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Evaluation of Hydrochemistry of Kirkuk Irrigation Project, Kirkuk, Northern Iraq

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ABSTRACT

The irrigation project is considered one of the important projects in Iraq, as the study area is one of the important agricultural areas, which mostly depends on groundwater wells as well as surface water from the Kirkuk Irrigation Project. This study aims to estimate the irrigation project for drinking, agriculture, and irrigation purposes. (46) Water samples were collected in humid and dry seasons in (2023-2024) and analyzed; several methods and classifications were used, including comparison with Canadian standards, Piper hydrochemical facies classification, and classifications for irrigation purposes. The major and minor elements and heavy metals were analyzed. The physical properties were measured, including pH, electrical conductivity, total dissolved solids, turbidity, and total hardness. It indicates that the Piper scheme of the hydrochemical facies is calcium-magnesium-bicarbonate. The results show, according to the Canadian water quality index, that the water is poor and unsuitable for human use, and does not have an excellent water condition due to turbidity and calcium concentration, pH, and magnesium values exceeding the permissible limit according to WHO and IQS, so it is considered unsafe for drinking. The results show, according to the classifications of SAR, MH, %Na, SP, salinity hazard, and Wilcox, that the study area is generally suitable and good for irrigation and agricultural uses for most soils and agricultural crops. Analyzed Pearson's correlations in some of the studied parameters in both seasons reveals that the correlation coefficient is strong and significant positive and negative.

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التقييم الهيدروكيميائي لمشروع ري كركوك، شمالي العراق

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الملخص

يعد مشروع الري من المشاريع المهمة في العراق حيث تعد منطقة الدراسة من المناطق الزراعية المهمة والتي تعتمد في الغالب على المياه المأخوذة من الآبار الجوفية وكذلك المياه السطحية من مشروع ري كركوك. هدفت هذه الدراسة إلى تقييم المشروع لأغراض الشرب والزراعة والري. تم جمع (46) عينة مياه في الموسمين الرطب والجاف في (2023-2024) وتم تحليلها, وتم استخدام عدة طرق وتصانيف منها المقارنة مع المعايير الكندية وتصنيف بايبر للسحنات الهيدروكيميائية وعدة تصانيف لأغراض الري. تم تحليل العناصر الرئيسية والثانوية والثقيلة وتم قياس الخصائص الفيزيائية ومنها الرقم الهيدروجيني والتوصيلية الكهربائية والمواد الصلبة الذائبة الكلية والعكورة والصلابة الكلية. ويشير مخطط بايبر إلى أن السحنات الهيدروكيميائية كانت كالسيوم-مغنيسيوم-بيكربونات. وأظهرت النتائج أن مؤشر جودة المياه كان من الفئة الرديئة وغير صالحة للاستخدام البشري ولم يكن المياه في حالة ممتازة بسبب العكورة وتركيز الكالسيوم وقيم الأس الهيدروجيني والمغنيسيوم التي تجاوزت الحد المسموح بها حسب (WHO) و (IQS) والتي تعتبر غير آمنة للاستخدامات البشرية. وأظهرت النتائج حسب التصانيف SAR و MH و Na% و SP و Salinity Hazard و Wilcox أن منطقة الدراسة مناسبة بشكل عام وجيدة للري و للاستخدامات الزراعية لاغلب الترب والمحاصيل الزراعية. وتم تحليل ارتباط بيرسون في بعض المتغيرات المدروسة في كلا الموسمين وأظهر ارتباطاً إيجابياً وسلبياً قوياً وذو دلالة إحصائية.

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Introduction

Water quality depends largely on the intended uses of water for assessing water quality and the methods for comparing and analyzing results (Babiker et al., 2007). Therefore, understanding the basics of water is mainly to assess its suitability for different uses. Furthermore, it is possible to conclude the change in quality due to (water-rock) interaction (weathering) or another kind of human effect (Todd, 1980). Water pollution affects water quality, thereby threatening human health, economic development, and social welfare (Singh, 2014; Chandra et al., 2014). A hydrogeochemical study of surface water within the Kirkuk irrigation project is conducted to evaluate the main ion chemistry and water quality index for drinking and irrigation uses. For this purpose, samples from the project water were collected and analyzed for pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, total hardness (T.H.), main cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and main anions (HCO_3^-, Cl^-, NO_3^-, and SO_4) (Milovanovic, 2007). A major contribution to the development of the Water Quality Index, a model proposed by the Canadian Council of Ministers for the Environment (CCME) (Khan et al., 2003). In the current study, the quality index is relied upon, which is one of the most effective methods for assessing the environmental status of water resources (Kong et al., 2017; Ebrahimi et al., 2015). In this paper, binary correlation coefficients are used to determine the geochemical association between heavy elements and ions in different ranges for the purpose of determining the geochemical association between heavy elements, major ions (positive and negative), total dissolved solids, and pH values (Odat, 2015). This water is used in agriculture, industry, or for irrigation purposes, and measures the Kellies ratio (KR), sodium percentage (SP), and sodium adsorption ratio (SAR). The study aims to evaluate the hydrogeochemical water of the Kirkuk Irrigation Project by stating the geochemical relationships that link these elements, classifying Kirkuk Irrigation Project water according to the international standard specifications, and evaluating the suitability of the project water for drinking, agricultural, and irrigation purposes in the region.

