الثانية. بينما اعتماداً على تركيز البيكربونات فإن مياه لبئري تغيير من درجة معتدلة قليلاً إلى تقييد غير شديد في الاستخدام بعد التصحيح. بشكل عام، في معظم الحالات ادت تصحيح الأزواج الأيونات و الفعالية إلى تقليل خطر الملوحة بسبب تحويل نوعية المياه نحو النوعية الأفضل. وقد أوضحت النتائج الرئيسية دور الأزواج الأيونات و الفعالية في معظم الحالات في تحويل المياه من نوعية إلى أخرى ومن ثم تقليل خطر الملوحة للاستخدام في الري.

الكلمات المفتاحية: المياه الجوفية ، تصنيف المياه، الأزواج الأيونات ، الفعالية و منطقة مخمور

1 INTRODUCTION

Groundwater is a type of water resources in Iraqi Kurdistan region. Its electrical conductivity and chemical composition are differing among locations relying on physicochemical characteristics of catchment area, geological composition in climatic condition and types of wells.

The area of ground water is very large in Kurdistan region, its area in Erbil governorate represents more than half of Kurdistan's groundwater, that equal to (5000 km²) and the number of drilled wells is about (10000)^[1]. In Makhmur district the main source of irrigation water is groundwater due to low rainfall and absention of irrigation projects.^[2] The numerous water quality studies were conducted in Kurdistan region during 1955 to 2024. The first study was done at Altoncopri basin by Persoan-and Ralf company (1955) and the last one was done by Hamad (2024). Ion pairs means the approach of cation and anion in water or soil solution 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 depends on the difference between the valence of the contributed cation and anion in ion pair formation, for example the charge of (KHCO₃)⁰ and (MgSO₄)⁰ equal to zero, while the charge of (NaSO₄)⁻ and (MgHCO₃)⁺ equal to -1 and +1 respectively^[3]. Electrical conductivity had the same values before and after correcting ion pairs and activity, since ion pairs are non-conductance to electrical current^[2]. Correcting ion pairs and activity causes increase in sodium adsorption ratio (SAR) and decrease in salinity potential (SP) and residual sodium carbonate (RSC) due to high contributing of Ca⁺² and Mg⁺² 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^[3, 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 above 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

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of using saline water for irrigation^[2]. The water quality of 52 wells and springs in Rania district, the water qualities of (24,10,12 and 6) locations had, excellent, good, marginal and poor quality for irrigation respectively^[6]. This may be due to differing in geological formation of the study area.^[7] Studied the types of aquifers, geological formations and lithological thickness (100-680) meter in Rania district and their relation with water qualities of the studied area, they indicated that most of the studied area had excellent water quality or have no risk but 5% of the studied area have poor water quality or have risk for irrigation, This study is differing from other studies because included the relation between geological formation m lithological thickness, types of aquifers and water quality or risk index of water. Because there are no studies in Makhmur district about the influences of ion pairs and activity in conversion salinity risk of groundwater for agricultural uses using some classical international systems. For above reasons the purpose of this study was explained at the end of introduction.

Classification of irrigation water:

There are numerous international systems for irrigation water classification, some of them were selected in this investigation as a part of MSc thesis, 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 C₁S₁ to C₄S₄.as shown from Appendices (1 and 2)^[8].

2- Donnen classification.

This classification depending on soil permeability and water salinity potential as shown from appendix (3)^[9].

3-Wilcox classification.

This classification depends on Residual sodium carbonate (RSC) value., which classified irrigation water into 3 classes as explained in appendix(4)^[10].

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 (appendix,5)^[11].

The goals of this investigation are:

1- Classification of the groundwater of Makhmur district for irrigation using some international classification systems depending on concentration of ions and determined water parameters.

2- Focusing on the role of correcting ion pairs and activity on changing the water from class to other, then decrease or increase in salinity risk of groundwater or water of the study wells using some classical international systems.

2- MATERIALS AND METHODS

2.1 Study area.

The study was conducted during the wet season of 2024, the water samples were taken from 15th of May, 2024 from 36 wells agricultural lands of Makhmur districts which including (Center Makhmur, Gwer, Dibaga and Qaraj) (table 1. and figure, 1a)

Table 6: Geographical position system (GPS) reading of the study locations (wells).

