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ASSESING THE GROUNDWATER SUITABILITY FOR IRRIGATION IN WESTERN IRAQ

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ABSTRACT

The main objective of this study is to map of the groundwater quality irrigation index (IWQI) in the western part of Iraq for the purpose of determining ideal locations for groundwater quality, to meet the demand for water in the future. To achieve this purpose, 84 wells distributed in the study area have been sampled. The collected samples analyzed chemically for varies parameters that affect to the irrigation water quality. These chemical parameters are Electrical Conductivity (EC), Na^+, Cl^-, HCO_3^- and calculated sodium adsorption ratio (SAR). These chemical analyses have been transferred to the platform of geographic information systems (GIS) to create water quality database including spatial distributions map for each parameter using the inverse distance interpolation technique (IDW). These parameters were used to calculate the values of Irrigation Water Quality Index that have been moved to the platform of GIS for the production of IWQI map. The results show that small part of the study area belong to **Low Restriction (LR)** categories for irrigation water and about 50% of the groundwater samples belong to **Moderate Restriction (MR)** category. The results also showed that 28% of the groundwater covering 39 Km^2 falls within the **High restriction (HR)** category while 20% of studied water samples classified as **Sever Restriction (SR)**. Accordingly, this groundwater is only suitable to use with high permeability soils, which have the ability to tolerate high content of salts.

تقييم صلاحية المياه الجوفية لأغراض الري في غرب العراق

مفيد سعدي الحديثي

المستخلص

الهدف الرئيسي من هذه الدراسة هو رسم خريطة لمؤشر جودة المياه الجوفية للري لغرض تحديد مواقع مثالية للمياه الجوفية في الجزء الغربي من العراق، لتلبية الطلب على على هذه المياه مستقبلا. ولتحقيق هذا الغرض تم اختيار 84 بئر ماء موزعة في منطقة الدراسة جمعت منها عينات المياه. هذه العينات تم تحليلها كيميائيا للعديد من المحددات الكيميائية التي تؤثر على نوعية مياه الري وهي الموصلية الكهربائية والصوديوم والكلور والبيكاربونات ونسبة امتزاز الصوديوم المحسوبة. تم نقل هذه المحددات إلى منصة نظم المعلومات الجغرافية لإنشاء خرائط التوزيعات المكانية لكل محدد باستخدام معكوس المسافة لتقنية الاستكمال الداخلي (interpolation technique) واستخدمت هذه المعلمات لحساب قيم مؤشر جودة المياه التي تم نقلها إلى منصة نظم المعلومات الجغرافية لإنتاج خريطة مؤشر جودة مياه الري (IWQI). بينت النتائج بأن جزء صغير من منطقة الدراسة يقع ضمن فئة التقييد القليل لاستخدام هذه المياه لاغراض الري ونسبة 50% من مياه الآبار تقع ضمن فئة التقييد المتوسط. وبينت النتائج ايضاً بأن 28% من المياه والتي تغطي مساحة 39 كم^2 من المساحة الكلية لمنطقة الدراسة تقع ضمن التقيد العالي لاستخدام هذه المياه لأغراض الري أما النسبة المتبقية والبالغة 20% فهي تقع ضمن التقيد الشديد جداً لاستخدامات الري وهذه المياه لاتسخدم إلا مع الترب ذات النفاذية العالية والتي لها القدرة على تحمل نسبة عالية من الاملاح.

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INTRODUCTION

Recently the increasing population growth in the western part of Iraq in an unplanned way that is invited to think about decisions related to water management. In this region, there is a largely untapped area and the amount of the rainfall is insufficient and most of their parts far from the river, so it is necessary to use different integration techniques to determine the ideal sites for groundwater prospect and assessing the suitability of groundwater for irrigation purpose. Researchers at the United States Salinity Laboratory (USSL) (1954) and Wilcox (1955) established the standards diagrams for irrigation water. In recent years many researchers like Simsek and Gunduz (2007), Jerome1 and Pius (2010) and Rokbani *et al*. (2011) used the irrigation water quality index (IWQI) as a management tool for groundwater quality. In 2010 Meireles *et al*., has develop the irrigation water quality index (IWQI) model to classify the water quality for irrigation in the Acarau Basin, northern Carar state, Brazil. In this study chemical parameters such as EC, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, HCO_3^{-} and SAR^{o} have been used for assessment of groundwater quality to develop a water quality index (WQI) model that reflects soil salinity and sodicity risks and water toxicity to plants. The results observed in this study showed that there is a limited use of water for irrigation purposes on the western side of the studied basin. In the present study, this model has been used to evaluate the quality of irrigation waters in the western part of Iraq. Various workers have applied integrated IWQI with GIS technique to assess the water quality for irrigation use. Omran and Marwa (2015) has assessed the drainage water for irrigation using Irrigation Water Quality Index (IWQI) and integrated this index with GIS technique. This study shows that this method can help the maker decision to understand the status of the drainage water quality by summarizing the observation data or showed the spatial distribution of the quality index. Al-Mussawi (2014) and Rasul and Waqed (2015) have also shown that this method could provide an efficient tool to understand the status of the groundwater quality; and to have the opportunity for better use of this water in future.

The present study has been undertaken with the objective to assess the suitability of groundwater quality for irrigation purposes in the western part of Iraq using IWQI and ArcGIS software to show the spatial distribution of this index.

The study area is equivalent to one-third of the area of Iraq, bounded by latitudes 30° 30' 00" to 35° 00' 00" North and longitude 38° 55' 00" to 44° 10' 00" East (Figure 1). According to the census of 2014 the population is about 1, 000, 600 most of whom live in the urban areas. Historically, the region was known as the "Brigade of Dulaimi".

Studying geological formations within the area is of great importance because of their impact on the hydraulic characteristics of the aquifer, where water is stored or transported vertically or horizontally through these formations in addition to their impact on the aquifer geometry and the chemistry of groundwater system for these reservoirs (Tariq, 2015). Physiographically the study area is located within the two main zones in Iraq, namely the Western Desert and Aljazera Zones, so it has different geological formations extending from an "Early Permian to the Holocene age as shown in Table (1) and Figure (2).

