ROLE OF ION PAIRS AND ACTIVITY IN ESTIMATION OF IONIC STRENGTH FROM ELECTRICAL CONDUCTIVITY OF IRRIGATION WATER*

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ABSTRACT

This study was carried out in Erbil governorate, Iraq during 2020 to estimate the regression relations between the ionic strength of 354 water samples and their electrical conductivity then influence of correcting ion pairs and activity on this relation. Results indicated that electrical conductivity regards as an accurate measure of ionic strength for irrigation water. Correcting ion pairs plus activity had a great effect on the regression values between ionic strength values and electrical conductivity of the studied water samples. Highly significant correlation coefficient was recorded between ionic strength and electrical conductivity before correction and after correcting ion pairs and ion pairs plus activity with the correlation coefficient values of (r= 0.99, 0.93** and 0.97**) respectively. Correcting ion pairs and ion pairs plus activity caused a decrease in the slope of the regression from 0.0157 to 0.0104 and 0.0047 respectively. Neglecting intercept values from the regression line caused an increase in the slope of regression relation to 0.0112 and 0.0058 for correcting ion pairs and ion pairs plus activity respectively.**

Key words: ionic strength, ion pairs, activity, irrigation water.

***Part of a Ph.D. dissertation for the first author.**

مجلة العلوم الزراعية العراقية -2023: 54(3):755-767 رجب واسماعيل

دورالأيونات المزدوجة و الفعالية في تقدير القوة الأيونية في التوصيل الكهربائي للمياه الري.

كاذين سرياز رجب اكرم عثمان اسماعيل
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المستخلص

اجريت هذه الدراسة خلال عام 2020 لتقدير القوة الايونية ل 354 نموذج من المياه من قيم التوصيل الكهربائي و تأثير الأيونات المزدوجة والفعالية في العلاقة بينهما في محافظة اربيل, دلت النتائج على ان التوصيل الكهربائي يعد معياراً دقيقاً للتقدير القوة الأيونية للمياه الري. ان تصحيح الأزدواج الأيوني مع الفعالية لهما تأثير كبير في علاقة الأنحدار بين القوة الأيونية و التوصيل الكهربائي للمياه المدروسة. سجلت قيم معامل الأرتباط عالية المعنوية بينهما و بلغت r= **0.99, ** 0.93 و **0.97 قبل و بعد تصحيحهما على التوالي. تصحيح الأزدواج الأيوني و الفعاية الى انخفاضاً من ميل خط الانحدار من 0.015 الى 0.0104 و 0.0047 على التوالي.بعد اهمال قمة التقاطع يتصحح الأزدواج الايوني و الازدواج الايوني + الفعالية (مرور الخط الانحدار بنقطة الاصل)ادت الى زيادة ميل الى 0.0112 و 0.0058 على التوالي .

الكلمات المفتاحية: القوة الأيونية, الأيونات المزدوجة,الفعالية ,مياه الري.

Received:2/7/2021, Accepted:31/10/2021

INTRODUCTION

Water regards as one of the most important parts of natural resources, on the other hand, water resources are representing groundwater such as wells, springs, surface waters such as rivers, streams, karezes, and lakes. Dizayee (9) demonstrated that the Erbil district regards as the most important agricultural land in Iraq, and the groundwater regards as one of the popular water resources for different uses, especially agricultural uses. The Erbil Basin is one of the most important basins in the Iraqi Kurdistan region in terms of adequate quantity and quality of groundwater in comparing with the area of a groundwater basin in other governorates which is equal to more than (5000 km^2) and the number of drilled deep wells is about (10000) wells(16 and 23). UNDP(25) emphasized the increase in the requirement for groundwater in the Iraqi Kurdistan region due to the decrease in rainfall in comparing with the last decades, for this reason, most of the farmers are depending on using groundwater for irrigation due to the shortage or absence of irrigation projects and building of dams on Euphrates and Tigris rivers in riparian countries. In general, the surface and spring water had good quality for irrigation in comparing with groundwater (well water) since some studies conducted by (23, 22 and 19) indicated to existing bad groundwater qualities in numerous locations in northern Iraq. The most important point in studying the quality of water resources is the activity of ions in state of their concentration, since the active ions can absorb by plants and contributing in chemical reactions in soil solution since apart of concentration of ions in water are absorbing by plants which represents active ions (10 and 11). The determination of active ions from their concentration depends on the ionic strength values which is the rapid, economic, and accurate method is determining ionic strength from electrical conductivity especially after correcting ion pairing and ion-pairing plus activity. (Esmail 11) indicated that the ion pairs and ion activity depending on the ionic composition of water. On the other hand, the kind of ions plays an important role in limiting the amount of ion pairs in water which may cause the conversion in water quality from class to other class depending on global classifications of water (21 and 2). It is necessary to explain ion pairs before focusing on the relation between ionic strength and electrical conductivity of irrigation water since the ion pairs are non-conductive for electric which causes conversion in regression coefficient between ionic strength (I) and electrical conductivity (EC) (11). Adams (1) and Bohn *et al.* (6) were described that the approaching cations and anions in water to each other for a distance equal or less than 0.5 nm, in this case, connections between ions which is different in charge by columbic force and each ion keeps its hydration shell this phenomenon called ion pairs. Saloom and Oleiwi (24) studied water quality for surface water which included (Tigris, Euphrates, Shatt Al-Arab, and Diyala) but, not included correcting ion pairs and activity. Alhadithi and Hassan (3and14) studied groundwater quality in western Iraq which did not included correcting ion pairs and activity. There are two main methods for determining ionic strength the first one depends on the concentration of cations and anions that requires time and chemicals…. etc. The second one depends on EC only for this reason determining the regression relation between EC and I is necessary for water resources with a large number of samples. On the other hand for determining the activity of ions we must determine ionic strength after that from Debye – Huckel model if ionic strength is less than 0.2 mol L^{-1} the activity coefficient can be determined for ions then depending on the Daivs model if I more than 0.2 mol L^{-1} the activity of the ions can be calculated (7, 12 and 1). It is too difficult in the case of a huge number of samples to determine soluble cations and anions which are necessary for determining ionic strength. For the above reasons, the researchers tried to determine ionic strength from electrical conductivity. Ponnamperuma et al,.(18) determined the regression relation between I and EC for soil solution samples of flooded soils and some samples of water without correcting ion paring and activity or they depended only on the concentration of ions, they obtained the following relation between ionic strength (mol L^{-1}) and electrical conductivity (dS m^{-1}) for solutions having different ionic strength values ranging from 0.024 to 0.064 mol L^{-1} was as follow: I(mol L^{-1})= 0.016 EC (dS m^{-1}). It means the regression correlation or the slope of the relation between I and EC had the mean value of 0.016. Griffin and Jurinak (13) corrected model for ion-pairing only for 27 soil extracts and 124 water samples from the river by which recorded the relation below:

I (mol L^{-1}) = 0.013EC (dS m^{-1}). It means correcting ion-pairing resulted in the decrease the regression coefficient to 0.013, with a correction coefficient value of r= 0.99**, between them. The mentioned relation was studied by some researchers (21, 5, and 2) depending on small water samples for deep wells only or not included water samples for springs and rivers. They pointed out that electrical conductivity is a sufficiently accurate measure for determining ionic strength. Since there are little or no studies about the relation between ionic strength and EC for water resources in the Kurdistan region depending on an adequate or huge number of samples, then correcting ion pairing and ion-pairing plus an activity for these reasons this study was selected to develop the relationship between ionic strength(I) and electrical conductivity (EC) after correcting ion pairs formation and ionic activity for 354 water samples from different water resources(rivers, springs, and wells) in Erbil governorate.

MATERIALS AND METHODS

1- Water sampling: The water samples were taken from (177) locations during the wet and dry season of 2020 which means the total number of samples was 354 samples which included (82,72, and 200 samples from rivers, springs, and wells) respectively in Erbil governorate as shown from the figure (1).

2- Water chemical analysis: The chemical properties of water samples (EC, pH, $Ca^{2+,}$ $Mg^{2+,}$ Na^+, K^+, $CO_3{}^{2-}$, $HCO_3{}^-$, Cl^-, $SO_4{}^{2-}$ and $NO_3{}^-$) were determined according to (4).

3- Calculating of Ion pairs according to (17).

ion strength, ion pairs, and ion activity were calculated by using a computer program which was prepared by (17) depending on some equations used by (6), (1), and (15). Ionic strength (I) of water samples was calculated ed by the following expression:

$$\mathbf{I}=\frac{1}{2}\sum Ci\,Zi^{2} \text{……………………………… (1)}$$

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

Zi is the valence of ions.

The ionic strength plays a central role in the Debye–Huckle equation as follows:

$$-\log y=\frac{AZi^{2}\sqrt{I}}{1+Bd\sqrt{I}} \text{…… ……… (2)}$$

Where:

y = Activity coefficient of ion

I = Ion strength (mol. L^{-1}).

A = 0.509 at 25 C° has been modified to be used up to **I** = 0.1 mol. L^{-1}, **B** = 0.3285 at 25 C°,

Zi = Ionic charge, **d** = Ion size parameter

The relation between concentrations and the activity coefficient was described as follow:

a=

□*c…………………………...(3) Where: **a** = Ion activity, y = Activity coefficient

c = Ion concentration

The regressing and correlation coefficient were determined using the SPSS program, Version (26).