NO.	Location	Latitude	Longitude	elevation(m)	
1	Kawr	37 ⁰ 94'82" N	40 ⁰ 04'85.0" E	267	Gwer
2	Tarjan	38 ⁰ 99'77" N	39 ⁰ 98'78.5" E	296	
3	Shamamar	38 ⁰ 40'27" N	39 ⁰ 98'49.1" E	285	
4	Zhiba	38 ⁰ 05'17" N	39 ⁰ 97'94.0" E	274	
5	Shamshula	37 ⁰ 53'21" N	39 ⁰ 97'94.0" E	248	
6	Abusheta	37 ⁰ 12'84" N	39 ⁰ 97'65.7" E	237	
7	Zmarajasm	36 ⁰ 45'67" N	39 ⁰ 88'52.5" E	224	
8	Darmanawa	36 ⁰ 95'22" N	39 ⁰ 85'30.8" E	285	
9	Makhmur	36 ⁰ 90'67" N	39 ⁰ 61'80.4" E	252	
10	Dugrdkanhussein	36 ⁰ 17'20" N	39 ⁰ 60'96.0" E	230	
11	Garasor	36 ⁰ 63'96" N	39 ⁰ 65'19.8" E	251	
12	Sirma	35 ⁰ 44'98" N	43 ⁰ 30'48.5" E	269	
13	Garabasha	36 ⁰ 80'20" N	39 ⁰ 64'10.7" E	260	
14	Hawarghal	35 ⁰ 54'23" N	43 ⁰ 27'54.9" E	325	
15	Khalidiya	34 ⁰ 40'12" N	39 ⁰ 64'39.1" E	385	
16	Adla	35 ⁰ 87'40" N	39 ⁰ 38'17.0" E	380	
17	Hasarok	35 ⁰ 48'61" N	39 ⁰ 46'56.5" E	210	Qaraj
18	Shendr	35 ⁰ 67'44" N	39 ⁰ 41'40.1" E	190	
19	Ankawa	35 ⁰ 48'61" N	39 ⁰ 44'28.2" E	195	
20	Chwargoman	38 ⁰ 48'76" N	39 ⁰ 47'14.6" E	249	
21	Kalashkhan	38 ⁰ 81'15" N	39 ⁰ 43'69.0" E	374	
22	Dinkawa	37 ⁰ 77'00" N	39 ⁰ 34'38.8" E	201	
23	Qalatasoran	37 ⁰ 87'42" N	39 ⁰ 51'63.5" E	250	
24	Grdarasha	37 ⁰ 84'85" N	39 ⁰ 43'16.7" E	219	
25	Ruala	36 ⁰ 83'16" N	39 ⁰ 40'79.1" E	201	
26	Grdachal	37 ⁰ 43'59" N	39 ⁰ 42'16.7" E	265	
27	Hushtraluk	35 ⁰ 93'20" N	39 ⁰ 48'68.0" E	215	
28	Qabrsaid	35 ⁰ 30'05" N	39 ⁰ 12'53.9" E	195	
29	Doma azea	36 ⁰ 63'49" N	39 ⁰ 27'00.4" E	210	
30	Malakagha	39 ⁰ 62'52" N	39 ⁰ 68'27.7" E	338	
31	Jana	39 ⁰ 62'52" N	39 ⁰ 68'27.7" E	338	
32	Shorija	38 ⁰ 67'46" N	39 ⁰ 75'75.1" E	329	
33	Milhorti	36 ⁰ 84'00" N	39 ⁰ 80'04.0" E	276	
34	Dibaga	39 ⁰ 43'91" N	39 ⁰ 74'06.4" E	394	
35	Talamira	36 ⁰ 87'83" N	39 ⁰ 61'81.3" E	298	
36	Majidmalaqara	38 ⁰ 02'44" N	39 ⁰ 77'28.9" E	289	

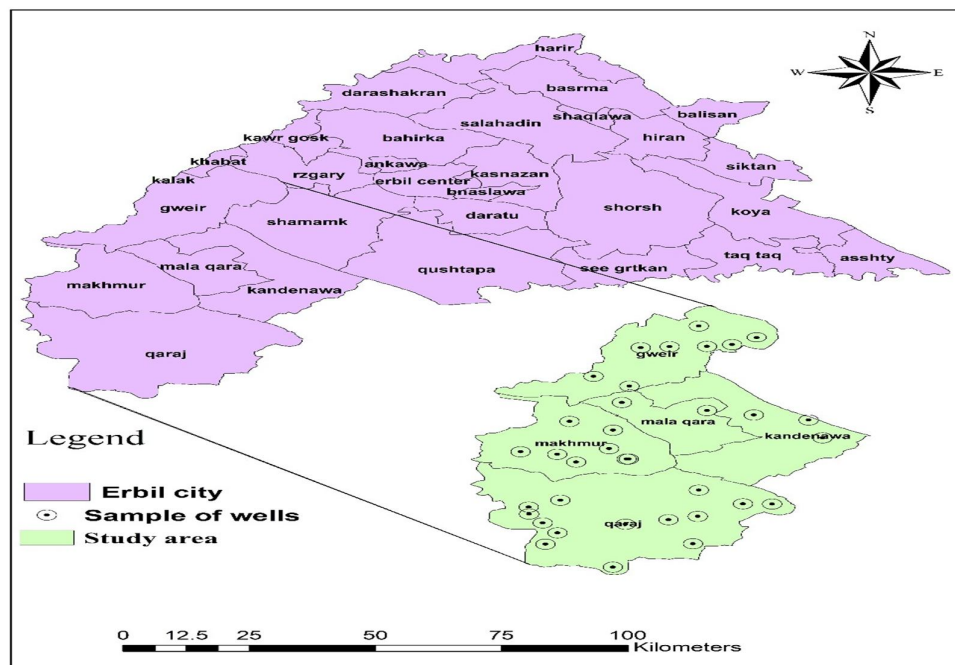


Figure 1a: Map of the study locations

2-1-1 Description of the study area:

The study area is located between the longitude ($43^{\circ} 58'34''$ E and $43^{\circ}37' 82''$ E latitude ($35^{\circ}26'70''$ N and $35^{\circ} 15' 56''$ N.)