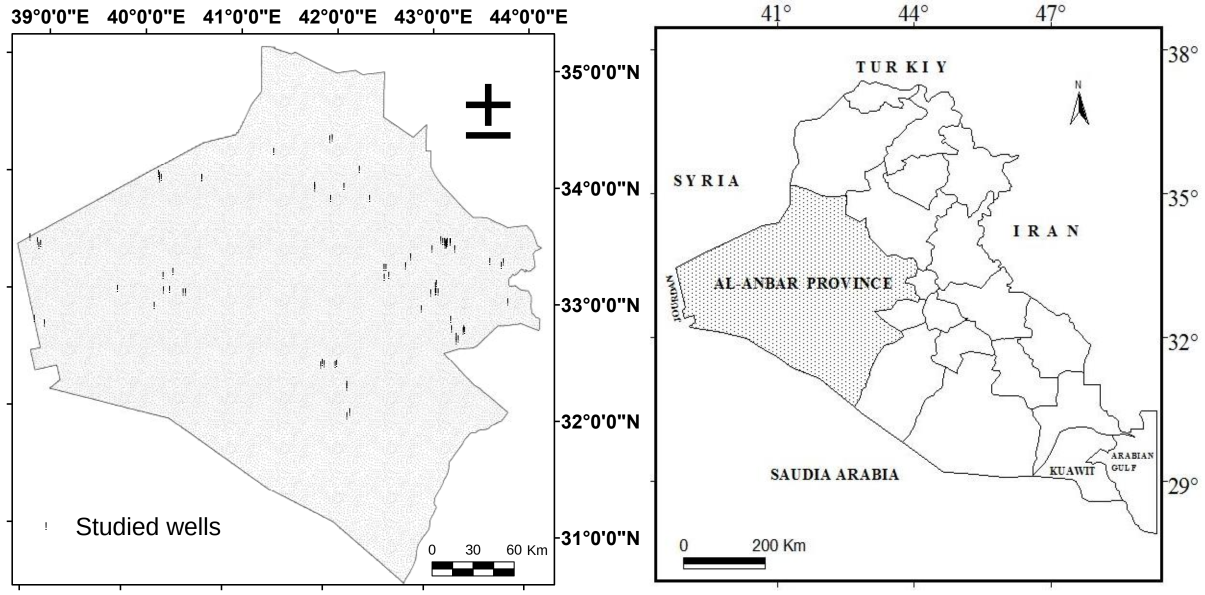

Fig.1: Location map of the study area and the selected wells

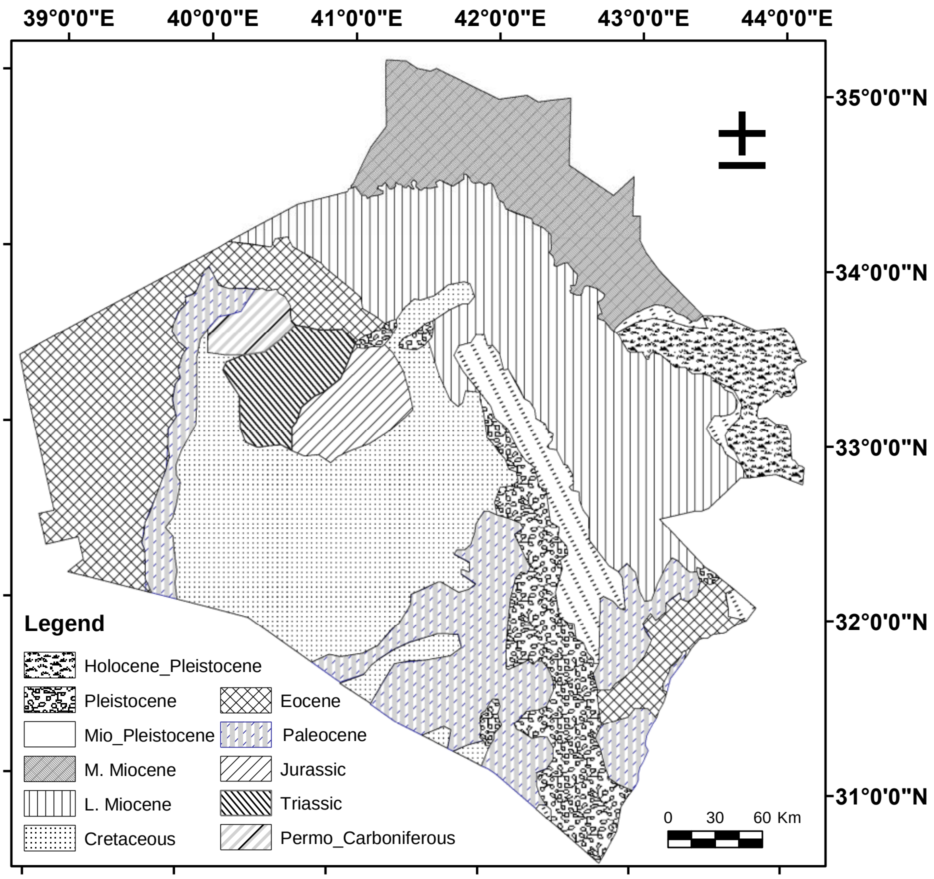

Fig.2: Geological map of the study area (After Bayan, 2010)

Table (1) shows the geological formations in the study area including: Mulussa, Zor Horan, Ubaid, Hussainiyat, Amij, Muhaiwir, Najmah, Nahr Umr – Muddud, Rutba – Msad, Hartha – Tayarat, Marbat/ Digma, Umm Er Radhuma, Dammam, Sheikh Alas, Baba, Anah, Ghar, Euphrates, Fatha and Injana Formations (Sissakian *et al*., 2007). Also it is noted that the Tertiary deposits includes sandy gravel/ Horan, Habbariya and Quaternary deposits include alluvial sediment terraces and valleys (Sissakian *et al*., 2007).

Table 1: Geological Formations in the study area (Bayan, 2010)

Era	Period		Age	Formation	Descriptions
Cenozoic	Quaternary		Holocene – Pleistocene	Recent deposits	Alluvial sediments, valley and depression fills, etc.
	Tertiary	Neogene	Pleistocene	Sandy gravel/ Horan, Habbariya, Mesopotamia	Sandy gravel, Conglomerate
			Mio-Pleistocene	Zahra Fn.	Limestone, Sandy, Limestone
			U. Miocene	Injana Fn.	Interbedded of clay stones and Sandstones
			M. Miocene	Fatha Fn.	Gypsum and Anhydrite, limestone marl and clay
			L. Miocene	Euphrates Fn.	Fossiliferous, chalky, limestone, Dolomitic
			L. Miocene	Ghar Fn.	Sandstone and Calcareous Sandstone
		Paleogene	U. Oligocene	Anah Fn.	Fossiliferous, Coralline limestone
			M – U. Oligocene	Baba Fn.	Hard limestone and Dolomite
			L. Oligocene	Shurau/ Sheikh Alas Fns.	Carbonates
			Eocene	Ratga/ Dammam Fns.	Dolomite. Dolomite limestone, Limestone
			Paleocene	Akashat/ Um Ur Radhuma Fns.	Phosphates Limestone/ Dolostone, Dolomite
Mesozoic	Cretaceous		U. Cretaceous	Marbat/ Digma Fns.	Sandy limestone interbedded with pebbly sandstone
			U. Cretaceous	Hartha – Tayarat Fns.	Dolomitic limestone, silty clay sandstone
			U. Cretaceous	Rutba – Msad Fns.	Dolomite – sandstones
			L. Cretaceous	Nahr Umr – Muddud	Silt, Marl, Dolostone, Limestone
	Jurassic		U. Jurassic	Najmah Fn.	Sandstone ,limestone, Marl, Marly limestone
			M. Jurassic	Muhaiwir Fn.	Marl, sandstones, carbonate
			L – M. Jurassic	Amij – Hussainiyat Fns.	Claystones, sandstones, Iron Ore and dolomite
			L. Jurassic	Ubaid Fn.	Dolomite, Gypsious, Marl, Dolomitic Limestone
	Triassic		U. Triassic	Zor Horan Fn.	Marl, Marly limestone, Dolostone, Gypsum, Marl
Paleozoic			U. Triassic	Mulussa Fn.	Limestone, Dolomite limestone and Dolostone
	Permo-Carboniferous			Gaara Fn.	Interbedded of clay stones and Sandstone

