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Keyword: ***Groundwater quality, ion pair, ion activity, salinity-potential, Erbil plain***

INTRODUCTION

One of the most important factors in a region's sustainable development is the availability of suitable water for various uses. Most of the water resources suffer from a decrease in their quantities and deterioration in quality due to the environmental changes associated with continuous industrial and agricultural expansion, despite the significant expansion of the use of brackish water in irrigation and the expansion of studies in this area, the field management of water use for agricultural purposes still requires further research to reduce the risk of saline soils that cost a lot of human life (AL-Hadithy, 2011).

Ground water is the most important source of water for irrigation, drinking, domestic; industrial uses (Singh et al., 2014). Also it is acknowledged to be a reliable source for agricultural activities in arid and semi-arid regions (Narany et al., 2014). It can boost farm productivity by supplementing surface water supplies and if the water quality is good, it can be applied directly to crops or pasture. However, management may be required depending on the water salinity and sodium hazard.

Groundwater is a major source of water and it is at the forefront in areas where surface water is not available; as in areas away from rivers and desert areas.

Furthermore, groundwater has the ability to mobilize and transport soluble salts when it moves through the soil profile that causes salinity which is a measure of the total amount of salt dissolved in groundwater and can be a good indicator of its suitability for various uses. (Sema et al., 2012).

The salts present in soils can easily be mobilized and transported by the movement of groundwater, capillary rise and evaporation, and leaching and biological activity. Ultimately, this may lead to the accumulation or depletion of salts in different parts of the soil. Groundwater has the ability to mobilize and transport soluble salts when it moves through the regolith. It is very important to know the water level and its movements, in particular with respect to rainfall events and agricultural practices for example irrigation (Moreton, 2014).

Ion pairs are fairly weak associations that form strictly from the electrostatic attraction of ions with opposite charge. The water molecules surrounding an ion that was explained of are not removed from the ions when they form ion pairs. After having addressed the formation of both ion pairs and complexes, it is necessary to reconsider how to calculate ion activities from measured total concentrations. If there were no ion pairs or complexes then just take the measured values of M (concentration) and determine I (ionic strength), then γ (activity coefficient), and finally a (activity). The ion pairs and ion activity depended on ionic composition of water (Radstake et al., 1988; Esmail, 2001).

However, studies indicate the importance of the ionic composition (dissolved ions content), ionic efficiency and ionic coupling in the effect on the ratio of sodium adsorption in water and soil, as well as the readiness of plant nutrients and the saline composition of water and soil. All reactions occurred in soil solution depends mainly on ion activity and to ion concentration (Lindsay and Norvell, 1979). In addition all the chemical, physico-chemical and biochemical processes that occur in the soil-water-nutrient system depend on the efficiency and the ionic effect on the ionic pairs. Therefore, it is necessary to consider mentioned processes in irrigation water and soil.

Numerous studies were conducted in the Kurdistan region about the effect of water quality on soil chemical properties and plant growth by (Esmail, 1986, 1992; Dohuki, 1997; Mam Rasul, 2000; Esmail, 2001; Salih, 2008; Baba, 2010; Kareem, 2010 and Alani, 2015).

In Erbil plain; more than 30% of the water supply is derived from wells. The history of ground water utilization in northern Iraq begins in the antiquity (about 7000 year B.C.), (Al-Tamir, 2007).

MATERIAL AND METHOD

The study area is located around the Erbil city and situated between latitudes of northern 35.253942° to 36.348443° and longitudes of eastern 43.264947° to 44.353321° (Fig. 1). Area of the studied region is about 7000 km^2, and the mean annual rainfall is about (250-400) mm. The experimental site was located at the Grdarasha (36.1136° N, 44.0114°E). The study was conducted by planting a wheat crop during 11/12/2015 to 30/5/2016. Selected farm was divided to three equal plots with letting space about 75 cm and every plot divided to seven experimental units. The dimension of each unit had the space of 150 cm × 75 cm and the distance between them was 50 cm.

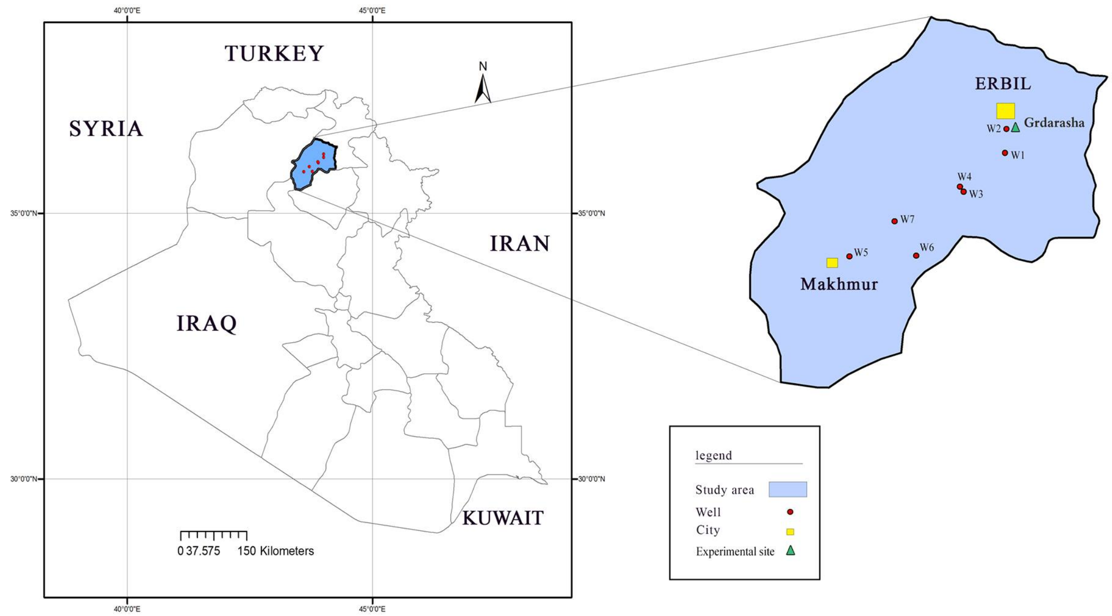


Fig.1. Location map for the study area

The effects of seven groundwater sources (Table 1) on soil properties were investigated. The RCBD model was used with three replications. The soil in the plot is to the Silty Clay Loam. Irrigation of wheat was carried out in soil at a rate of totally 158 liters per plot.