The area of the studied locations is 2690 km². The elevation ranges between 190-394 meter above sea level.

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 Gure is semi- arid with the average of rainfall of 250-500 mm per year.

The geological formation was explained in figure (1b), the dominate geological formations are [12].

- Mukdadiyah (Lower Bakhtiari) formation pebbly sandstone, siltstone and claystone.
- Injana (Upper Fars) formation) sandstone, siltstone and claystone.
- Fatha (Lower Fars) formation) gypsum, marl, limestone, red claystone, siltstone and sandstone.
- Bai Hassan (Upper Bakhtiari) formation conglomerate sandstone and claystone Residual soil and polygenetic deposits) silty and clayey soil, locally gypsiferous and pebbly.
- (Bai Hassan (upper Bakhtiari) formation) conglomerate sandstone and claystone.
- Gercus Formation The formation consists of red clastic rock, which is mainly constituted by claystone, siltstone, and sandstone, with a different layer of conglomerate in the upper part. The main rock type of this formation is the claystone. The sandstone is less abundant than the claystone and occurs in thin beds. Red clay, siltstone, and sandstone, also a tongue of limestone called Avana formation. Gypsum lenses and halite occur near the top of formation [12and 13].

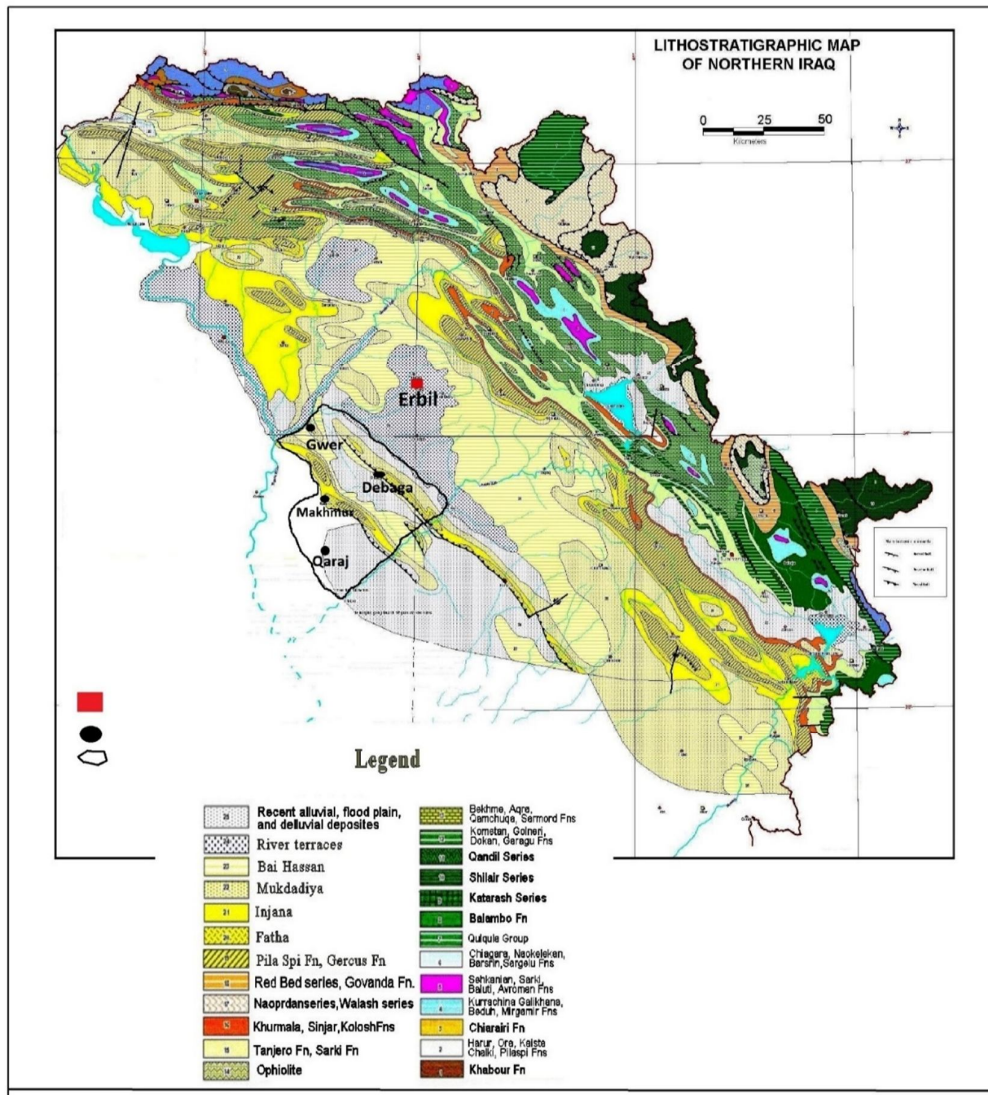


Figure 1b: The geological formation of the study area.

2.2 Sampling:

The water samples were taken during the wet and dry season May and October of 2024, the samples were taken from 36 wells their depth ranged between (200-350 m) in Makhmur district figure (1a). The samples were collected in a plastic bottle of 2500 ml, then kept in the refrigerator at (4 °C) then sent to the laboratory for analysis.

2.3 Water Analyses.

^[14] 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}).