Three types of aquifers have been observed in the study area such as confined, unconfined and mixed aquifer namely Umm Er Radhuma, Muhaiwir, Mulussa, Euphrates, Fatha, Gaara, Anah and Dammam (Bayan, 2010). Table 2 shows all types of aquifers and their names distributed in the wells of the study area. The spatial distribution of water table elevation map above Mean Sea Level (AMSL) has been prepared (Figure 3). As shown in Figure 3 the flow direction generally is from SW to NE which indicates that the western part of the study area acts as the recharge area to the aquifers.

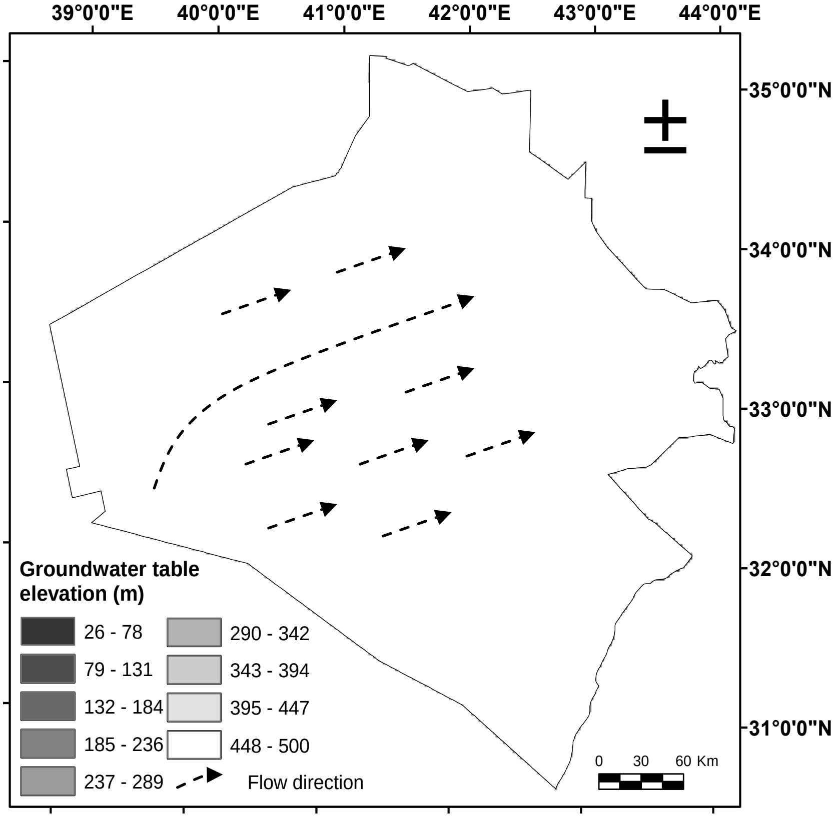

Fig.3: Groundwater table elevation contour (AMSL) map showing groundwater flow direction in the study area

Table 2: Aquifers type and name distributed over wells in the study area

Well No.	Aquifer type	Aquifer name
1, 2, 3, 4, 25, 26, 27, 28, 29, 30, 31, 32, 41, 57, 85, 60	unconfined	Umm Er Radhuma
5, 6,7, 8, 9, 10,11	unconfined	Muhaiwir
12, 13, 72, 79, 80	unconfined	Mulussa
14, 15, 16, 17, 18, 19, 38, 39, 40, 54, 55, 56, 67, 68, 69, 70, 71,73, 78, 80	unconfined	Euphrates
20, 21, 22, 23, 24, 45, 46, 47, 48, 49, 50, 51, 52, 53, 61, 62, 63, 64, 65, 66, 74	confined	Fatha
33	unconfined	Ga'ara
34, 35, 36, 37	mixed	Euphrates + Umm Er Radhuma
42, 43, 75, 76, 77, 81, 84	unconfined	Anah
44, 59, 83	mixed	Dammam + Anah

METHODOLOGY

- **Sampling and Laboratory work**

Forty eight water samples were collected and analyzed by the General Company for Drilling Wells (Al-anbar Branch) during April, 2010. Cations and anions in addition to other physical parameters such as PH, Total Dissolve Soiled (TDS) and Electrical conductivity (EC) have been measured in all water samples collected. Conductivity, TDS and pH meter has been used for measuring the EC, TDS and pH respectively. Cations (Ca^{+2}, Na^{+}, and K^{+}) have been analyzed by flame photometer, Mg^{+2} in EDTA titration method, HCO_3^{-2} and Cl^{-}

analyzed by H_2SO_4 and $AgNO_3$ titration method, respectively. The measured values of the chemical parameters are summarized in Table (3).