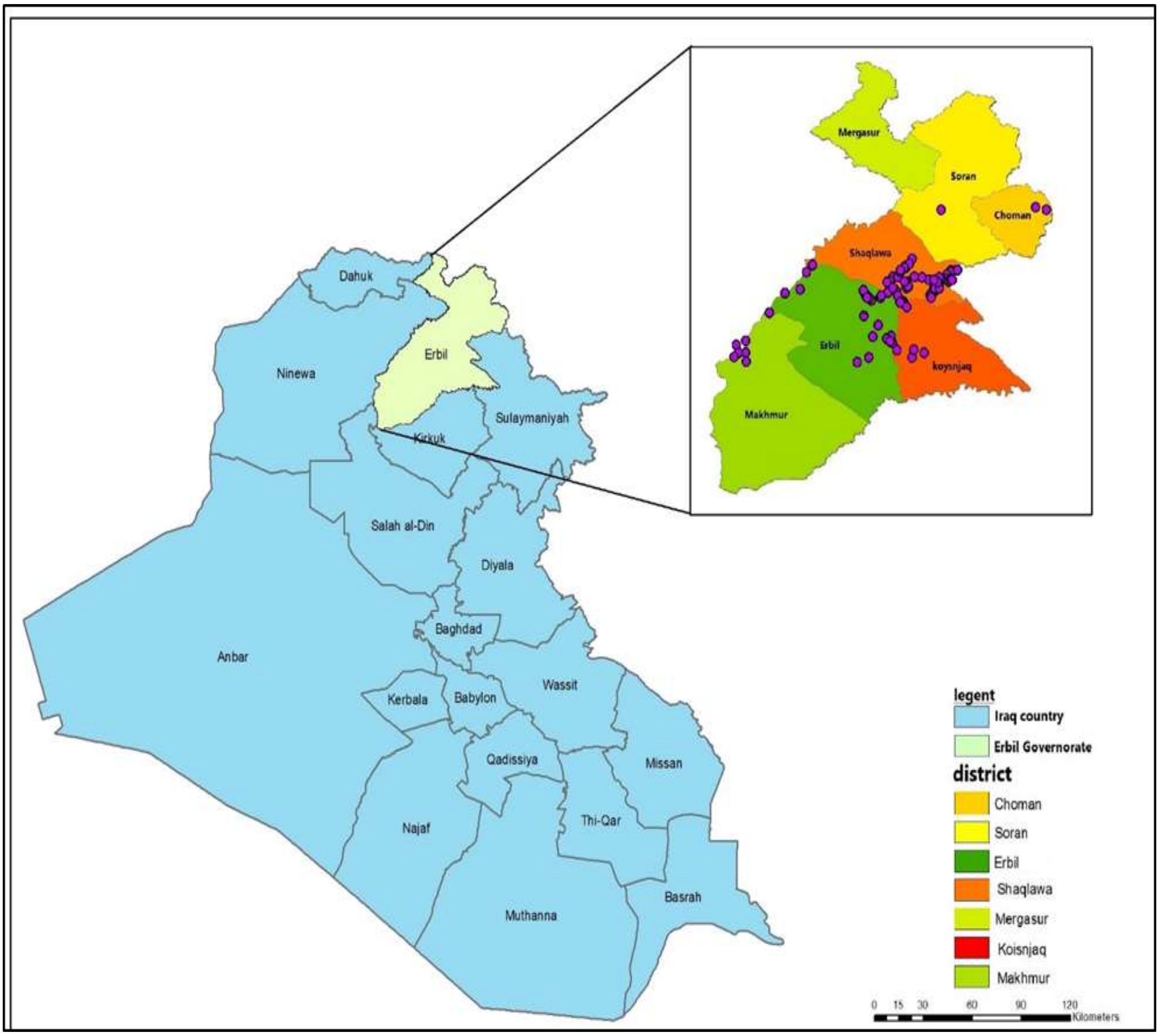

Figure 1. Map for the studied locations

RESULTS AND DISCUSSION

Table 1 shows the concentration of cations and anions (mmol L^{-1}), pH, EC, and ionic strength for studied water samples in both wet and dry seasons for studied water samples. This table regards as a database for calculating ionic strength and the relation between EC and ionic strength, amount and type of cations and anions contributed to ion pairing.

Table 1. Range and mean for water studied parameters (mmol L^{-1}) and ionic strength before correcting ion pairs in wet and dry seasons. *

Water resources	Chemical Properties	Wet season		Dry season	
		Range (Max. – Min.)	Mean ±SE	Range (Max. – Min.)	Mean ±SE
River	Ca^{+2}	2.439 - 0.479	1.107±0.073	3.000 - 0.920	1.508±0.076
	Mg^{+2}	2.997 - 0.368	1.128±0.095	2.936 - 0.573	1.476±0.094
	K^{+}	0.366 -0.005	0.045±0.011	0.135 - 0.008	0.036±0.004
	Na^{+}	4.917 -0.022	0.540±0.161	4.565 - 0.043	0.503±0.158
	Cl^{-}	2.157 -0.263	0.579±0.073	2.326 - 0.409	0.888±0.076
	SO$_4^{+2}$	2.090 -0.125	0.664±0.087	3.595 - 0.140	1.073±0.132
	HCO$_3^{-}$	8.785 -1.360	3.101±0.239	6.753 - 2.032	3.411±0.153
	CO$_3^{-2}$	0.00	0.00	0.00	0.00
	I(mol L^{-1})	0.020-0.003	0.008±0.001	0.026-0.005	0.011±0.001
	EC (dSm^{-1})	1.390 - 0.240	0.506±0.044	1.670 - 0.350	0.650±0.043
	pH	7.580 - 6.990	7.226±0.028	7.550 - 6.730	7.161±0.026
Spring	Ca^{+2}	12.156-0.887	2.339±0.507	13.200-0.973	2.721±0.573
	Mg^{+2}	5.600-0.632	1.735±0.210	7.094-0.580	2.056±0.272
	K^{+}	0.857-0.005	0.104±0.034	0.925-0.003	0.082±0.029
	Na^{+}	11.700-0.035	1.083±0.403	9.043-0.043	1.004±0.346
	Cl^{-}	7.344-0.276	0.917±0.230	5.089-0.352	1.065±0.164
	SO$_4^{+2}$	7.605-0.090	1.118±0.316	9.775-0.140	1.326±0.341
	HCO$_3^{-}$	27.192-1.754	5.962±1.000	30.356-2.098	6.831±1.227
	CO$_3^{-2}$	0.00	0.00	0.00	0.00
	I(mol L^{-1})	0.059-0.005	0.014±0.003	0.068-0.006	0.017±0.003
	EC(dSm^{-1})	3.680-0.320	0.935±0.156	4.210-0.370	1.066±0.176
	pH	7.690-5.720	6.779±0.064	7.620-5.570	6.765±0.076
Well	Ca^{+2}	29.142-0.240	2.759±0.401	29.510-0.370	3.279±0.430
	Mg^{+2}	19.895-0.479	2.414±0.289	18.481-0.510	2.667±0.299
	K^{+}	1.269-0.005	0.107±0.015	1.483-0.005	0.102±0.017
	Na^{+}	43.478-0.039	6.582±0.996	44.217-0.057	6.167±0.947
	Cl^{-}	120.500-0.211	3.962±1.301	110.946-0.381	4.115±1.204
	SO$_4^{+2}$	35.105-0.075	3.972±0.681	38.225-0.160	4.577±0.727
	HCO$_3^{-}$	10.818-1.442	4.771±0.168	10.897-1.639	4.570±0.158
	CO$_3^{-2}$	0.00	0.00	0.00	0.00
	I(mol L^{-1})	0.201-0.006	0.026±0.003	0.194-0.006	0.029±0.004
	EC(dSm^{-1})	14.250-0.390	1.710±0.223	13.750-0.370	1.798±0.222
	pH	8.650-0.012	7.353±0.081	8.620-6.240	7.329±0.033

***= Ionic strength calculated from raw data, not from the range values**

Table (2) explains the range, mean and standard error for the concentration of cations, anions, pH, EC, and ionic strength after correcting ion pairs for the studied water resources (rivers, springs, and wells) in both wet and dry season using the special program as mentioned in 17.