2.4 ^[2] Ion pairs and activity were determined according to special program prepared by Esmail and Rajab (2022), that depended on models which summarized as follow:

$$\text{Ionic strength (I)} = 0.5 \sum C_i Z_i^2 \dots \dots \dots (1)$$

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

Z_i = valence of ions.

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

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$$-\text{Log } \gamma = AZi^2 \sqrt{I} + Bdi\sqrt{I} \dots\dots\dots (2)$$

Where: γ = Activity coefficient, I = 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.

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

Where: a = Ionic activity, γ = Activity coefficient, c = concentration in mmol L⁻¹.

The parameters were determined as follow:

1- Sodium Adsorption Ratio (SAR).

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

Concentration of Na, Ca and Mg in meq L⁻¹ = mmole_c L⁻¹

2- Salinity Potential (SP) as Represented by [8].

$$SP = (Cl^- + \frac{1}{2} SO_4^{2-}) \dots\dots\dots (5)$$

Concentration of Cl⁻, and SO₄²⁻ in meq L⁻¹ = mmole_c L⁻¹

3- Residual Sodium Carbonate (RSC) as mentioned by [9].

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

Concentration of CO₃²⁻, HCO₃⁻, Ca²⁺ and Mg²⁺ meq L⁻¹ = mmole_c L⁻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].

5-The accuracy of data were tested according to models mentioned by [1].

3 RESULTS AND DISCUSSION

The physicochemical properties of the study water were explained in Table (7).

Table 7: Physicochemical properties of the studied water samples (Raw data).

no.	Location	pH	EC	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻	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	4.60
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	3.90	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	3.20
19	Ankawa	7.3	6.80	10.50	6.40	0.20	33.90	36.00	10.20	0.00	2.80
20	4 goman	7.1	4.86	11.45	8.40	0.20	8.70	6.40	18.35	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	2.71	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	135.9	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	17.49	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	7.75	36.40	25.20	17.20	0.00	1.00
36	Majd	8.0	4.02	9.25	5.70	0.20	10.00	8.50	14.70	0.00	1.00

Table 8. refers to ionic activity which determined from table (7) using the program mentioned before. The pH and EC were not changed because they are not contributing in ion pairs since only cations and anion are contributing in ion pairs except Cl^- [2]

Table 8: Physiochemical properties of the studied waters after correcting ion pairs and activity.

Wells No.	pH	EC dS m ⁻¹	Ca ^{+2*}	Mg ^{+2**}	K ^{***}	Na ^{***}	Cl ^{**}	SO ₄ ^{-2**}	CO ₃ ^{-2**}	HCO ₃ ^{-**}
			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	2.84	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	1.90
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 9. represents the mean, range and standard deviation (SD) of the study groundwater properties before and after correcting ion pairs and activity. The activity coefficient of ions were determined by dividing activity to concentration after subtracting amount of ions contributing in ion pair formation using special program^[2]. The activity coefficient of chlorite =1 because it is not contributing in ion pairing^[2].

Table 9: Range, mean and standard deviation for the properties of study water samples before and after correcting ion pairs and activity.

Water properties	Unit	Before correcting ion pairs and activity			After correcting ion pairs and activity			Activity coefficient		
		Range	Mean	S D	Range	Mean	S D	Range	Mean	S D
		mmole L ⁻¹			mmole L ⁻¹					
EC	dS m ⁻¹	18.5-0.89	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⁺	mmol L ⁻¹	45.50-0.75	16.26	12.19	17.29-0.46	5.61	4.61	0.61-0.39	0.42	0.08
Mg ²⁺		37.59-0.38	10.04	9.48	14.82-0.24	4.04	3.6	0.63-0.39	0.46	0.09
K ⁺		3.10-0.09	0.16	0.49	2.32-0.08	0.17	0.37	0.89-0.34	0.81	0.09
Na ⁺		135.87-3.00	11.75	24.16	53.00-2.66	10.03	13.8	0.92-0.78	0.83	0.03
Cl ⁻		79.92-1.56	12.36	19.93	79.92-1.56	12.36	19.93	1.00 - 1.00	1.00	-
SO ₄ ⁻²		97.71-2.88	17.2	20.56	71.80-1.47	5.66	4.81	0.73-0.51	0.55	0.1
HCO ₃ ⁻		4.62-0.99	2.78	0.81	3.9-0.75	2.21	1.75	0.88-0.37	0.79	0.09

Table 10. explains the values of SAR, SP, RSC, SAR**, SP**, RSC** and the ratio between them. 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 versa for Na (table, 9 and 11). The ratio between SP**/SP was ranged between 0.58-0.94, this may be due high contributing of SO₄²⁻ and low activity coefficient of it (table, 9). 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 ,9 and 11), Similar results were obtained by ^[1 and 5]. 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 ^[3 and 4] since these studies also conducted in Erbil governorate near Makhmur district and the are similar in geological formation and disagree with ^[15 ,16 and 17] since their study was done in Sulaimani governorate which is differing in the location and geological composition of study area which caused differing in water chemical composition with the water composition of Makhmur district.