Table 3: Chemical analysis of groundwater samples in the study area
(Units in meq. l^{-1} except EC in (µs/cm) and TDS in ppm)

Well No.	Ph	EC	TDS	K^+	Na^+	Mg^{+2}	Ca^{+2}	Cl^-	SO_4^{-2}	HCO_3^-	SAR	R.D
1	7.2	871	650	0.03	3.70	2.46	2.70	5.49	2.92	0.36	2.30	0.65
2	7.3	716	533	0.02	2.74	1.64	2.00	3.69	2.58	0.30	2.03	-1.31
3	7.2	741	555	0.02	3.13	1.97	2.15	4.00	2.67	0.31	2.18	2.05
4	7.2	873	660	0.03	3.83	2.54	2.75	5.61	2.98	0.36	2.35	1.13
5	7.3	1514	1053	0.03	4.00	1.64	4.50	5.07	4.38	1.07	2.28	-1.67
6	7.2	2520	1752	0.06	9.91	4.10	8.00	8.17	10.38	2.95	4.03	1.33
7	7.1	2910	2012	0.13	12.17	6.07	9.40	11.49	12.19	4.05	4.38	0.07
8	7.1	2990	2064	0.18	13.48	6.97	10.25	12.96	13.33	4.36	4.59	0.36
9	7.1	3004	2123	0.20	13.70	7.13	10.35	13.32	13.46	4.41	4.63	0.30
10	7.1	2980	2057	0.15	12.96	6.56	9.90	12.68	12.71	4.18	4.52	0.00
11	7.1	3002	2121	0.20	13.65	7.13	10.30	13.30	13.44	4.39	4.62	0.26
12	7.1	2990	2064	0.18	13.48	6.97	10.25	12.96	13.33	4.36	4.59	0.36
13	7.2	2700	1868	0.10	11.13	5.33	9.00	9.61	12.00	3.67	4.16	0.56
14	7.1	2890	2000	0.12	11.30	5.74	9.25	10.20	12.08	4.00	4.13	0.24
15	7.1	3008	2125	0.21	13.74	7.21	10.40	13.38	13.50	4.43	4.63	0.41
16	7.1	2970	2051	0.14	12.61	6.39	9.70	12.20	12.33	4.10	4.44	0.38
17	7.1	3230	2330	0.20	13.83	7.13	10.50	14.00	13.00	4.26	4.66	0.63
18	7.1	4690	3312	0.59	20.00	10.66	14.25	19.61	19.00	6.72	5.67	0.18
19	7.2	2690	1862	0.08	10.78	4.92	8.75	9.58	11.67	3.61	4.12	-0.65
20	7.2	5460	3994	0.51	18.70	12.30	12.00	16.00	20.29	7.21	5.36	0.00
21	7.2	4240	3114	0.51	18.26	9.84	13.50	18.00	17.50	6.51	5.35	0.12
22	7.2	5740	4173	0.64	20.22	13.93	13.25	18.00	22.00	7.70	5.48	0.35
23	7.2	3400	2426	0.31	15.22	8.36	11.75	15.61	15.00	4.67	4.80	0.50
24	7.3	668	473	0.02	2.17	0.82	1.50	2.62	1.52	0.25	2.02	1.38
25	7.2	2430	1691	0.05	10.65	4.10	8.00	8.45	10.81	3.39	4.33	0.31
26	7.4	2270	1608	0.49	15.87	8.69	7.65	14.31	16.40	1.66	5.55	0.51
27	7.1	2660	1858	0.54	13.39	4.92	6.90	6.20	12.92	6.08	5.51	1.10
28	7.3	1788	1269	0.28	5.96	7.30	6.40	7.01	11.58	1.00	2.28	0.85
29	7.7	1940	1397	0.23	7.30	6.72	5.85	8.76	9.50	1.31	2.91	1.35
30	7.5	770	590	0.03	2.17	1.97	2.00	2.73	1.77	1.93	1.54	-2.15
31	7.8	1209	899	0.31	11.04	1.39	2.00	5.32	6.48	3.28	8.48	-1.13
32	7.2	1016	850	0.03	6.04	2.21	2.50	5.15	4.35	1.11	3.94	0.74
33	7.3	1298	965	0.03	6.61	2.54	2.85	5.77	5.02	1.16	4.03	0.30
34	7.2	3990	2922	0.13	15.61	9.02	10.55	12.82	18.04	4.02	4.99	0.61
35	7.4	3880	2858	0.15	10.78	13.93	13.45	12.42	21.38	4.26	2.91	0.34
36	7.3	4200	3038	0.53	19.39	11.48	15.00	17.30	24.58	4.28	5.33	0.26
37	7.2	3550	2310	0.14	17.83	7.22	9.05	14.00	13.65	5.98	6.25	0.89
38	7.2	2970	2136	0.36	18.61	3.03	3.45	10.17	10.67	4.39	10.34	0.43
39	7.4	3230	2465	0.12	14.00	7.21	9.35	9.32	14.23	7.23	4.86	-0.17
40	7.8	3630	2474	0.18	18.39	10.49	8.55	15.58	16.44	4.75	5.96	1.14
41	7.3	820	613	0.02	2.22	2.05	2.10	2.62	1.81	2.05	1.54	-0.71
42	7.6	4520	3342	2.51	22.13	11.48	15.80	19.27	24.60	7.74	5.99	0.29
43	7.7	3560	2647	0.15	10.65	13.52	13.25	12.39	21.23	4.26	2.91	-0.40
44	7.3	3940	2871	0.41	17.00	10.57	13.50	15.52	20.67	4.02	4.90	1.57

Continue Table 3:

Well No.	Ph	EC	TDS	K^+	Na^+	Mg^{+2}	Ca^{+2}	Cl^-	SO_4^{-2}	HCO_3^-	SAR	R.D
45	7.3	3700	2898	0.43	18.61	10.08	13.80	16.59	22.08	4.07	5.39	0.22
46	7.3	3300	2362	0.18	15.96	7.79	7.30	13.15	14.19	5.74	5.81	-2.89
47	7.3	4190	2980	2.12	17.83	10.74	13.00	15.52	20.83	7.34	5.17	-0.01
48	7.4	4190	2975	2.17	17.74	11.07	12.90	15.58	20.81	7.30	5.12	0.22
49	7.1	3430	2645	0.05	14.70	8.69	10.40	14.08	15.63	7.38	4.76	-4.58
50	7.4	3180	2335	0.08	16.30	8.52	11.15	18.31	16.02	5.07	5.20	-4.43
51	7.2	2870	2034	0.41	18.48	3.11	3.60	10.14	10.73	4.34	10.08	0.76
52	7.8	3380	2400	0.08	16.22	8.52	11.25	14.93	16.10	5.05	5.16	-0.02
53	7.2	6650	4706	1.28	26.00	14.02	17.40	19.41	31.90	8.38	6.56	-0.83
54	7.2	1610	1100	0.13	3.43	5.57	4.45	4.79	7.52	0.79	1.53	1.84
55	7.2	3150	2300	0.10	8.26	7.87	8.00	4.82	16.63	1.66	2.93	2.40
56	7.2	4050	2940	0.20	18.39	8.11	10.40	13.46	16.08	7.39	6.04	0.23
57	7.2	1373	989	0.06	6.39	2.54	2.90	5.21	4.81	1.07	3.87	3.51
58	7.4	1729	1200	0.33	13.26	6.07	9.00	12.39	17.73	1.49	4.83	-4.90
59	7.1	3720	2700	0.13	15.87	8.03	7.00	13.18	14.15	5.75	5.79	-3.20
60	7.3	1802	1280	0.41	14.78	6.72	6.60	13.10	14.10	1.51	5.73	-0.35
61	7.8	4000	2810	0.18	15.43	7.70	10.40	16.87	14.19	2.62	5.13	0.05
62	7.4	2930	2275	0.26	12.83	10.90	12.40	19.49	14.79	2.05	3.76	0.07
63	7.2	2460	2074	0.15	10.43	9.02	11.00	19.01	9.58	1.72	3.30	0.47
64	7.3	2600	2164	0.18	11.30	9.67	11.25	18.00	12.29	1.89	3.50	0.35
65	7.4	2600	2165	0.18	11.30	9.67	11.25	18.00	12.29	1.89	3.50	0.35
66	7.2	5420	3868	0.51	15.22	12.30	12.00	20.70	12.79	5.30	4.37	1.56
67	7.4	2940	2582	0.33	14.13	12.30	13.25	20.42	17.71	2.18	3.95	-0.38
68	7.4	3510	2646	0.20	10.87	11.48	15.00	19.01	19.42	0.85	2.99	-2.26
69	7.4	3050	2252	0.05	11.74	6.15	8.50	13.52	10.94	2.30	4.34	-0.59
70	7.3	3610	2710	0.23	13.04	12.13	15.25	20.28	19.63	1.02	3.53	-0.33
71	7.9	2960	2494	0.13	20.87	6.31	7.75	12.51	20.00	2.51	7.87	0.06
72	7.1	913	784	0.00	1.48	1.64	3.25	4.79	1.56	0.66	0.95	-4.76
73	7.2	3770	2712	0.36	11.39	13.11	10.00	13.80	17.60	3.48	3.35	-0.03
74	7.8	5680	3750	0.31	26.96	14.59	14.50	23.10	22.08	6.00	7.07	4.81
75	7.1	4790	3365	0.06	16.65	15.25	15.80	19.58	26.77	1.13	4.23	0.29
76	7.1	3470	2621	0.22	10.22	15.16	14.15	18.96	18.44	3.16	2.67	-1.01
77	7.9	2870	2536	0.13	20.87	6.15	8.00	12.48	19.79	2.70	7.85	0.24
78	7.8	3630	2723	0.18	18.39	10.25	8.55	16.42	15.81	4.75	6.00	0.51
79	7.1	925	692	0.20	1.39	1.48	3.50	1.69	4.10	0.82	0.88	-0.32
80	7.3	812	619	0.28	2.09	2.30	4.10	2.06	5.25	1.05	1.17	2.38
81	7.9	5910	3862	0.59	24.30	14.84	17.15	37.01	14.10	6.00	6.08	-0.21
82	7.2	815	625	0.28	2.13	2.38	4.20	2.11	5.29	1.05	1.17	3.07
83	7.8	3440	2266	0.38	7.30	14.59	13.00	11.89	19.00	4.10	1.97	0.42
84	7.7	3100	2384	0.15	18.00	7.13	9.20	14.08	14.90	3.70	6.30	2.68

- **Accuracy of analysis**

Mazur in 1990 method has been used in the present study to calculate the accuracy of chemical analysis through the relative difference account (R.D) using the following equation in order to measure the validity of the results of hydrochemical analyzes.

$$R.D = (\sum C - \sum A) / (\sum C + \sum A)*10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 1$$

Where, (∑C) and (∑A) is the summation of the concentrations of cations and anion respectively. If the value of R.D is less than 5% the accuracy of the analysis is very high and if it is between 5% -10% are medium and, if it is greater than 10% it will not be relied upon in the chemical changes. When using the R.D method of analysis in the present study, it is clear that the tests are accurate and can be relied upon in analyzes in hydrochemical changes (Table 3).

- **IWQI Calculation**

The physiochemical parameters of (EC), (Na^+), (Cl^-), (HCO_3^-) and Sodium Absorption Ratio (SAR) are the most convenient parameters to the irrigation use. The sodium adsorption ratio (SAR) has been calculated based on concentration of Ca_2^{2+}, Mg^{2+}, Na^+, K^+ in milli equivalent unite using the following equation (Fipps, 2003).

$$SAR = Na^+ / [(Ca^{2+} + Mg^{2+})/ 2]^{0.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

These parameters have been selected to calculate the water quality index (IWQI) model developed by (Meireles *et al*., 2010) which is includes three steps:

1- Identify the most useful convenient parameters to the irrigation use which have mentioned in the above section.
2- A definition of quality of the parameter **(q_i)** measurement values and aggregation weights **(w_i)** which has been presented in Table 4 and Table 5.
3- Calculation of **Qi** using the following equation depending on the tolerance limits shown in Table (5) which have been planned by the "California University Committee of Consultants – UCCC" and by the criteria recognized by (Ayers and Westcot, 1999):

$$Qi = q_{imax} - [(x_{ij} - x_{inf}) * q_{iamp})/ x_{amp}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

Where q_{imax} is the maximal value of qi for the category; x_{ij} is the parameter spotted value; x_{inf} is the value that corresponding to the minimal limit of the category to each parameter belongs; q_{iamp} is the category amplitude; x_{amp} is the category ampleness to each parameter belong".

The uppermost limit x_{amp}, of the last category of each parameter, was sighted as the highest value obtained in the chemical analysis of water samples. Finally, the IWQI was calculated using the following equation:

$$IWQI = \sum_{i=1}^{n} q_i w_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

The values of weight (w_i) of the each chemical parameter used in the irrigation water quality index has been suggested by Meireles *et al*. (2010) as specified in Table (4). According to Meireles (2010), limitations to the used water classes were proposed after computing the total index value as presented in Table (6). The values of IWQI for suitability of water for irrigation categories have been divided into five categories varying from (0 to 100) and it is none dimensional parameter. The categories are divided depending on the proposed groundwater quality index that is set by the existing groundwater quality indices. It has been defined on the basis of the salinity hazard problems, soil water infiltration lowering, as well as toxicity to plants as noticed in the classifications or categorizations suggested by Bernardo (1995) and Holanda and Amorim (1997).