Table 1. Geographic parameters for the studied groundwater

No.	Elevation (amsl)	Coordinates	
		Latitude	Longitude
W1	400	36.0517 N	44.0078 E
W2	412	36.1136 N	44.0114 E
W3	332	35.9508 N	43.8994 E
W4	320	35.9636 N	43.8897 E
W5	305	35.7817 N	43.6014 E
W6	285	35.7833 N	43.7756 E
W7	327	35.8733 N	43.7192 E

Soil was tested before the study and its results are shown in Table 2. After harvesting, sampling was done at three depths (0-10, 10-20 and 20-30) cm. Soil samples were physically and chemically tested (NRCS, 2014), after passing through a sieve of 2 mm. Also, all groundwater samples were chemically analyzed, and the results are shown in (appendix 1).

The following methods are used to calculation of the required parameters; Richards (1954) for Sodium adsorption ratio (SAR), Ayers and Westcot (1976) for Adjusted sodium adsorption ratio (Adj.SAR), Suarez (1981) for Adjusted sodium adsorption ratio (Adj.RNa), Doneen (1954) for Salinity potential (SP) and Wilcox's (1955) for Residual sodium carbonates (RSC).

Table 2. Some physical and chemical properties of the soil before experiment

Parameter of average soil	pH	EC $dS.m^{-1}$	Organic Matter $gm.Kg^{-1}$	Total $CaCO_3$ $gm.Kg^{-1}$	CEC $Cmol.Kg^{-1}$	Bulk Density $Mg.m^{-3}$	Texture name	Soil textural % Clay	Silt	Sand	Total rainfall mm	Active water revised by experiment unit liter
	7.55	0.65	7.9	340	23.20	1.25	SiCL	38	46	16	330	158

Depth of soil cm	Concentraion.$mmolc.L^{-1}$ Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	NO_3^{-}	SO_4^{2-}	Mg^{2+}/Ca^{2+}	Na^{+}/Ca^{2+}	RSC	SAR	Adj.SAR	Adj.RNa
0-10	1.50	1.22	1.30	0.10	0.80	1.32	0.40	1.00	0.81	0.87	-1.40	1.11	1.49	1.03
10-20	1.50	1.20	1.20	0.10	0.70	1.35	0.40	0.95	0.80	0.80	-1.35	1.03	1.50	0.95
20-30	1.30	1.21	1.10	0.10	0.70	1.32	0.40	0.90	0.93	0.85	-1.19	0.98	1.92	0.87

The statistical methods were used to analyze the results of the research. In all cases, Tukey's H.S.D multiple range tests were applied at ($P \leq 0.05$) for comparing between the means of treatments by using SPSS 22.0 (SPSS Inc., Chicago, III) (Casanova et al., 2004). But the ion strength [1], ion pairs [2], ion activity [3] were calculated by using computer program which was prepared by Mam Rassol (2000) depending on some equations used by Davies (1962), Adams (1971) and Jeff (1988).

$$I = \frac{1}{2} \sum C_i Z_i^2 \qquad [1]$$

Where; I is ion strength, Ci is the actual molar concentration of each ion and Zi is ion valence.

$$-\log \gamma = \frac{A Z_i^2 \sqrt{I}}{1 + Bd\sqrt{I}} \qquad [2]$$

Where; I is Ion strength ($mol.L^{-1}$), A is 0.509 at 25 Cº, B is 0.3285 at 25 Cº , Zi is Ionic charge and d is Ion size parameter.

a =[3] *c γ

Where; a is Ion activity,   is Activity coefficient and C is Ion concentration.

RESULT AND DISCUSSION

1- Groundwater evaluation

Assessment of major ions and trace elements in groundwater are shown in Fig. 2. According to these results, the amount of calcium, magnesium, sodium, and sulfate increases from north-east to southwest. The range of changes in the concentration of calcium is from 2.4 to 17.1, magnesium from 1.1 to 14.9, sodium from 0.42 to 7.42 and sulfate from 0.5 to 35.1 $mmolc.L^{-1}$.