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

NO.	EC dS m ⁻¹	SAR	SAR**	SAR**/ SAR	SP	SP**	SP**/SP	RSC	RSC**	RSC**/ RSC
		(mmol _c L ⁻¹) ^{0.5}	mmolc L ⁻¹		mmolc L ⁻¹					
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
15	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

SAR, SP and RSC = their values depending on concentration or before correction

SAR**, SP** and RSC = their values depending on ion pair and activity or after correction.

Table 11. focused on types of ion pairs and their concentrations that determined from raw data using special program. The series of ion pairs depending on their mean were as follow:

$(CaSO_4)^0 > (MgSO_4)^0 > (CaHCO_3)^+ > (NaSO_4)^- > (MgHCO_3)^+ > (NaHCO_3)^0 > KSO_4^-$. 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.

Table 11. 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) ⁰	mmol L ⁻¹	5.91 - 0.04	1.26	1.38
(CaHCO ₃) ⁺		0.16 - 0.01	0.09	0.04
(MgSO ₄) ⁰		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) ⁰		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

The number of ions contributed in ion pairs were documented in table (11) which 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⁺ > SO₄⁻² > HCO₃⁻.

Water classification:

The study waters were classified according to some classifications which are affecting by correcting ion pairs and activity as explained below:

-Richard classification (1954):

The results of classification depending on EC and SAR values in table (10) were summarized in table (12). The results indicated that before correcting ion pairs and activity the water of (9, 1, 22 and 4) wells had C₃S₁ , C₃S₂ , C₄S₁and C₄S₂ classes respectively , while after correcting ion pair and activity the water quality for(9,1,16,8,1and 1) wells had C₃S₁,C₃S₂,C₄S₁, C₂ S₄ and C₄S₃) respectively (table, 12).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 wells number (7,12,17,19 and 22) were changed from C₄S₁ to C₄S₂ and well number 18 from C₄S₂ to C₄S₃ respectively. This may be due to high initial SAR values of water for the mentioned wells

mentioned wells (table ,10). 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], because the initial SAR value is high because if initial SAR is close to 10 correction ion pair and activities cause increase it to more than 10 or to another class 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) and it is impossible to increase this value to more than 10.

Table 12: Influence of correcting ion pairs and activity on water according to Richard's classification

Water class before correcting ion pair and activity	No. of wells	Water class after correcting	No. of wells	Change in water classes
C ₃ S ₁	9	C ₃ S ₁	9	0
C ₃ S ₂	1	C ₃ S ₂	1	0
C ₄ S ₁	22	C ₄ S ₂	16	-6
C ₄ S ₂	4	C ₄ S ₂	8	+5
0	0	C ₄ S ₃	1	+1

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 (10) explains that 72.22% of wells had high saline water which ranged from 2.25 to 18.50 dS m⁻¹.

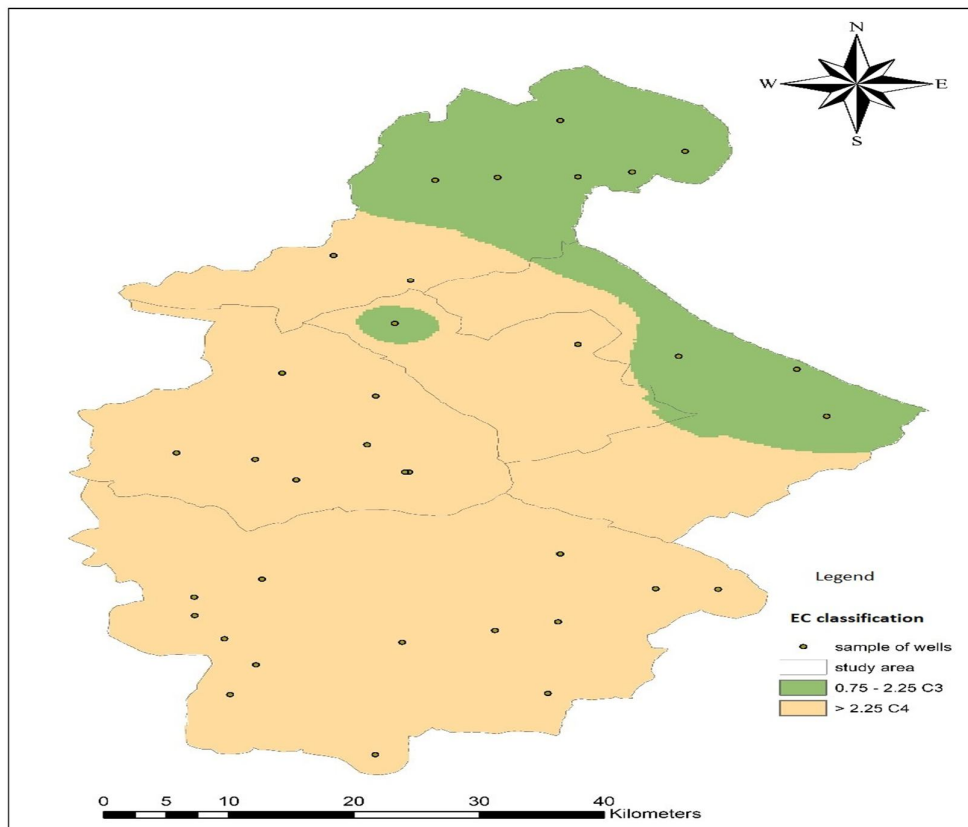


Figure 2: Spatial distribution of water EC of the study wells.