Table 4: Weights for the IWQI parameters according to (Meireles *et al*., 2010)

Weight (wi)	Parametre
0.211	EC
0.204	Na^{+2}
0.202	HCO_3
0.194	Cl^-
0.189	SAR
1.0	Total

Table 5: Parameter limiting values for quality measurements (qi) calculations (Ayers and Westcot, 1999)

HCO_3^-	Cl^-	Na^+	SAR $(meq/l)^{1/2}$	EC (µS/cm)	q_i
(meq/l)					
$1 \leq HCO_3 < 1.5$	$1 \leq Cl < 4$	$2 \leq Na < 3$	$2 \leq SAR < 3$	$200 \leq EC < 750$	85 – 100
$1.5 \leq HCO_3 < 4.5$	$4 \leq Cl < 7$	$3 \leq Na < 6$	$3 \leq SAR < 6$	$750 \leq EC < 1500$	60 – 85
$4.5 \leq HCO_3 < 8.5$	$7 \leq Cl < 10$	$6 \leq Na < 9$	$6 \leq SAR < 12$	$1500 \leq EC < 3000$	35 – 60
$HCO_3 < 1$ or $HCO_3 \geq 8.5$	$1 < Cl \geq 10$	$Na < 2$ or $Na \geq 9$	$2 \leq SAR \geq 12$	$EC < 200$ or $EC \geq 3000$	0 – 35

Table 6: Water Quality Index Characteristics (Meireles *et al*., 2010)

Recommendation: Plant	Recommendation: Soil	Water use restrictions	IWQI
No toxicity risk for most plants	May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability	No restriction (NR)	85 – 100
Avoid salt sensitive plants	Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay	Low restriction (LR)	70 – 85
Plants with moderate tolerance to salts may be grown	May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts	Moderate restriction (MR)	55 – 70
Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and HCO_3 values	May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS cm^{-1} and SAR above 7.0	High restriction (HR)	40 – 55
Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and HCO_3	Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation	Severe restriction (SR)	0 – 40

RESULT AND DISCUSSION

Establishing water quality database has been carried out in the present study using 84 groundwater samples from the study area. The database which has been created includes measurement of chemical parameters such as pH, TDS, EC, Ca_2^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^- and SAR as presented in Table (2). It has been observed that the predominant cation trend in the study area is $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ and predominant anions is $SO_4^{2-} > Cl^- > HCO_3^-$.

- **Assessment of Irrigation Water Quality Index**

According to Ayers and westcot (1985), there are four main groups of the restrictions that are related to assess the quality of irrigation water.

1. Concentration of total soluble salts (Salinity hazard)
2. Proportion of the relative sodium to the other cations (Sodium hazard)
3. Bicarbonate and values of pH (Diverse effect)
4. Chloride and sodium toxicity

The suitability of irrigation water and the probability of plant toxicity can be defined by combinations of these materials or substances (Fipps, 2003).

– **Concentration of Total Soluble Salts (Salinity Hazard):** The spatial distribution map of measured electrical conductivity (EC) has been prepared as shown in Figure 4. It can be noted that (EC) values ranging from 625 µS/cm to 6654 µS/cm. As electrical conductivity is a good measurement of salinity hazard it can be that the agricultural fields in central and western of the study area have the best quality irrigation water. It may be concluded that the values of EC decrease with the aquifer's depth and increase with groundwater flow direction.

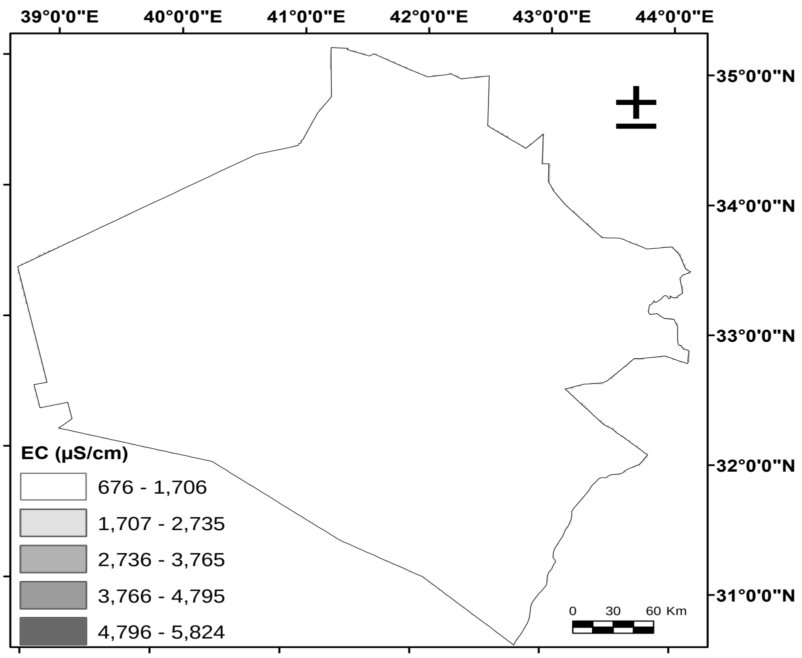

Fig.4: Spatial distribution map of (EC) in the study area

– **Proportion of the relative sodium to the other cations (Sodium Hazard):** Sodium Hazard is expressed as (SAR) Sodium Absorption Ratio which has been obtained from the equation number 2. The SAR values vary from 0.9 to 10.3 increasing from the SW to NE following the general movement of the groundwater flow direction as shown in Figure (5).

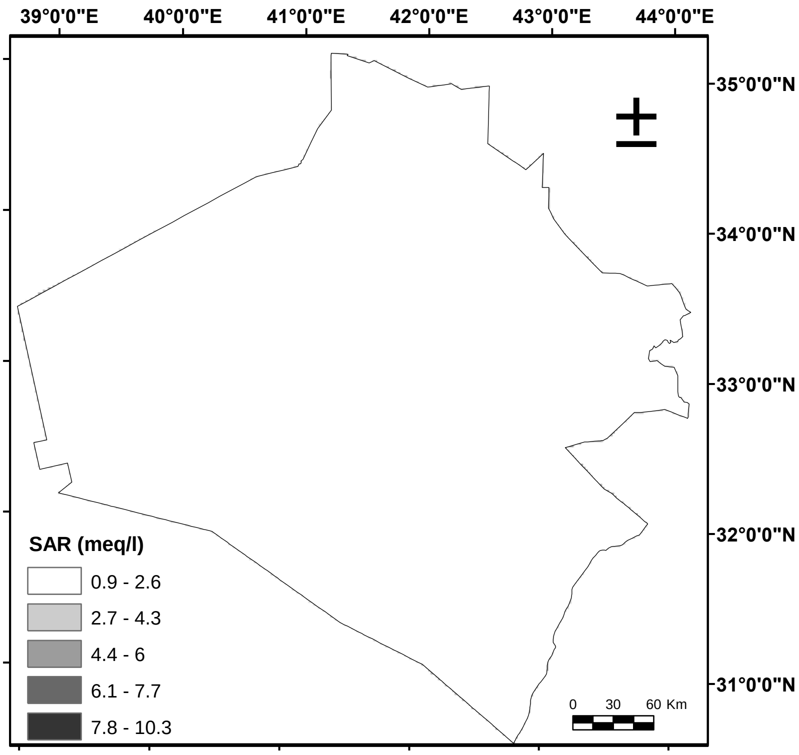

Fig.5: Spatial distribution map of the SAR value

– **Chloride and Sodium Toxicity:** Sodium and chloride ions are defining the specific ion toxicity. The Sodium (Na^+), of the spatial distributions map, shows that the concentration of Na^+ varies from 1.4 to 26.9 (meq/l), Figures (6). The other parameter defining the specific ion toxicity is chloride concentration which ranges from 1.69 to 37.01 (meq/l) in the study area. Figure 7 shows the spatial distribution map of Cl^- concentrations which are observed to be relatively high in all water samples as compared with good irrigation water quality values. It is clearly increasing from the SW to the NE following the general trend of the groundwater flow direction