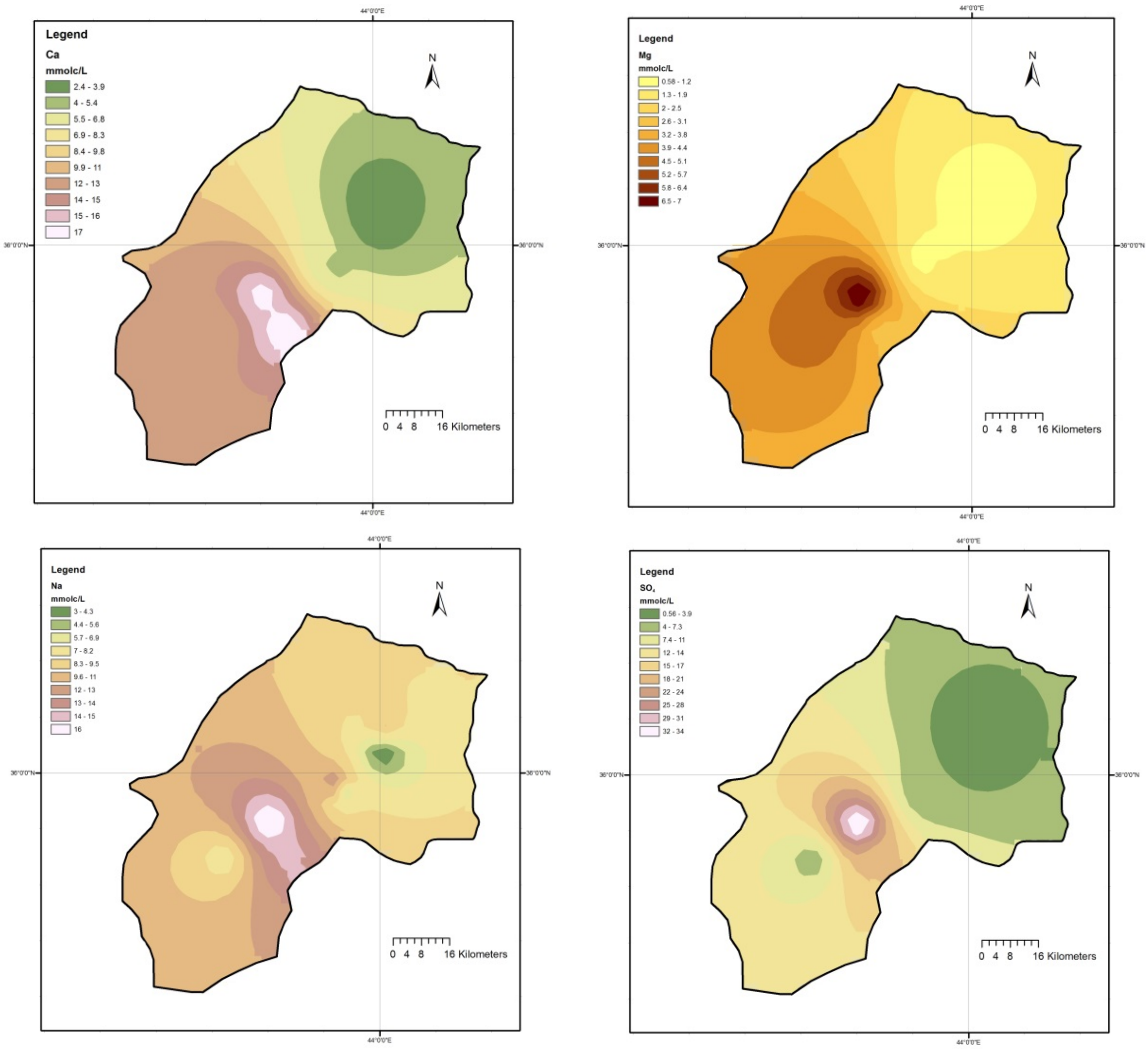


Fig. 2. Spatial distribution of Ca^{2+}, Mg^{2+}, Na^{+} and SO_4^{2-} in study area

Also, the levels of salinity of water, range from 0.4 to 5.6 $dS.m^{-1}$, according to the spatial distribution from northeast to southwest. In the same way, the SAR has a similar spatial distribution (Fig. 3).

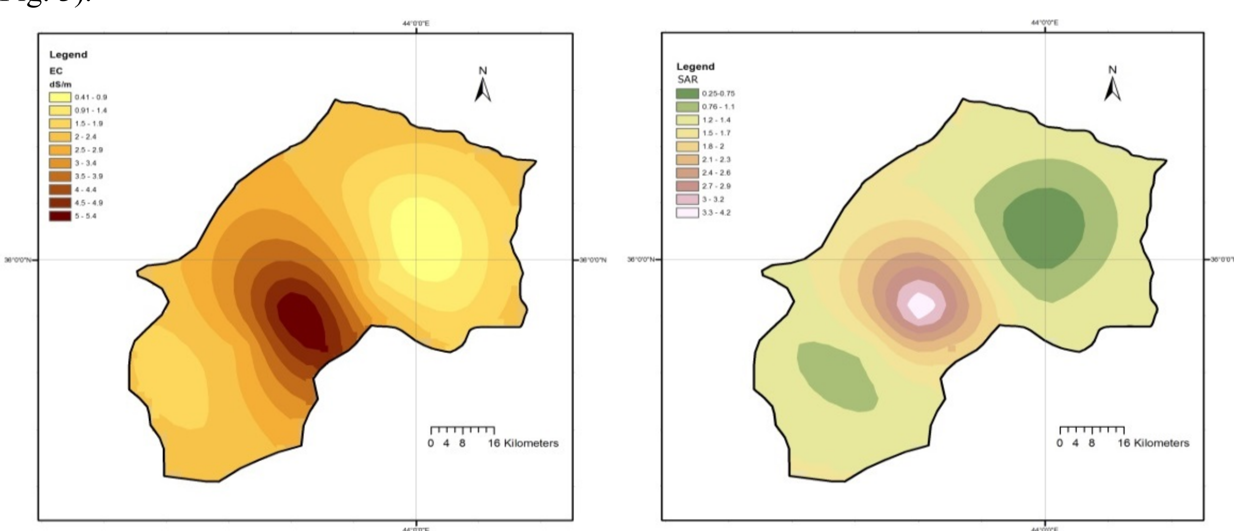


Fig. 3. Spatial distribution of EC and SAR in study area

Groundwater of study area can be classified as Fig. 4 according to Richards, 1954 method. North and northeast parts are C2S1 including the water of W1 and W2. Also, South and Southwest parts are involve C3S1 water of W3 and W4; whereas C4S1 category includes water of W5, W6 and W7.