Figure (3) Explains 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 S_1 , S_2 and S_3 water classes depending on SAR values. The mentioned colors represent the water of 31, 4 and 1 wells that had S_1 , S_2 and S_3 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 (S_1 class) . The high waters SAR values in this study of may be due to existing spots of halite in the study area ^[12 and 13].

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 correction 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 S_4 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].

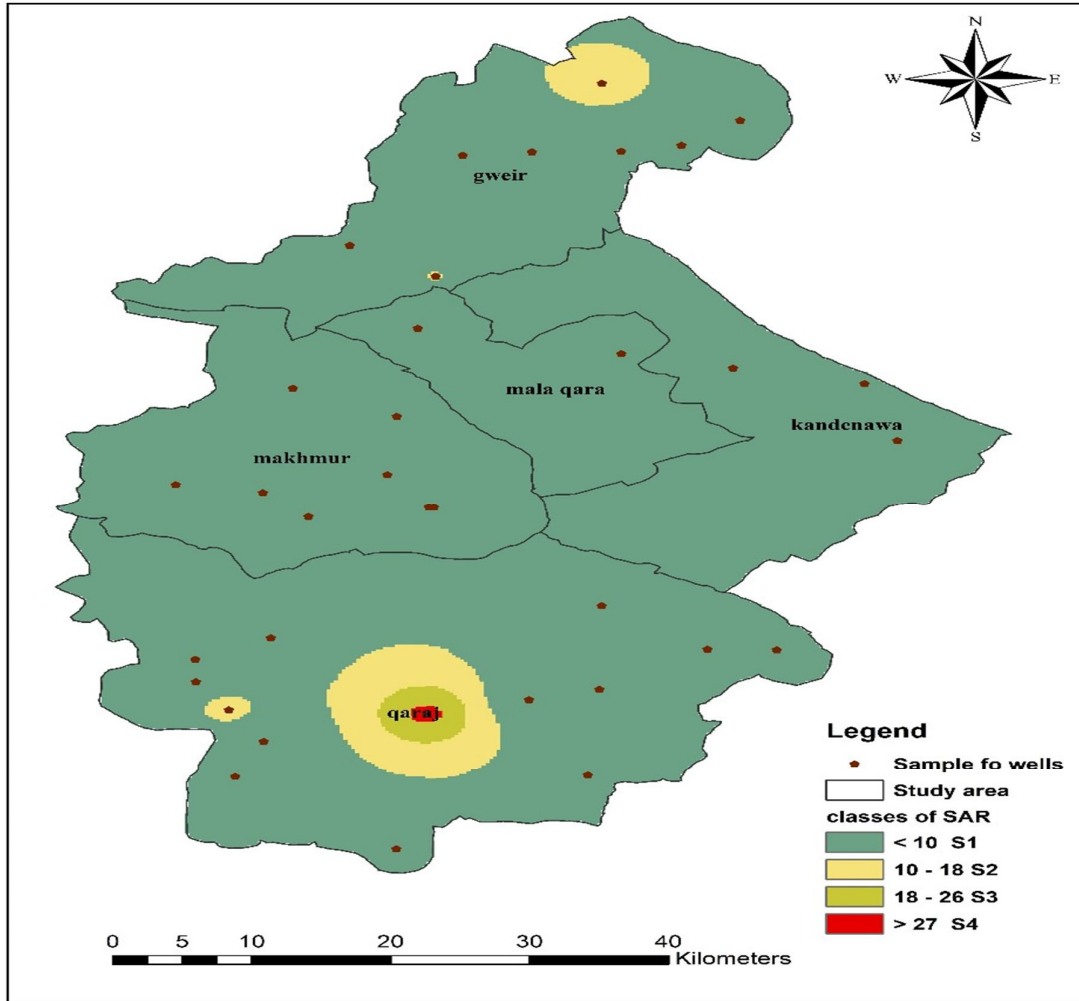


Figure 3: Spatial distribution of water SAR value before correcting ion pair and activity.