– **Miscellaneous effects:** There are additional parameters that must be carefully evaluated in the water of irrigation which add to the hazards and effects discussed in the above sections. It includes the pH values of the water and bicarbonate ion concentrations which are considered within the range of the miscellaneous effects of sensitive crops. The (pH) values of the well water samples for all the sites found to range from 7.08 to 7.91 with a main of 7.3. Spatial distribution map of the (pH) values is prepared as shown in Figure (8). The optional value of (pH) for irrigation water ranges from 6.5 to 8.4 (Ayres and Westcot, 1994). Accordingly all groundwater samples are within this range.

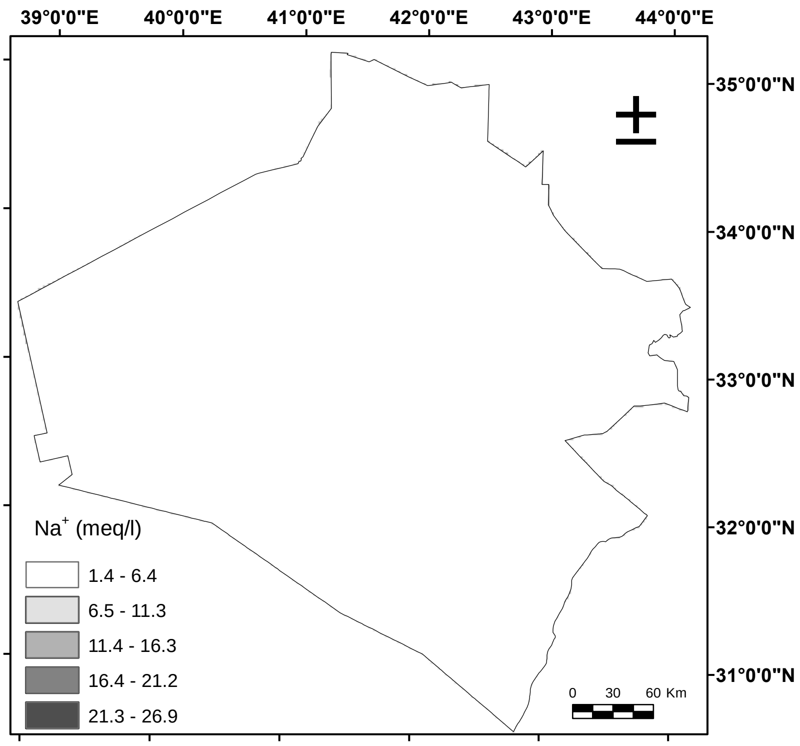

Fig.6: Spatial distribution map of the Sodium ion concentration

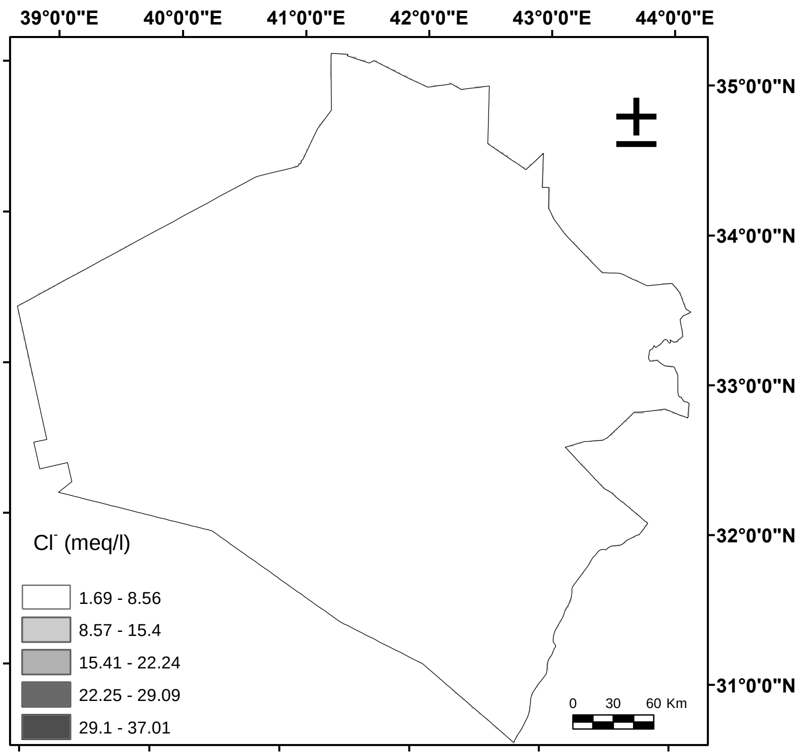

Fig.7: Spatial distribution map of the chloride ion

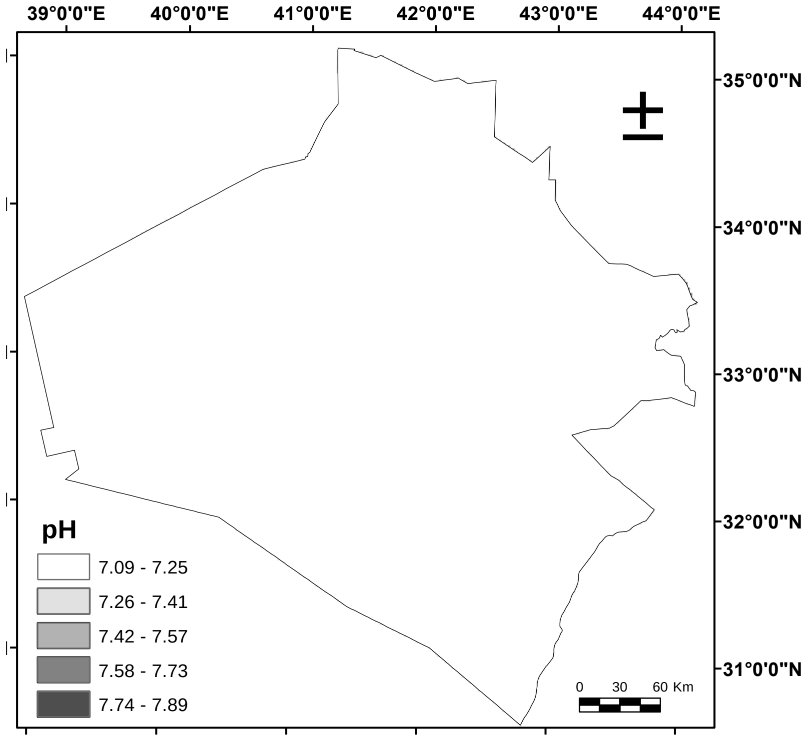

Fig.8: Spatial distribution map of the pH value

The bicarbonate ions (HCO_3^-) is responsible for charging the high (pH) values to more than 8.5 and, therefore, is the main component of alkalinity in the water (Omran and Marwa, 2015). The high level of carbonates helping magnesium and calcium ions to leave the sodium ion is dominant and form of insoluble minerals in the solution (Simsek and Gunduz, 2007). Accordingly, it is considered indirectly responsible in charge of the high concentrations of sodium and the hazard caused on the soil and irrigated crops (Spandana *et al.*, 2013). In general, the ideal bicarbonate concentration values for irrigation are less than 90 mg/l (Ayers and Westcot, 1985). Spatial distribution map of the bicarbonate concentration values has been generated as presented in Figure (9). It has been clearly observed that the concentration of bicarbonate ion is relatively low in central part of the study area and it increases towards the north-east following the general movement of the groundwater flow direction.