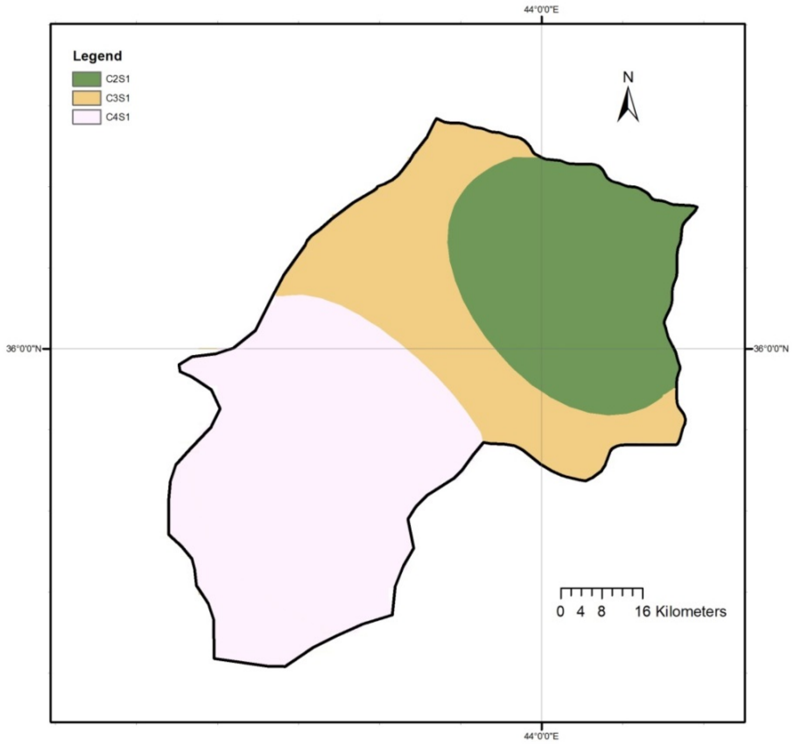


Fig. 4. Water classes in study area

2- Effect of Ion pair and Ion activity on soil chemical properties

The results showed that the water quality had different effects on the electrical conductivity on the depths of soil. The EC in the first layer (0-10) cm was greater than the second (10-20) cm and third (20-30) cm layers. This is the opposite of the results (Al-kaysi and Al-Jumily, 2001) because it was carried out only three times of irrigation in the spring. In this season, the temperature is high, so the amount of evapotranspiration increases and also causes moving up the water with capillary force to the upper soil layers (Table 3).

Table 3 shows that water quality causes nutrient accumulation and increases the positive (Na^{+}, Mg^{2+}, Ca^{2+}) and negative (Cl^{-}, SO_4^{2-}, HCO_3^{-}) ions in the topsoil. It is caused by high temperature in the spring.

However, the amount of pH in the upper layer in this study was decreased more than the lower layers, because there is an inverse relationship between the amount of calcium and the amount of hydrogen and has a direct relation with the amount of soil salts (Al-Busaidi and Cookson, 2003).

3- RSC and SP

Water quality has different effect on the soil, as shown in Table 3. An increase in RSC is found on the lower depth (20-30 cm) when comparing with upper soils, which is due to the accumulation of ions calcium and manganese, while SP is higher in the upper layers compared to with the lower layers, due to the presence of high chlorine and sulfate ions.

Table 3. Some chemical properties of the soil in different depths after irrigation

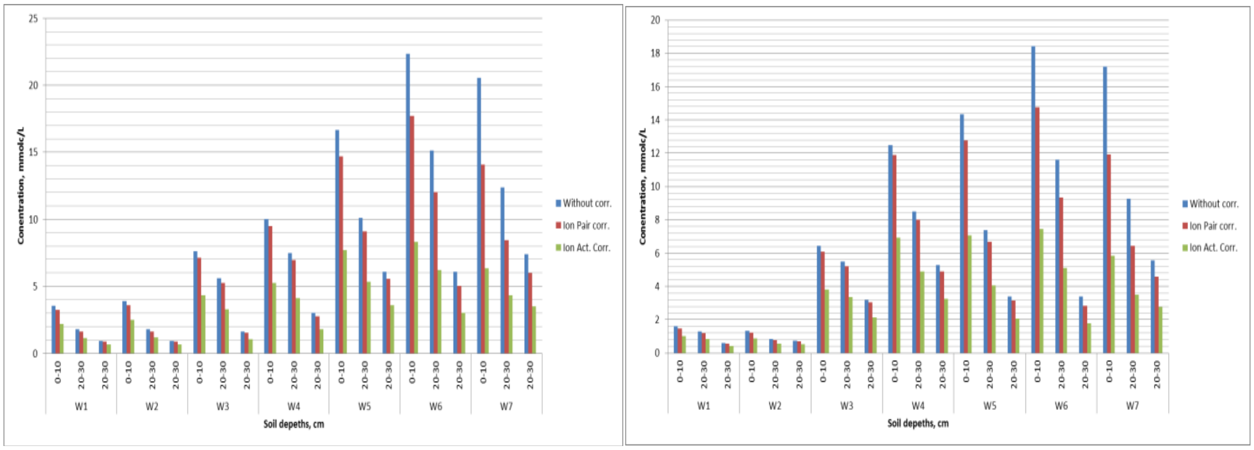
Well No.	Soil depth.cm	mmolc.L^{-1}								pH	EC dS.m^{-1}	RSC	S.P
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}				
W1	0-10	3.56	1.61	3.48	0.13	1.40	0.93	1.43	4.47	8.03	0.74	-0.70	2.12
	10-20	1.80	1.30	1.39	0.08	1.20	0.96	1.33	3.90	8.16	0.57	0.80	1.87
	20-30	0.93	0.61	1.34	0.09	1.07	0.50	1.17	1.37	8.18	0.57	-0.18	1.65
W2	0-10	3.89	1.33	1.30	0.08	1.27	0.87	1.56	2.00	8.09	0.57	-3.22	2.05
	10-20	1.78	0.85	1.69	0.06	1.20	0.85	1.54	2.13	8.04	0.57	-0.49	1.97
	20-30	0.94	0.73	1.21	0.16	0.90	0.52	1.04	1.87	8.07	0.53	0.19	1.42
W3	0-10	7.61	6.44	2.39	0.12	2.27	0.85	1.83	2.67	7.93	0.70	-11.39	3.18
	10-20	5.61	5.50	2.60	0.06	2.00	0.72	0.91	4.27	8.03	0.60	-6.84	2.46
	20-30	1.61	3.19	2.39	0.08	1.60	0.73	0.85	2.33	8.05	0.53	-2.46	2.03
W4	0-10	10.00	12.50	3.57	0.09	4.33	1.71	1.73	3.20	8.13	1.03	-19.30	5.20
	10-20	7.47	8.50	2.53	0.05	3.10	0.64	1.54	4.27	7.98	0.81	-11.70	3.87
	20-30	3.00	5.28	2.69	0.06	1.83	0.77	1.89	3.23	8.07	0.72	-5.04	2.78
W5	0-10	16.67	14.33	1.96	0.12	2.33	0.52	6.56	5.33	8.01	1.12	-25.67	5.61
	10-20	10.11	7.37	1.86	0.11	2.00	0.43	4.18	2.80	7.98	0.91	-14.68	4.09
	20-30	6.06	3.39	1.78	0.06	1.50	0.33	2.37	2.13	7.97	0.83	-7.31	2.69
W6	0-10	22.33	18.44	7.39	0.13	11.50	1.09	19.59	5.00	8.16	4.10	-35.78	21.30
	10-20	15.11	11.61	5.73	0.15	7.37	0.96	15.08	2.70	8.10	2.79	-24.02	14.91
	20-30	6.06	3.39	3.26	0.06	4.20	0.97	6.79	2.82	8.15	1.04	-6.62	7.59
W7	0-10	20.56	17.22	18.70	0.21	5.23	1.25	36.25	4.87	8.04	4.86	-32.91	23.36
	10-20	12.39	9.26	10.39	0.13	4.17	1.01	25.41	3.60	8.02	3.31	-18.05	16.87
	20-30	7.39	5.56	4.52	0.10	3.23	1.02	9.37	1.80	8.01	1.52	-11.15	7.92
Tukey's HSD values	0-10	1.13	1.05	0.007	0.002	0.50	0.02	0.39	0.29	0.03	0.16		
	10-20	0.35	0.62	0.19	0.003	0.36	0.004	0.006	0.19	0.09	0.24		
	20-30	0.42	0.29	0.008	0.04	0.32	0.041	0.007	0.69	0.004	0.30		