Table 2. Range and mean for studied water parameters (mmol L^{-1}) of water resources after correcting ion pairs in the wet and dry season.*

W.R	W.P	Wet season		Dry season	
		Range (Max – Min)	Mean ±SE	Range (Max – Min)	Mean ±SE
River	Ca^{+2}	2.073 – 0.460	1.011 ± 0.061	2.435-0.857	1.343±0.059
	Mg^{+2}	2.645 – 0.353	1.037 ± 0.081	2.501-0.543	1.333±0.077
	K^{+}	0.364 – 0.005	0.045 ± 0.011	0.134-0.008	0.036±0.004
	Na^{+}	4.889 – 0.022	0.538 ± 0.161	4.528-0.043	0.500±0.157
	Cl^{-}	2.157- 0.263	0.579 ± 0.073	2.326-0.409	0.868±0.072
	SO_4^{+2}	1.642- 0.112	0.548 ± 0.068	2.765-0.115	0.865±0.102
	HCO_3^{-}	8.489 – 1.343	3.027 ± 0.229	6.476-1.987	3.307±0.145
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I*(mol L^{-1})	0.018 – 0.003	0.007 ± 0.001	0.022-0.005	0.009±0.001
	EC(dSm^{-1})	1.390 – 0.240	0.506 ± 0.044	1.670-0.350	0.650±0.043
	pH	7.580 – 6.990	7.226 ± 0.028	7.550-6.730	7.161±0.026
Spring	Ca^{+2}	4.584-0.611	1.191±0.177	10.092-0.91	2.261±0.421
	Mg^{+2}	4.405-0.608	1.527±0.155	5.471-0.547	1.787±0.204
	K^{+}	0.854-0.005	0.104±0.034	0.921-0.003	0.082±0.029
	Na^{+}	11.569-0.035	1.075±0.400	8.943-0.043	0.996±0.343
	Cl^{-}	7.344-0.276	0.917±0.230	5.089-0.352	1.069±0.163
	SO_4^{+2}	5.392-0.076	0.816±0.219	6.827-0.116	0.957±0.229
	HCO_3^{-}	24.788-1.722	5.676±0.905	27.497-2.047	6.462±1.103
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I*(mol L^{-1})	0.047-0.005	0.012±0.002	0.052-0.006	0.014±0.002
	EC(dSm^{-1})	3.680-0.320	0.935±0.156	4.21-0.37	1.066±0.176
	pH	7.690-5.720	6.779±0.064	7.62-5.57	6.765±0.076
Well	Ca^{+2}	29.142-0.240	2.759±0.401	26.443-0.318	2.558±0.324
	Mg^{+2}	19.895-0.479	2.414±0.289	16.540-0.450	2.124±0.219
	K^{+}	1.269-0.005	0.107±0.015	1.469-0.005	0.100±0.017
	Na^{+}	43.478-0.039	6.582±0.996	42.858-0.056	6.076±0.928
	Cl^{-}	120.500-0.211	3.962±1.301	110.946-0.381	4.115±1.204
	SO_4^{+2}	35.105-0.075	3.972±0.681	27.925-0.130	3.393±0.511
	HCO_3^{-}	10.818-1.442	4.771±0.168	10.563-1.561	4.397±0.150
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I*(mol L^{-1})	0.120-0.006	0.020±0.002	0.175-0.006	0.023±0.003
	EC(dSm^{-1})	14.250-0.390	1.710±0.223	13.75-0.37	1.798±0.222
	pH	8.650-0.012	7.353±0.081	8.62-6.24	7.329±0.033

***= Ionic strength calculated from raw data, not from the range values**

Table 3 refers to the activity of cations and anions, pH, EC, and ionic strength after correcting ion pairs and ion pairs plus an activity for the studied water samples for both wet and dry seasons

Table 3. Range and mean for studied water parameters of water resources (mmol L^{-1}) after correcting ion pairs and activity in the wet and dry season.

Water resources	Chemical properties	Wet season		Dry season	
		Range (Max –Min)	Mean ±SE	Range (Max – Min)	Mean ±SE
River	Ca^{+2}	1.314-0.351	0.712±0.036	1.423-0.614	0.916±0.032
	Mg^{+2}	1.667-0.272	0.736±0.049	1.616-0.407	0.919±0.046
	K^{+}	0.317-0.005	0.040±0.010	0.123-0.007	0.032±0.004
	Na^{+}	4.292-0.020	0.481±0.141	3.927-0.038	0.444±0.137
	Cl^{-}	2.157- 0.263	0.579 ± 0.073	2.326-0.409	0.868±0.072
	SO_4^{+2}	0.981-0.087	0.368±0.042	1.547-0.080	0.556±0.059
	HCO_3^{-}	7.453-1.261	2.757±0.199	5.617-1.816	2.997±0.124
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I**(mol L^{-1})	0.013-0.003	0.006±0.000	0.015-0.004	0.007±0.00
	EC (dSm^{-1})	1.390-0.240	0.506±0.044	1.670-0.350	0.650±0.043
	pH	7.580-6.990	7.226±0.028	7.550-6.730	7.161±0.026
Spring	Ca^{+2}	4.584-0.611	1.191±0.177	4.893-0.572	1.338±0.192
	Mg^{+2}	2.311-0.463	0.997±0.073	2.803-0.406	1.136±0.098
	K^{+}	0.751-0.005	0.092±0.030	0.795-0.002	0.072±0.025
	Na^{+}	9.824-0.032	0.936±0.344	7.786-0.040	0.863±0.295
	Cl^{-}	7.344-0.276	0.917±0.230	5.089-0.352	1.069±0.163
	SO_4^{+2}	2.794-0.055	0.452±0.106	3.406-0.081	0.527±0.108
	HCO_3^{-}	20.464-1.595	4.984±0.736	22.511-1.862	5.622±0.891
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I**(mol L^{-1})	0.028-0.004	0.009±0.001	0.030-0.005	0.009±0.001
	EC (dS^{-1})	3.680-0.320	0.935±0.156	4.210-0.370	1.066±0.176
	pH	7.690-5.720	6.779±0.064	7.620-5.570	6.765±0.076
Well	Ca^{+2}	10.994-0.150	1.194±0.124	9.040-0.209	1.364±0.113
	Mg^{+2}	8.306-0.311	1.143±0.097	6.508-0.308	1.221±0.088
	K^{+}	0.958-0.005	0.089±0.012	1.039-0.005	0.083±0.012
	Na^{+}	33.868-0.036	5.391±0.771	33.081-0.052	5.014±0.725
	Cl^{-}	120.500-0.211	3.962±1.301	110.946-0.381	4.115±1.204
	SO_4^{+2}	8.972-0.043	1.394±0.187	9.533-0.089	1.574±0.190
	HCO_3^{-}	8.827-1.184	4.063±0.138	8.896-1.288	3.856±0.128
	CO_3^{-2}	0.00	0.00	0.00	0.00
	I**(mol L^{-1})	0.122-0.004	0.014±0.002	0.106-0.005	0.015±0.001
	EC (dSm^{-1})	14.250-0.390	1.710±0.223	13.750-0.37	1.798±0.222
	pH	8.650-0.012	7.353±0.081	8.620-6.24	7.329±0.033