- **Generation of Irrigation Water Quality Index (IWQI) map**

Irrigation water quality index (IWQI) map has been produced according to IWQI values which were calculated by using equation (4). It can be considered as a general suited map for providing information and observation data visually about irrigation water in the study area represented by the spatial distribution of the index of the water quality for irrigation. As the map shows the spatial distribution of the quality of the groundwater in the study area as index values, so it is now easy for decision-makers to assess the quality of groundwater for irrigation purposes. Figure 10 shows the spatial distribution of the IWQI in the study area. It is interesting to note that the IWQI in the central part of the study area represent 50% of the groundwater samples has moderate restriction irrigation water. Small part of study area is classified as low restriction for using of irrigation water. Towards the northeast of the study area 28% of groundwater becomes highly restricted covering 39 km^2 and about 20% severely restricted for irrigation.

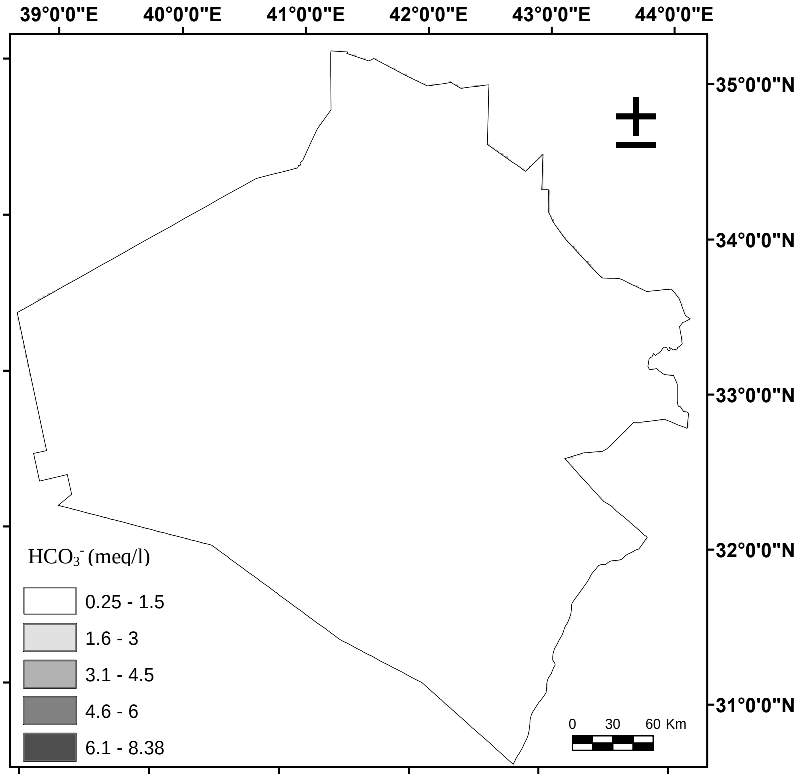

Fig.9: Spatial distribution map of the HCO_3^-

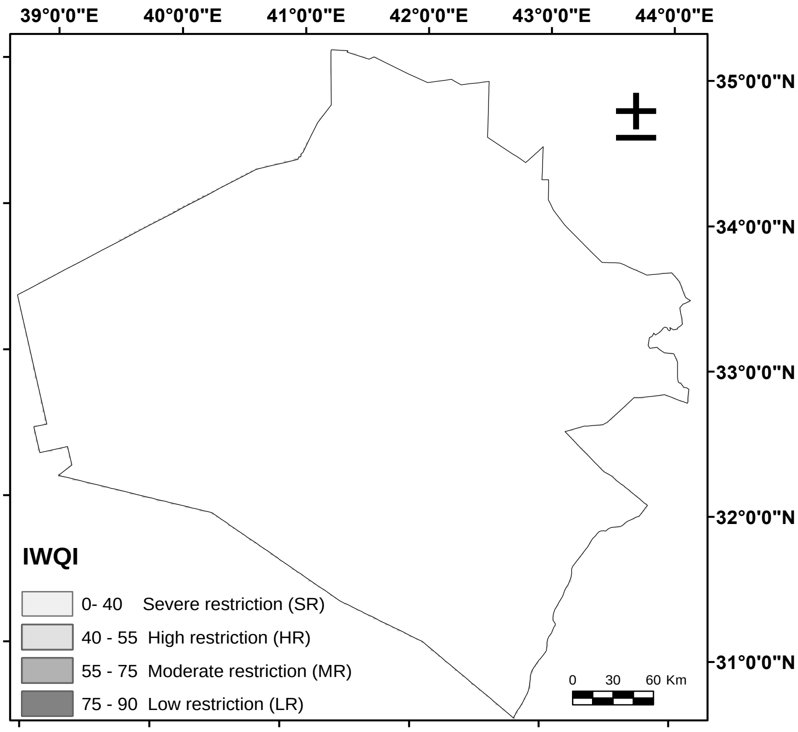

Fig.10: Irrigation water quality index (IWQI) map

CONCLUSION

It is concluded from the analysis of the irrigation water quality index map that the groundwater in the study area becomes more suitable for irrigation purposes in the central part and towards the south-west.

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