S.P = Salinity potential.

The concentration of all elements and electrical conductivity was decreased after computing the ion pair, as shown in appendix 2. Apart from nitrate and chlorine, they do not participate in ion pair phenomena (Esmail, 1992). Similarly, the RSC and SP were increased after computing the ion pair. It was also changed by (Salih, 2008).

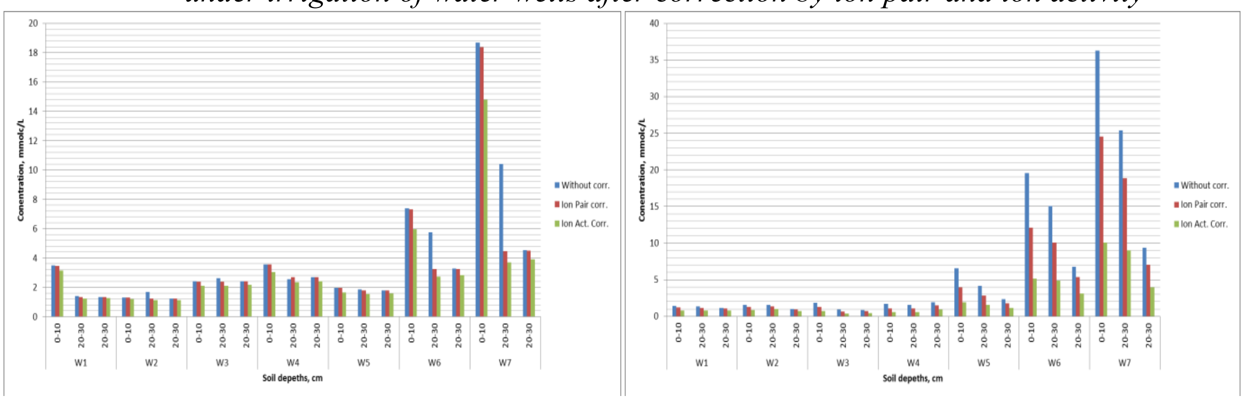
The concentration of the elements is reduced after computing the ion pair and ionic activity in all layers (Fig. 5, 6 and appendix 2, 3). This was also due to the participation of some ions such as calcium, magnesium, sulfate and bicarbonate in ion pair, but the amount of Chlorine and Nitrate did not show any differences among the soil layers.

According to the results of appendix 3, the concentration of all elements after the calculation of ionic activity was increased. Apart from chlorine, this does not contribute to ionic activity. In the same way, the RSC and SP were increased, which also agree with the results of (Alani, 2015).



A B

Fig. 5. Changes in Calcium (A) and Magnesium (B) concentration at different depths of Grdarasha soil under irrigation of water wells after correction by ion pair and ion activity



A B

Fig. 6. Changes in Sodium (A) and Sulfate (B) concentration at different depths of Grdarasha soil under irrigation of water wells after correction by ion pair and ion activity

In Tables 4 and 5, the ratio of ions and ionic strength are described when participating in ion pair and ion activity, which cause the decrease in the number of soluble cations and anion in soil depth (20-30) cm compare with soil layer (0-10) cm.

Table 4. The number of ions contributed in ion pairs of soil at different depths (mmolc.L^{-1}).

Well No.	Soil depth.cm	ion pair contribute mmolc.L^{-1}					
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	HCO_3^{-}
W1	0-10	0.315	0.125	0.012	0.0004	0.239	0.113
	10-20	0.165	0.104	0.004	0.0003	0.156	0.061
	20-30	0.066	0.038	0.003	0.0003	0.086	0.012
W2	0-10	0.288	0.087	0.003	0.0003	0.278	0.052
	10-20	0.153	0.064	0.003	0.0002	0.165	0.030
	20-30	0.066	0.045	0.002	0.0005	0.081	0.018
W3	0-10	0.481	0.363	0.005	0.0003	0.556	0.150
	10-20	0.342	0.290	0.006	0.0001	0.246	0.199
	20-30	0.088	0.152	0.004	0.0002	0.141	0.054
W4	0-10	0.529	0.591	0.008	0.0002	0.634	0.250
	10-20	0.494	0.495	0.007	0.0001	0.487	0.258

	20-30	0.246	0.385	0.008	0.0002	0.421	0.114
W5	0-10	1.990	1.579	0.010	0.0009	2.601	0.495
	10-20	1.020	0.680	0.007	0.0007	1.358	0.178
	20-30	0.500	0.252	0.005	0.0003	0.586	0.088
W6	0-10	4.644	3.676	0.076	0.0024	7.503	0.487
	10-20	3.104	2.263	0.030	0.0027	5.036	0.198
	20-30	1.038	0.536	0.022	0.0007	1.420	0.100
W7	0-10	6.498	5.294	0.339	0.0072	11.704	0.390
	10-20	3.930	2.813	0.075	0.0042	6.524	0.189
	20-30	1.400	0.984	0.035	0.0015	2.297	0.080