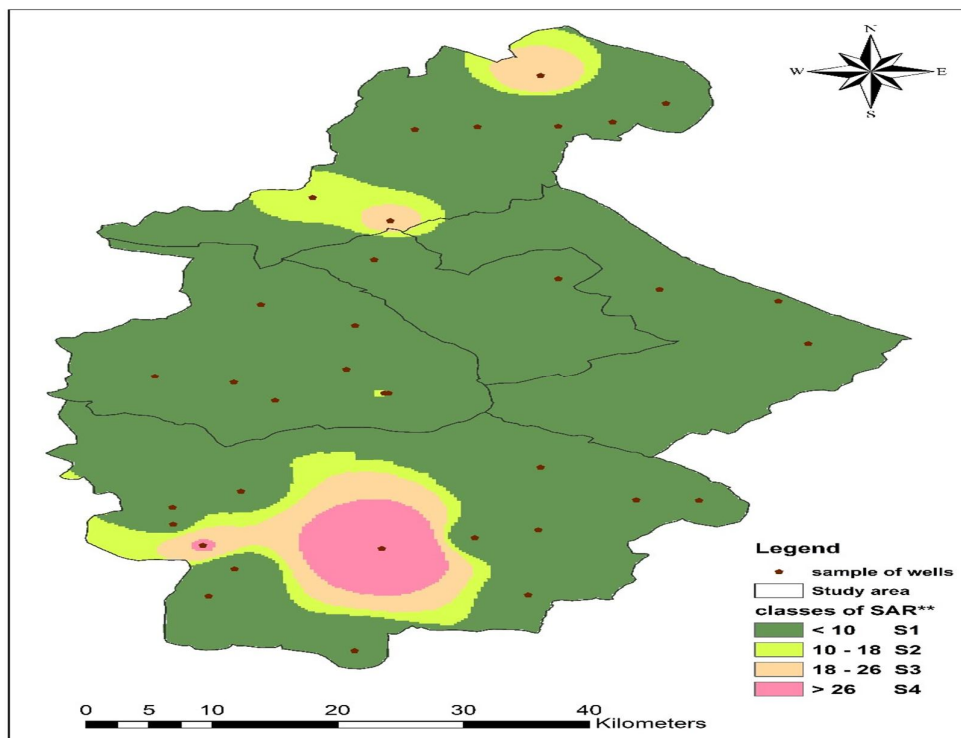


Figure 4: Spatial distribution of SAR** value classes after correcting ion pair and activity.

-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 (0.51-0.73) (Table,10 and 8). As shown from table (13) and depending on SP and SP** values in table (10) 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 (9,7and20) 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,13). 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 [3].

Table 13: [9] classification the of study wells depending on (SP).

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

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 geological formation of the study area (High gypsum and spots of halite) [12 and 13].

Correcting ion pairs and activity caused change the of 4 well from bad to moderate quality due to the reasons mentioned before.

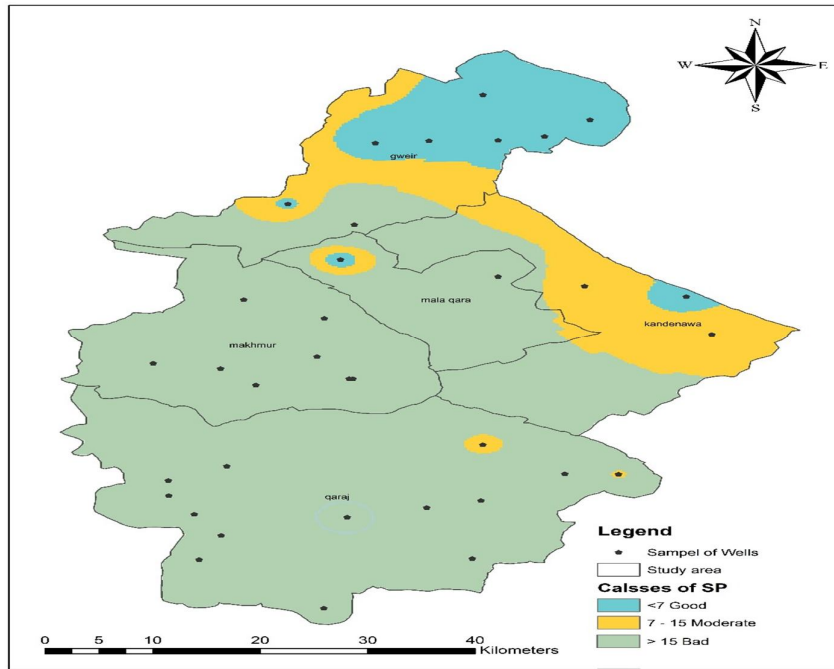


Figure 5: Spatial distribution of water classes depending on SP values.

Ayers and Westcot classification:

^[1] In Ayers and Westcot classification the focusing was on both SAR and HCO_3^- because only these two parameters were affecting by correcting ion pair and activity (table, 14). 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.

Table 14: Effects of correcting ion pairs and activity on water classes

Parameters	Water classes before correction			Water classes after correction			Conversion 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

This may be due to contribution of $0.03 - 0.34 \text{ mmole L}^{-1}$ 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 ^[5].

As shown from table (14) 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. The limitation of this method is there are numerous parameters in this method and the results of water classification sometimes may be differing slightly among the studied parameters.

CONCLUSION

In general correcting ion pairs and activity caused shifting the water quality or classes towards the better class due to decrease in salinity potential (SP) and residual sodium carbonate (RSC). On the other hand, the mentioned correction causes increase in Sodium adsorption value (SAR) which theoretically increase the risk of irrigation water but practically have not negative effect or risk on irrigation water in the study area due to low initial value of SAR since the dominate cations in the study area are calcium and magnesium. The initial values of water chemical properties and parameters had great effect on conversion the water from class to another one.

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 an increase in contributing ions in ion pairs, then decreases 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.