***= Ionic strength calculated from raw data, not from the range values**

Figure 2a explains that the regression relation and correlation between ionic strength I (mol L^{-1}) and electrical conductivity EC(dSm^{-1})for 354 samples taken from water resources in Erbil governorate were significant with a coefficient of determination of R^2=0.98 it means there is the best correlation coefficient between them with the correlation coefficient value r=0.99**. Correcting ion pairs and ion pairs plus activity caused a decrease in the above relation to R^2= 0.86 and correlation coefficient value to (r= 0.94**). respectively with the correlation coefficient value equal to 0.93** and 0.97** respectively, the above relation can be expressed by the following models using the EXCELL program:

I= 0.0157EC - 0.0001………(4) depending on concentration or the data in table (1).

I*= 0.0104EC + 0.0031……..(5) after correcting ion pairs depending on table 2

I** =0.0068EC + 0.003………(6) after correcting ion pairs and activity

depending on table 3 It means correcting ion pairs and ion pairs plus activity caused a decrease in the slope of the regression line between ionic strength and EC from 0.0157 to

0.014 and 0.0057 respectively. This may be since the ion pairs are non-conductive for electric and the amount of active ions is less than the concentration of ions since the activity coefficient of the ions are less than one or the slope of the regression line is the resulted from dividing ionic strength over EC and in all cases the EC value is not affected by ion paring, while the ionic strength decreased with correcting ion pairing and ion-pairing plus activity which was caused decrees in the slope of regression line as explained from models (4 to 6). On the other hand, figures (2a and 2b) explain the decrease in the risk of ions or salts in the water for irrigation as mentioned by (20) due to a decrease in active ions since ion pairs are non-active and non-absorbed by plants. The amount of ions contributed to ion-pairing and activity caused a decrease in the ionic strength values for the studied water samples, while the mentioned corrections were not affected on EC value because ion pairs are non-conductive for electric which caused a decrease in the slop of relations. Table 4 shows the amount of ions contributed to ion-pairing which was responsible for shifting the slope downwards. After neglecting the intercepting values or obliging the relation line to cross the origin, the mentioned models converted to models 7,8 and 9 as follow which explained in figure 2b:

I (mol L^{-1}) = 0.0157EC (dS m^{-1}), ……… (7) R^2=0.99 and r=0.99**.

I* (mol L^{-1}) = 0.0112EC (dS m^{-1})……… (8) R^2=0.91 and r= 0.95**.

I** (mol L^{-1}) = 0.0075EC (dS m^{-1})……… (9) R^2=0.97 and r= 0.98**.

It means the slope of regression lines was increased due to neglecting the positive value of intercept since changing the positive value of intercept to zero causes an increase in slope and via versa.

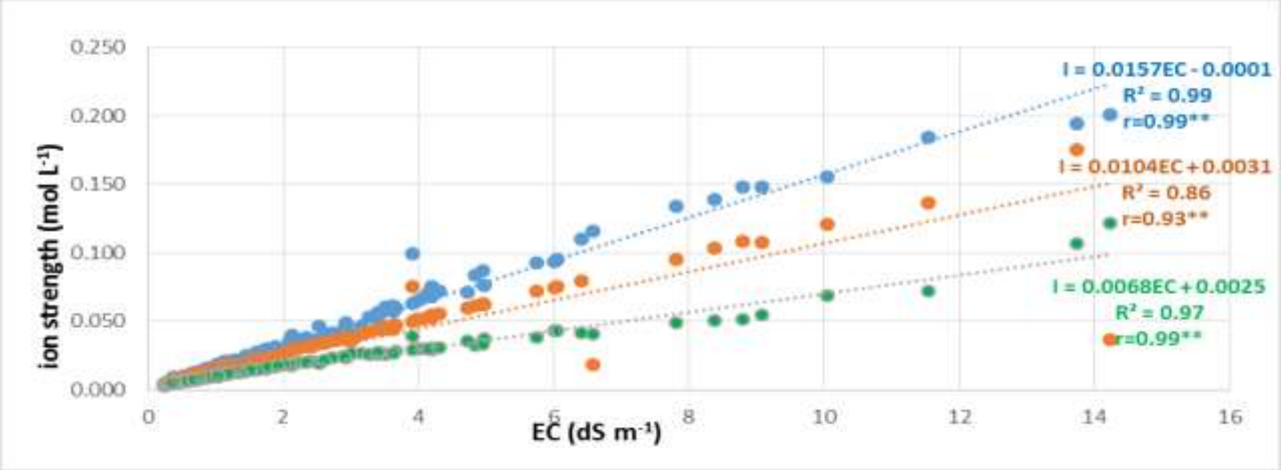

Figure 2a. The relation between ion strength and electrical conductivity of the studied water resources in Erbil governorate