Table 5. Effect of ion pairs and ion activity on the ionic strength values (mol.L^{-1}) of the soil solution at different depths

Well No.	Soil depth.cm	I (mol.L^{-1})	I (mol.L^{-1})*	I (mol.L^{-1})**
W1	0-10	0.018	0.017	0.013
	10-20	0.013	0.012	0.009
	20-30	0.008	0.007	0.006
W2	0-10	0.016	0.015	0.011
	10-20	0.011	0.010	0.008
	20-30	0.008	0.007	0.006
W3	0-10	0.036	0.033	0.022
	10-20	0.029	0.027	0.018
	20-30	0.015	0.014	0.011
W4	0-10	0.055	0.051	0.031
	10-20	0.040	0.037	0.024
	20-30	0.025	0.022	0.016
W5	0-10	0.080	0.068	0.038
	10-20	0.047	0.041	0.025
	20-30	0.027	0.024	0.016
W6	0-10	0.133	0.101	0.053
	10-20	0.092	0.070	0.039
	20-30	0.038	0.032	0.021
W7	0-10	0.163	0.116	0.057
	10-20	0.104	0.074	0.040
	20-30	0.050	0.041	0.025

** = Ionic strength after correcting ion pairs. ** = Ionic strength after correcting ion pairs and activity.*

4- SAR, AdjSAR and AdjRNa

Water quality in each of the three studied soils showed different impacts on the SAR, AdjSAR and AdjRNa as shown in Tables 6, 7 and 8. SAR in the upper layer (0-10 cm) was increased compared to the lower layers due to high levels of sodium, calcium and magnesium. But after calculating ion pair and ionic activity, SAR increased in the lower layers due to the participation of calcium and magnesium in the ion pair and ion activity. It increased sodium concentration because sodium does not participate in ion pair (Salih, 2008; Abood *and Abed,* 2013 and Alani, 2015).

Table 6. Effect of ion pairs and ion activity on SAR values of depth soil after irrigation

Well No.	SAR			SAR*			SAR**		
	Soil depth.cm								
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
W1	2.16	1.12	1.53	2.26	1.12	1.58	2.47	1.22	1.68
W2	0.81	1.48	1.32	0.83	1.10	1.37	0.91	1.19	1.46
W3	0.90	1.10	1.54	0.93	1.04	1.58	1.04	1.16	1.71
W4	1.06	0.89	1.32	1.09	0.98	1.37	1.23	1.10	1.51
W5	0.50	0.63	0.82	0.53	0.63	0.85	0.60	0.71	0.94
W6	1.64	1.57	1.50	1.82	0.99	1.63	2.12	1.14	1.83
W7	4.30	3.16	1.78	5.09	1.63	1.95	5.99	1.88	2.20

Table 7. Effect of ion pairs and ion activity on $A_{dj}SAR$ values of depth soil after irrigation water

Well No.	Adj SAR			AdjSAR*			AdjSAR**		
	Soil depth.cm								
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
W1	4.76	2.23	1.83	4.74	2.14	1.89	4.95	10.71	25.44
W2	1.53	2.36	1.85	1.58	2.86	1.78	2.36	11.27	23.64
W3	2.16	2.76	3.09	2.13	2.50	2.85	4.14	12.83	30.18
W4	2.66	2.41	2.91	2.72	2.55	3.02	6.42	13.53	28.70
W5	1.44	1.51	1.72	1.47	1.52	1.70	3.98	9.31	18.73
W6	4.91	3.92	3.45	5.27	2.37	3.43	15.70	16.17	38.40
W7	12.48	7.89	4.09	13.24	3.91	3.90	49.69	28.16	47.92

Table 8. Effect of ion pairs and ion activity on $A_{dj}RNa$ values of depth soil after irrigation water

Well No.	AdjRNa			AdjRNa*			AdjRNa**		
	Soil depth.cm								
	0-10	10-20	20-30	0-10	10-20	20-30	0-10	10-20	20-30
W1	2.69	1.24	1.31	2.75	1.24	1.32	2.86	1.29	1.37
W2	1.09	1.48	1.22	0.88	1.25	1.24	1.11	1.11	1.26
W3	1.04	1.31	1.56	1.06	1.22	1.59	1.12	1.29	1.67
W4	1.23	1.04	1.41	1.24	1.13	1.45	1.35	1.23	1.63
W5	0.64	0.76	0.92	0.66	0.75	0.94	0.72	0.79	0.97
W6	2.08	1.88	1.75	2.26	1.14	1.85	2.47	1.26	1.96
W7	5.45	3.85	1.93	6.21	2.00	2.07	6.68	2.09	2.16

According to the results of Table 9, Nitrogen and Phosphorus levels were not been changed in soil layers after irrigation with different sources of water. Groundwater does not contain these elements and can't cause changes in their concentration in the soil. While there is a difference in Nitrogen level in the upper layer compared to the lower layers. This was also due to having some nitrogen content in rain water. But the amount of potassium after irrigation is higher in the upper layer than in the lower layers (Al-kaysi et al., 2001).

Table 9. Effect of water quality on concentration of nitrogen and phosphors in soil at (10, 20 and 30) cm after harvesting

Well No.	Nitrogen %			P µg.g^{-1}		
	Soil depth.cm					
	0-10	10-20	20-30	0-10	10-20	20-30
W1	0.16	0.15	0.15	4.15	4.03	3.87
W2	0.17	0.16	0.14	4.03	4.07	3.97
W3	0.15	0.14	0.14	4.33	4.31	4.23
W4	0.16	0.15	0.12	4.57	4.23	4.23
W5	0.13	0.12	0.10	3.63	3.33	3.27
W6	0.14	0.13	0.12	4.87	4.80	4.57
W7	0.16	0.15	0.13	4.18	4.17	4.03
Tukey's HSD values	0.006	0.007	0.014	0.009	0.13	0.14

It is predictable that salinity will be a potential risk for the Erbil basin in near future. This study was performed to evaluate the salinity of groundwater potential Erbil plain. The calculation results will provide an overview to assist planners, managers, and state and local officials in evaluating the relative vulnerability of areas to groundwater contamination from various sources of pollution.