REFERENCES

- [1] Sajadi, M. D. and Esmail A. O. 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* 10,308-324. (2020)
- [2] Esmail, A.O., Effect of Composition and Ion Pair in Irrigation Water on Soil and Plant. Published Ph.D. Dissertation, College of Agriculture, University of Baghdad, Iraq. (1992)165p.
- [3] Rajab, S. K. and Esmail, A. O. Role of ion pairs and activity in estimation of ionic strength from electrical conductivity of irrigation water. *Iraqi Journal of Agricultural Sciences (IJAS)*, 54,755-767. (2023). <https://doi.org/10.36103/ijas.v54i3>
- [4] Esmail, A.O., and Salih, H.O., The role of ion pairs and ion activity in classification of Groundwaters for irrigation in Erbil plain. *Journal of Zankoy Sulaimani-Part A, Special Issue*,16,177. (2014)
- [5] Alani, A.S.K, The Chemical Composition of Irrigation Water and its Effect on Ion Paring, Some Chemical Properties of Soil and Plant Growth, Erbil-Kurdistan region- Iraq. Published M.Sc. Thesis, College of Agri. Salahaddin University, Iraq. (2015) 150p
- [6] Salam, B.M., 2019. Identifying Water Suitability for Different Uses in Rania District. Published M. Sc. Thesis. College of Agri. Univ. of Salahaddin, Erbil Kurdistan-Iraq.148p.
- [7] Salah, A.O., and AL-Manmi, D.A., Groundwater risk intensity map through modified drastic model in the Rania basin, Kurdistan Region of Iraq. *Passer Journal of Basic and Applied Sciences*,7,17-28. (2025) <http://passer.garmian.edu.krd/>
- [8] Richards, L.A., *Diagnosis and Improvement of Saline and Alkali Soils*, US Government printing Office. (1954)
- [9] Doneen, L.D., Salination of soil by salts in the irrigation water. *Eos, Transaction American Geophysical Union*,35, 943-950. (1954)

[10] Wilcox, L., Classification and Use of Irrigation Waters, US Department of Agriculture. (1955)

[11] Ayers, R.S. and Westcot, D.W. Water Quality for Agriculture, Food and Agriculture Organization of The United Nations Rome. (1994)

[12] Jassim, S.Z. & Goff, J.C. Geology of Iraq. Distributed by Geological Society of London. (2006)

[13] Esmael, S. and Seeyan, Sh. Hydrochemical investigation and quality of groundwater in Erbil-Pirmam area, Kurdistan Region, Iraq. Iraqi Geological Journal. 56 (1A), 67-85(2023). <https://www.igj-iraq.org>

[14] American Public Health Association (A.P.H.A.). Standard Methods for the Examination of Waste Water and Water. 20th ed. A. P. H. A., Washington (1998).

[15] Marif A. A. Assessment of the Water Quality for Goundwater Using IWQI Methods and Multivariate Statistical Analysis for Irrigation in Sulaimani Governorate, Kurdistan Region, Iraq. Published PhD dissertation. (2023).170p

[16] Marif AA, Esmail, A.O. Quality evaluation of water resources for irrigation in Sulaimani Governorate, Iraq. Applied Ecological and Environmental Researches.

[https://doi.org/10.15666/aeer/2103.\(2023\)](https://doi.org/10.15666/aeer/2103.(2023))

[17] Hamad Ali, A. Sh. Groundwater Investigation, Water Uses and Suitability for Qaladze-Sangaser Area Sulaimanya Governorate, IKR. Published MSc. Salahaddin University, College of Agricultural Engineering Sciences, Soil and Water Department. (2024) 160p.

Appendix (1) show water classes depending on EC and SAR values ^[8].

EC (dS m ⁻¹ at 25 °C)	Index	SAR Value	Index	Classes	Group
0 to 0.25	C ₁	<10	S ₁	Excellent	Low salinity
0.25 to 0.75	C ₂	10 to 18	S ₂	Good	Medium salinity
0.75 to 2.25	C ₃	18 to 26	S ₃	Fair	High salinity
> 2.25	C ₄	>26	S ₄	Poor	Very high salinity

Appendix (2) Explains the symbols for 16 water classes depending on Richards (1954) ^[8].

EC (dS m ⁻¹)	SAR values			
	S1 <10	S2 =10-18	S3 =18-26	S4 >26
C1 = 0-0.25	C1S1	C1S2	C1S3	C1S4
C2 = 0.25-0.75	C2S1	C2S2	C2S3	C2S4
C3 = 0.75-2.25	C3S1	C3S2	C3S3	C3S4
C4 > 2.25	C4S1	C4S2	C4S3	C4S4

Appendix (3) Water categories depending on Donnen's classification (1954) ^[9].

Water Category	Positional of salinity (SP) SP = (Cl ⁻ + 0.50 SO ₄ ²⁻) mmol charge per Liter		
	Soil permeability		
	High	Moderate	Low
Good	Less than 7	Less than 5	Less than 3
Moderate	7 to 15	5 to 10	3 to 5
Bad	More than 15	More than 10	More than 5

Appendix(4) Explains Wilcox classification depending on Residual sodium carbonate (RSC) value^[10].

Water classes of irrigation water	RSC (mmol _c L ⁻¹)
Probably safe	Less than 1.25
Marginal	1.25 to 2.5
Unsuitable	More than 2.5

Appendix (5) shows Ayers and Westcot classification (1994) depending on some selected parameters ^[11].

Potential irrigation	Unite	Degree of restriction of use (classes)		
Salinity (EC)	dS m ⁻¹	None	Slight to moderate	Severe
		< 0.7	0.7 – 3.0	> 3.0
SAR		< 3	3 – 9	> 9
Bicarbonate (HCO ₃ ⁻)	mmol _c L ⁻¹	< 1.5	1.5 -8.5	> 8.5