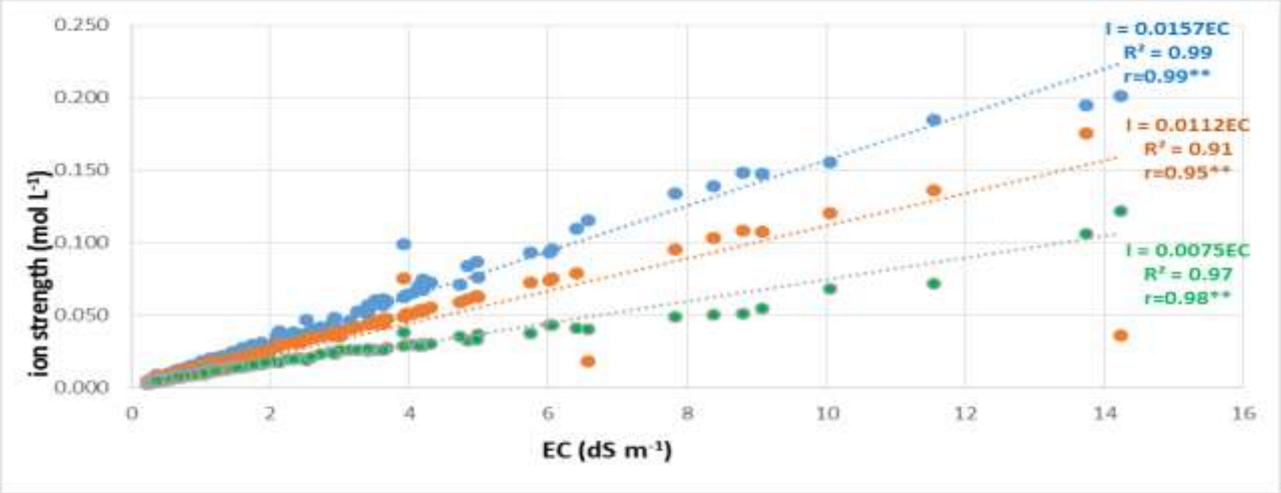

Figure 2b. Relation between ion strength and electrical conductivity of the studied water resources in Erbil governorate after neglecting intercept or crossing the regression line through the origin

Table 4. Explain the amount of ions contributing ion pairs

Water resources	Ions	Wet		Dry	
		Range (Max. – Min.)	Mean ±SE	Range (Max. – Min.	Mean ±SE
River	Ca^{+2}	0.366-0.019	0.096±0.013	0.565-0.039	0.159±0.018
	Mg^{+2}	0.352-0.011	0.091±0.014	0.503-0.019	0.143±0.018
	K^{+}	0.002-0.000	0.000±0.000	0.002-0.000	0.000±0.000
	Na^{+}	0.028-0.000	0.002±0.001	0.037-0.000	0.003±0.001
	SO_4^{+2}	0.448-0.013	0.116±0.019	0.830-0.021	0.211±0.030
	HCO_3^{-}	0.296-0.017	0.074±0.010	0.277-0.038	0.095±0.008
Spring	Ca^{+2}	2.838-0.040	0.373±0.130	3.263-0.055	0.460±0.154
	Mg^{+2}	1.195-0.024	0.208±0.056	1.623-0.033	0.269±0.070
	K^{+}	0.005-0.000	0.000±0.000	0.004-0.000	0.000±0.000
	Na^{+}	0.131-0.000	0.008±0.004	0.100-0.000	0.008±0.003
	SO_4^{+2}	2.213-0.014	0.302±0.101	2.948-0.024	0.369±0.115
	HCO_3^{-}	2.404-0.032	0.285±0.096	2.859-0.046	0.368±0.125
Well	Ca^{+2}	5.982-0.020	0.573±0.112	6.738-0.052	0.721±0.127
	Mg^{+2}	4.587-0.033	0.461±0.082	5.027-0.049	0.543±0.093
	K^{+}	0.016-0.000	0.002±0.000	0.018-0.000	0.002±0.000
	Na^{+}	1.271-0.000	0.093±0.021	1.359-0.000	0.091±0.021
	SO_4^{+2}	10.150-0.010	0.967±0.199	11.961-0.029	1.184±0.225
	HCO_3^{-}	0.753-0.040	0.161±0.013	0.791-0.047	0.173±0.014

Figure 3, explains the radar shape for the effect of ion pairs and ion pairs + activity on ionic strength values, the red color represents ionic strength values before correcting ion pairs and activity, the green color represents the ionic strength after correcting ion pairs only while the yellow color represents ionic strength after correcting ion pairs plus activity. The circles represent the ionic strength values the first inner cycle represents the zero value for ionic strength and the outer circle represents the highest ionic strength value, shifting the colors from the first inner cycle to other cycles means an increase in ionic strength values. It is appearing that the yellow color expanded from the first circle to the third circle, while the green color approached the seventh circle with the ionic strength value of (0.18 mol. L^{-1}), while the red color approached the outer circle with the ionic strength values of (0.21 mol. L^{-1}). Table 5, focused on the role of type of water resources and seasons on the regression coefficient value or slope between ionic strength and electrical conductivity and the influence of correcting ion pairing and ion-pairing plus activity on the mentioned relation. The table shows that the slope (b-value) is varied between 0.0154 - 0.0162 with the mean value of 0.0158. Correcting ion-pairing caused a decline in the mentioned range to 0.0098 – 0.0143 with the mean value of 0.0126. On the other hand, correcting ion pair plus activity caused a decrease in the range of slope value or regression value to 0.0072 – 0.0103with the mean value of 0.0082. The variation of the regression value before correcting, after correcting ion pairs, and correcting ion pairs plus activity were (0.0008, 0.0045, and 0.0031) respectively. It means the above corrections caused the decrease of regression values this may be since ion pairs are non-conductive or the reasons mentioned before.

For certifying the accuracy of regression models between ionic strength and electrical conductivity of the studied water samples, the best feting was done between estimated values of ionic strength which were obtained by using the regression models (model 7 to 9 between ionic strength and electrical conductivity or predicted values and the determined ionic strength from the concentration of cations and anions or actual values depending on concentration and after correcting ion pairing and ion-pairing plus activity. The highly significant correlation coefficient was recorded between them with the values (r=0.99**, 0.93**, and 0.99**) respectively as shown from figures (7, 8, and 9). These results emphasize the accuracy of the improved models for determining ionic strength from the electrical conductivity of water.