RECOMMENDATION

According to the results of this study and considering the future of the agriculture in terms of successful management of crop production, it seems that a large-scale, multifaceted study is required for groundwater in the region. On the other hand, ground water application can be recommended by the following conditions:

1. These wells can be used for irrigation particularly in permeable soils.
2. Better soil management is necessary by adding soil conditioner to guarantee continuous using of these wells for irrigation.
3. Time factor should be considered in water and soil relationship, as it might depend on average of soil physical properties fluctuating as a result of chemical change.
4. Using GIS in studying the role of ion pairs in limiting water quality.
5. The future field studies must be made on the role of ionic activity in the availability of nutrients for plants.

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APPENDIX

Appendix 1. Some chemical properties of irrigation water before experiment.

Well No.	Concentraion.mmolc.L^{-1}								pH	EC dS.m^{-1}	SAR	Adj.SAR	Adj.RNa	RSC	S.P (Cl^-+1/2SO_4^{2-}) mmolc.L^{-1}
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3	SO_4^{2-}	HCO_3^-							
W_1	2.40	1.10	0.57	0.01	0.35	0.15	0.50	3.10	7.60	0.40	0.43	0.84	0.61	-0.40	0.60
W_2	2.60	1.57	0.42	0.01	0.30	0.15	0.82	3.15	7.60	0.50	0.29	0.61	0.40	-1.02	0.71
W_3	4.50	4.83	2.80	0.15	1.30	0.60	4.14	5.12	7.50	1.40	1.30	3.25	1.72	-4.21	3.37
W_4	5.80	7.12	2.82	0.05	1.50	0.60	4.50	6.80	7.30	2.10	1.11	2.97	1.45	-6.12	3.75
W_5	11.55	9.65	3.22	0.15	1.82	0.50	5.35	5.40	7.20	2.50	0.99	2.69	1.44	-15.80	4.495
W_6	17.10	14.90	7.42	0.15	8.47	0.80	18.50	5.00	7.20	5.10	1.86	4.93	2.69	-27.00	17.72
W_7	16.45	13.92	16.20	0.15	4.40	0.90	35.10	4.45	7.50	5.60	4.16	10.77	6.07	-25.92	21.95

S.P = Salinity potential. Total rainfall = 330 mm

Appendix 2. Some chemical properties of soil solution at different depths after correcting ion pairs

Well No.	Soil depth.cm	mmolc.L^{-1}								pH	EC dS.m^{-1}	RSC	S.P
		Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-				
W1	0-10	3.240	1.486	3.467	0.129	1.40	0.93	1.193	4.35	8.03	0.74	-0.37	2.00
	10-20	1.63	1.20	1.34	0.08	1.40	0.93	1.18	3.84	8.03	0.74	1.01	1.79
	20-30	0.87	0.57	1.34	0.09	1.40	0.93	1.08	1.35	8.03	0.74	-0.09	1.61
W2	0-10	3.600	1.244	1.298	0.081	1.267	0.87	1.282	1.95	8.09	0.57	-2.90	1.91
	10-20	1.62	0.78	1.21	0.06	1.27	0.87	1.38	2.10	8.09	0.57	-0.30	1.89
	20-30	0.88	0.69	1.21	0.16	1.27	0.87	0.96	1.85	8.09	0.57	0.28	1.38
W3	0-10	7.130	6.081	2.385	0.118	2.267	0.85	1.275	2.52	7.93	0.70	-10.69	2.90
	10-20	5.27	5.21	2.38	0.06	2.27	0.85	0.67	4.07	7.93	0.70	-6.41	2.33
	20-30	1.52	3.03	2.39	0.08	2.27	0.85	0.71	2.28	7.93	0.70	-2.28	1.95
W4	0-10	9.471	11.909	3.560	0.091	4.333	1.71	1.095	2.95	8.13	1.03	-18.43	4.88
	10-20	6.97	8.00	2.68	0.05	4.33	1.71	1.05	4.01	8.13	1.03	-10.97	3.63
	20-30	2.75	4.89	2.68	0.06	4.33	1.71	1.47	3.12	8.13	1.03	-4.53	2.57
W5	0-10	14.677	12.754	1.948	0.120	2.333	0.52	3.960	4.84	8.01	1.12	-22.59	4.31
	10-20	9.09	6.69	1.77	0.11	2.33	0.52	2.82	2.62	8.01	1.12	-13.16	3.41
	20-30	5.56	3.14	1.78	0.06	2.33	0.52	1.78	2.04	8.01	1.12	-6.65	2.39
W6	0-10	17.689	14.768	7.314	0.127	11.500	1.09	12.09	4.51	8.16	4.10	-27.94	17.54
	10-20	12.01	9.35	3.23	0.15	11.50	1.09	10.04	2.50	8.16	4.10	-18.85	12.39
	20-30	5.02	2.85	3.24	0.06	11.50	1.09	5.37	2.72	8.16	4.10	-5.15	6.88
W7	0-10	14.057	11.928	18.36	0.201	5.233	1.25	24.54	4.48	8.04	4.86	-21.51	17.51
	10-20	8.46	6.44	4.45	0.13	5.23	1.25	18.89	3.41	8.04	4.86	-11.50	13.61
	20-30	5.99	4.57	4.49	0.10	5.23	1.25	7.07	1.72	8.04	4.86	-8.84	6.77

S.P = Salinity potential after correcting ion pairs.