Figure 3. The effect of correcting ion pairs and ion pairs + activity on ionic strength

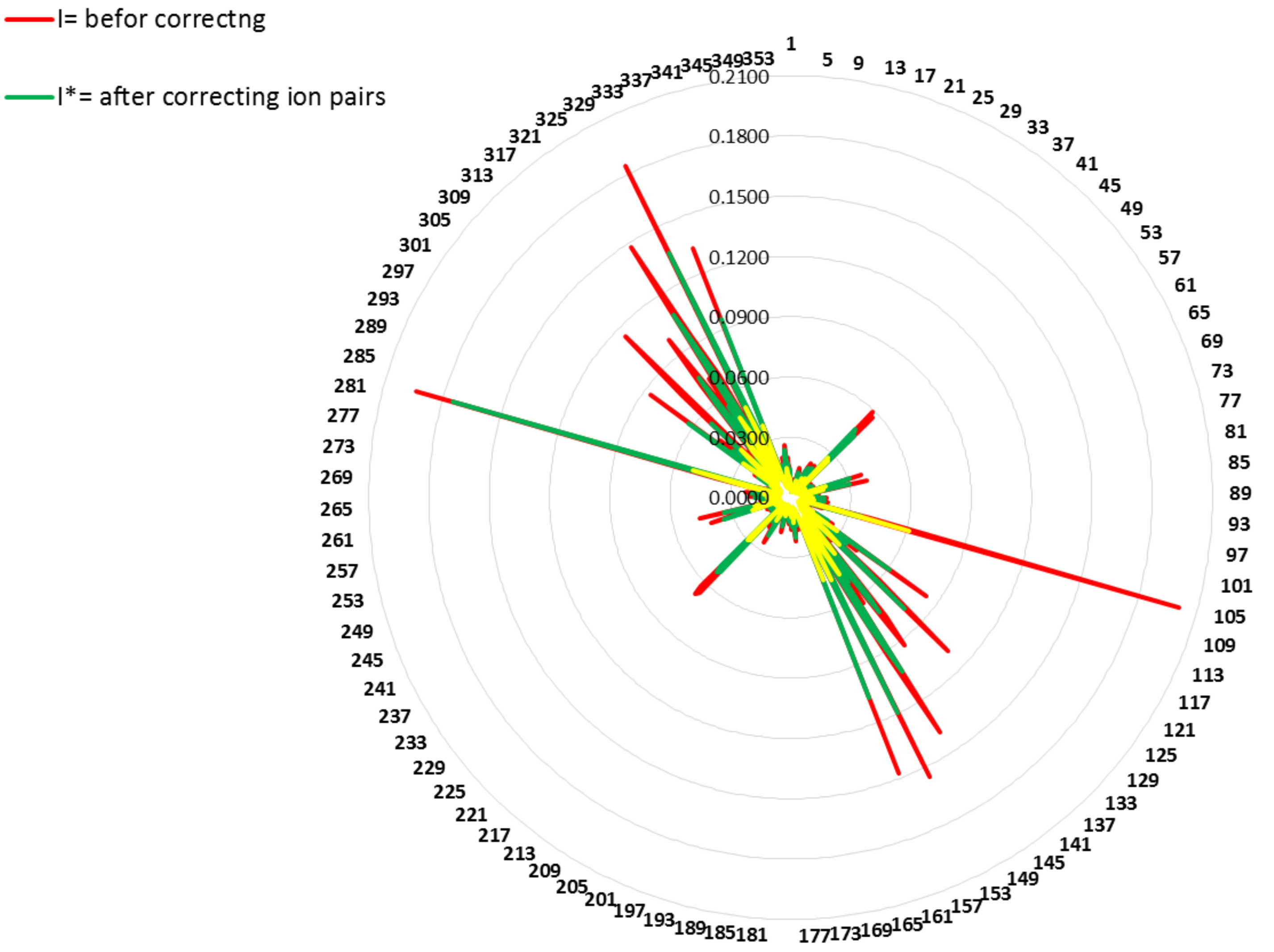

Figure 3. Radar shape for ionic strength befor and after correcting ion pairing and activity

Table 5. Influence of correcting ion pairing, ion-pairing plus activity on the regression value between EC and ionic strength

Water resources	Season	Regression value(b)	Regression value(b*)	Regression value(b**)
Rivers	Wet	0.0155	0.0140	0.0089
	Dry	0.0162	0.0143	0.0103
Springs	Wet	0.0157	0.0128	0.0082
	Dry	0.0159	0.0128	0.0080
Wells	Wet	0.0154	0.0098	0.0075
	Dry	0.0159	0.0121	0.0072
Range		0.0162 - 0.0154	0.0143 - 0.0098	0.0103 - 0.0072
Difference		0.0008	0.0045	0.0031
Mean for wet season		0.0155	0.0120	0.0082
Mean for dry season		0.0160	0.0130	0.0085