Appendix 3. Some chemical properties of soil solution at different depths after correcting ion pairs and activity

Well No.	Soil depth.cm	mmolc.L^{-1}								pH	EC dS.m^{-1}	RSC	S.P
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	NO_3^{-}	SO_4^{2-}	HCO_3^{-}				
W1	0-10	2.17	1.02	3.12	0.12	1.40	0.93	0.78	3.92	8.03	0.74	0.73	1.79
	10-20	1.16	0.86	1.22	0.07	1.40	0.93	0.82	3.51	8.03	0.74	1.49	1.61
	20-30	0.66	0.44	1.25	0.08	1.40	0.93	0.81	1.26	8.03	0.74	0.16	1.47
W2	0-10	2.50	0.88	1.18	0.07	1.27	0.87	0.87	1.77	8.09	0.57	-1.61	1.70
	10-20	1.18	0.58	1.11	0.05	1.27	0.87	0.99	1.94	8.09	0.57	0.18	1.69
	20-30	0.66	0.53	1.13	0.15	1.27	0.87	0.72	1.72	8.09	0.57	0.53	1.26
W3	0-10	4.33	3.82	2.09	0.10	2.27	0.85	0.75	2.21	7.93	0.70	-5.94	2.64
	10-20	3.30	3.36	2.11	0.05	2.27	0.85	0.40	3.60	7.93	0.70	-3.06	2.20
	20-30	1.06	2.14	2.17	0.07	2.27	0.85	0.48	2.07	7.93	0.70	-1.13	1.84
W4	0-10	5.25	6.91	3.04	0.08	4.33	1.71	0.58	2.52	8.13	1.03	-9.64	4.62
	10-20	4.11	4.90	2.33	0.04	4.33	1.71	0.60	3.49	8.13	1.03	-5.52	3.40
	20-30	1.78	3.24	2.39	0.05	4.33	1.71	0.92	2.78	8.13	1.03	-2.24	2.30
W5	0-10	7.68	7.05	1.64	0.10	2.33	0.52	1.94	4.07	8.01	1.12	-10.66	3.30
	10-20	5.32	4.06	1.54	0.09	2.33	0.52	1.58	2.27	8.01	1.12	-7.11	2.79
	20-30	3.58	2.08	1.58	0.05	2.33	0.52	1.12	1.82	8.01	1.12	-3.84	2.06
W6	0-10	8.29	7.45	5.95	0.10	11.50	1.09	5.18	3.67	8.16	4.10	-12.07	14.09
	10-20	6.21	5.11	2.71	0.12	11.50	1.09	4.85	2.09	8.16	4.10	-9.22	9.79
	20-30	3.04	1.78	2.84	0.05	11.50	1.09	3.13	2.38	8.16	4.10	-2.44	5.77
W7	0-10	6.36	5.84	14.78	0.16	5.23	1.25	10.05	3.60	8.04	4.86	-8.59	10.26
	10-20	4.32	3.49	3.71	0.10	5.23	1.25	9.00	2.85	8.04	4.86	-4.97	8.67
	20-30	3.48	2.76	3.89	0.09	5.23	1.25	3.94	1.49	8.04	4.86	-4.76	5.20

S.P** = Salinity potential after correcting ion pairs and activity

پوختە

ئاوی ژێرزەوی سەرچاوەیەکی گرنگی ئاودانی بەروبوومەکانە لە دەشتی هەولێر. ئەم توێژینەوەیە لە دوو ئاراستەدا ئەنجامدرا: هەڵسەنگاندنی چۆنێتی ئاوی ژێرزەوی و کاریگەریی لە سەر خەسڵەتە کیمیاییەکانی خاك لە پەیوەندی لەگەڵ ئایۆنی جووتەك و ئایۆنی چالاك. تاقیکردنەوەیەکی کێڵگەیی ئەنجامدرا بۆ وەرزی چاندنی گەنم لە بەرواری 2015/12/11 تا 2016/5/30 بە مەبەستی دۆزینەوەی ئاستی کاریگەری چەندین ئاوی ژێرزەوی جیاواز لەسەر خەسڵەتە کیمیاییەکان خاك لە ڕێگەی دیزاینی (RCBD)بە سێ دووبارەبوونەوە. هەروەها ئایۆنی جووتەك و ئایۆنی چالاك بۆ سێ ئاستی قوڵایی خاك هەژمارکرا.

ئەنجامەکان دەریانخست کە چۆنێتی ئاوی ژێرزەوی نزمبوونەوەیەکی گشتی لەخۆی نیشان دەدات لە ناوچەکانی باکوور بەرەو باشووری دەشتی هەولێر. لە پەیوەندی لەگەڵ خەسڵەتە کیمیاییەکانی خاك، گەیاندنی کارەبایی (EC) بە بڕی (0.65 – 4.86) جار زیادی کرد بە بەراورد لەگەڵ (EC_e)ی سەرەتایی. بەرزبوونەوەی خەستی کەتیۆن و ئەنیۆنەکان لە ئاودا بوو بە هۆی بەرزبوونەوەی خەستیان لە شیرەی خاك. زیاد بوون لە خەستی ئایۆنە پۆزەتیف و نەگەتیڤەکانی ئاو لە سەر ئاستی (0.05) بۆتە هۆی زیادبونێکی بەرچاوی خەستیەکان لەگیراوەی خۆڵەکەدا، بەرزترین خەستی بۆ هەریەکە لە Ca^{2+}, Mg^{2+} و Cl^{-} یەکسان بووە بە 18.44, 22.33 و 11.50 ملیمکافی.لتر$^{-1}$ تۆمارکرا لە ئاوی شەشەم ئاستی (0-10) سم. بەرزترین خەستی بۆ Na^{+} و SO_4^{2-} یەکسان بوو بە 18.70 و 36.25 ملیمکافئ.لتر$^{-1}$ تۆمار کرا لە ئاوی حەوتەم ئاستی (0-10) سمئاستی پێوەرەکانی خاك لەپاش هەژمارکردنی ئایۆنی جووتەك و ئایۆنی چالاك، دابەزینی بەخۆیەوە بینی لە سەرجەم مامە لە و چینەکانی خاکدا. لە لایەکی تر، بڕی توخمە خۆراکییەکان لە خاکی سەرودا کۆبوونەوەی نیشاندا بە بەراورد بە چینەکانی خوارووتر.