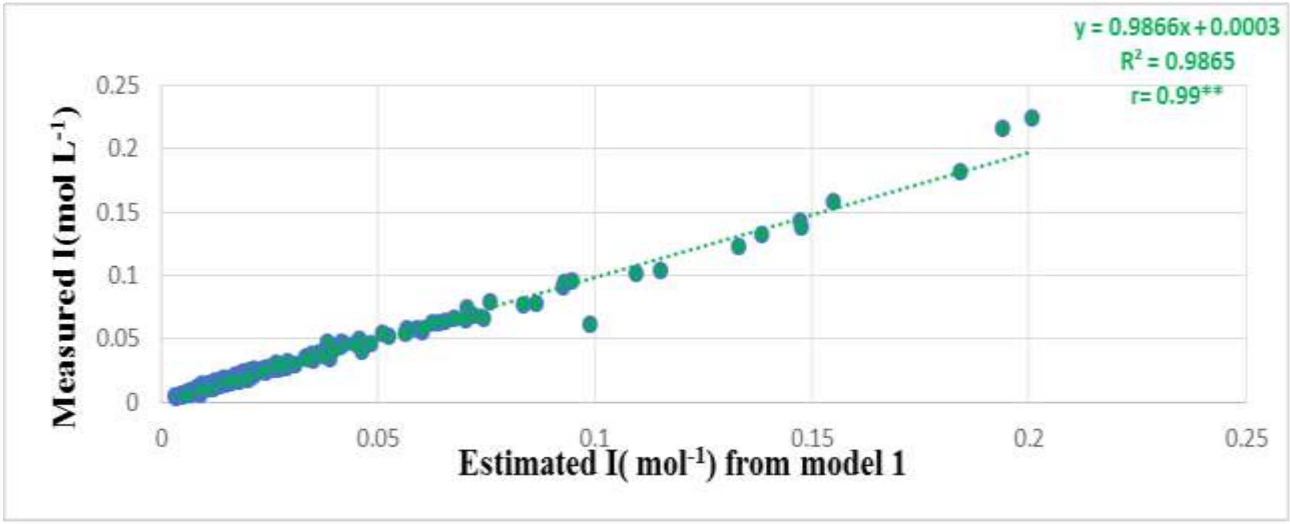

Figure 4. Relation between measured I depending on concentration and estimated I using model NO. (1).

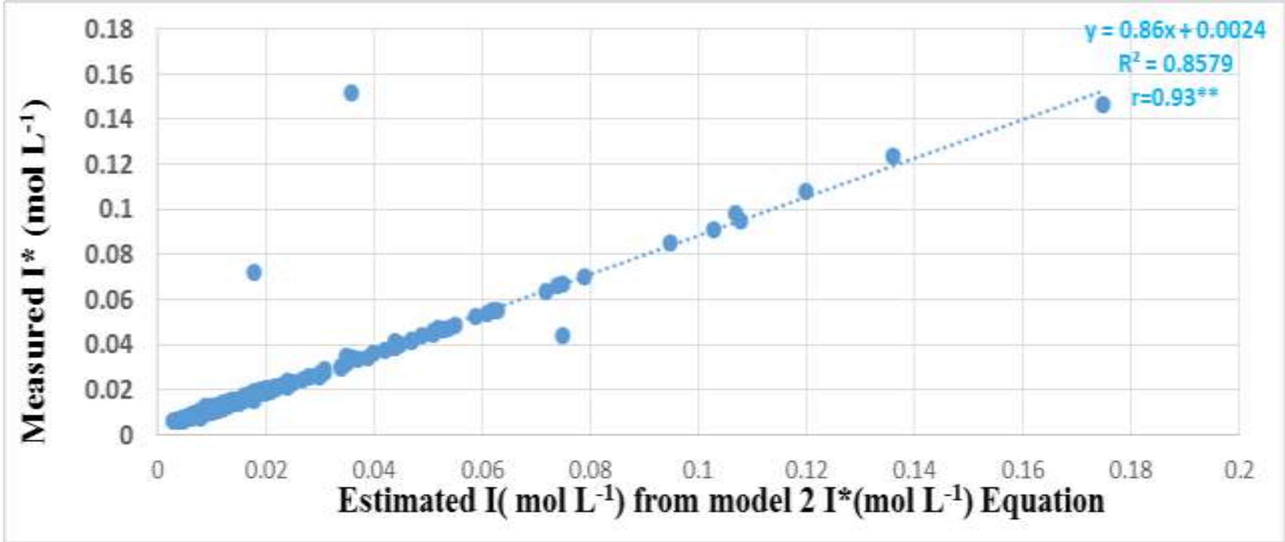

Figure 5. Relation between measured I* and estimated I* after correcting ion-pairing using model NO. (2).

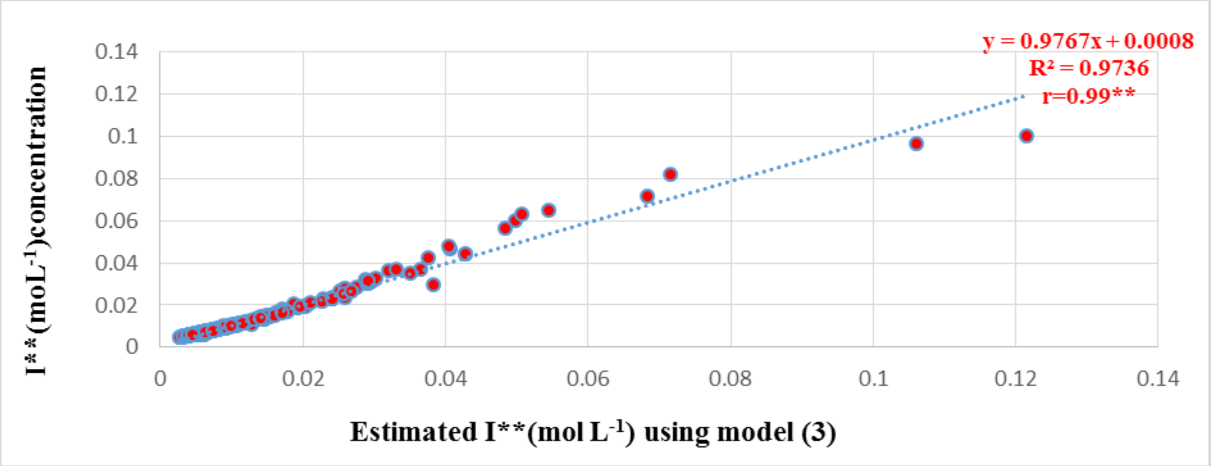

Figure 6. Relation between measured I and estimated I** after correcting ion pairing and activity using model (NO.3).**

CONCLUSION

The best and most accurate relation was recorded between ionic strength and electrical conductivity with the significant correlation between them, and neglecting intercept value caused a slight increase in the slop for the regression line between ionic strength and activity. The increase in the amount of ion-pairing in water samples caused a decrease in the slop of relation. This relation caused simplifying the determination of activity coefficient and activity of ions in the water resources.

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