A previous study by Al-Kilabi (2013) examined groundwater and the effect of a suitable period for irrigation on its assessment of the quality in the Al-Hawija area, Kirkuk, Iraq. It was found that the surface groundwater in the study area is not suitable for drinking, especially during the period of abstinence, but is suitable for animals to drink. Most of the pure water samples are not suitable for irrigation under normal conditions, while most of the surface water samples are suitable for irrigation. Al-Hamdani (2009) studied the relationship between groundwater and irrigation and drainage projects in the Daquq Basin, south of Kirkuk, and the sources of pollutants, their quantities, and their changes in the high-water season. He found that the water of the Daquq Basin is suitable for drinking, industry, construction, livestock and irrigation.

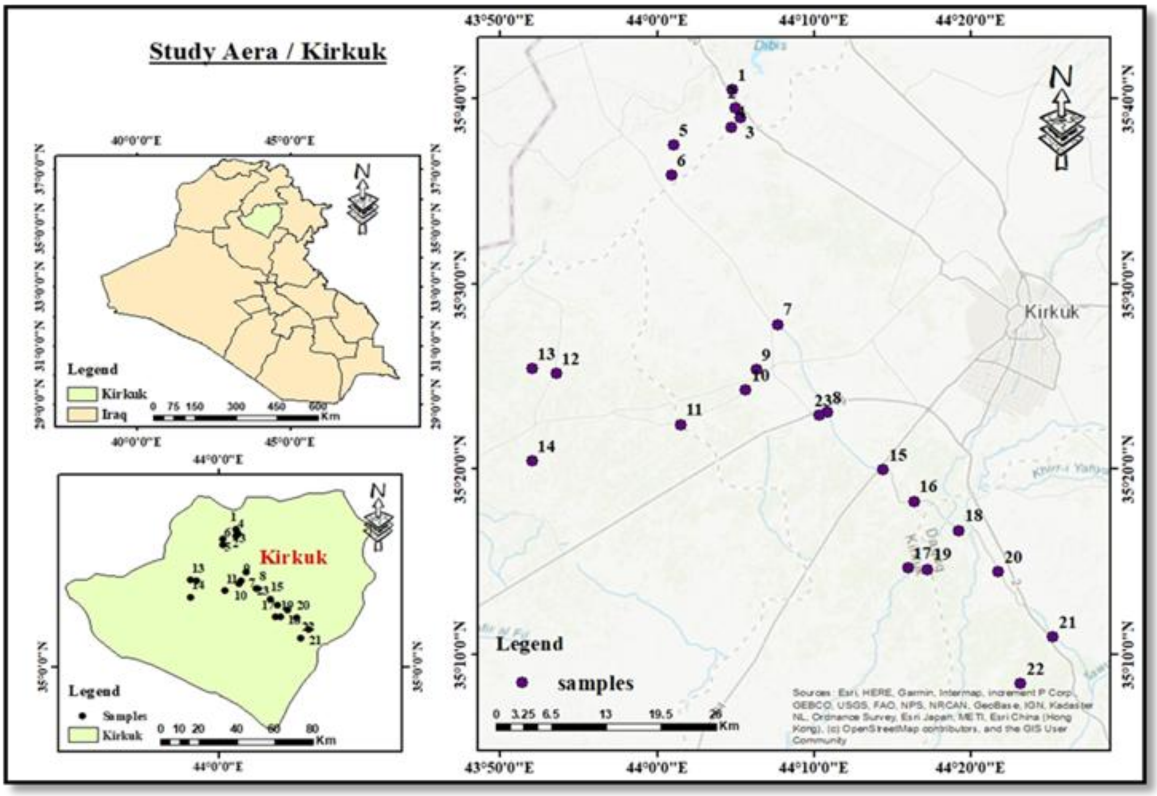

Fig. 1. Map of the Study area.

Location of the study area

The area of study is located in Kirkuk Governorate, northeastern Iraq, between latitudes (35°14’00”21-35°67’79”1) N and longitudes (43°86’41”20-44°42’09”59) E, which lies in zone (38N) in UTM (Fig. 1). The Lesser Zab River passes through northwest, in addition to some seasonal rivers such as the Khassa River, which goes along the middle of Kirkuk. The area of interest is represented by the Kirkuk Irrigation Project, which extends from northwest of Kirkuk Governorate from the Dibis Dam to the south of Kirkuk Daquq City (Fig. 2). The project is considered a part of the irrigation system in the region passing through the area of Dibis and Mulla Abdullah**,** and also passing through the area of Maktab Khalid and then to Taza and Daquq Town. It aims to improve agriculture and save water.

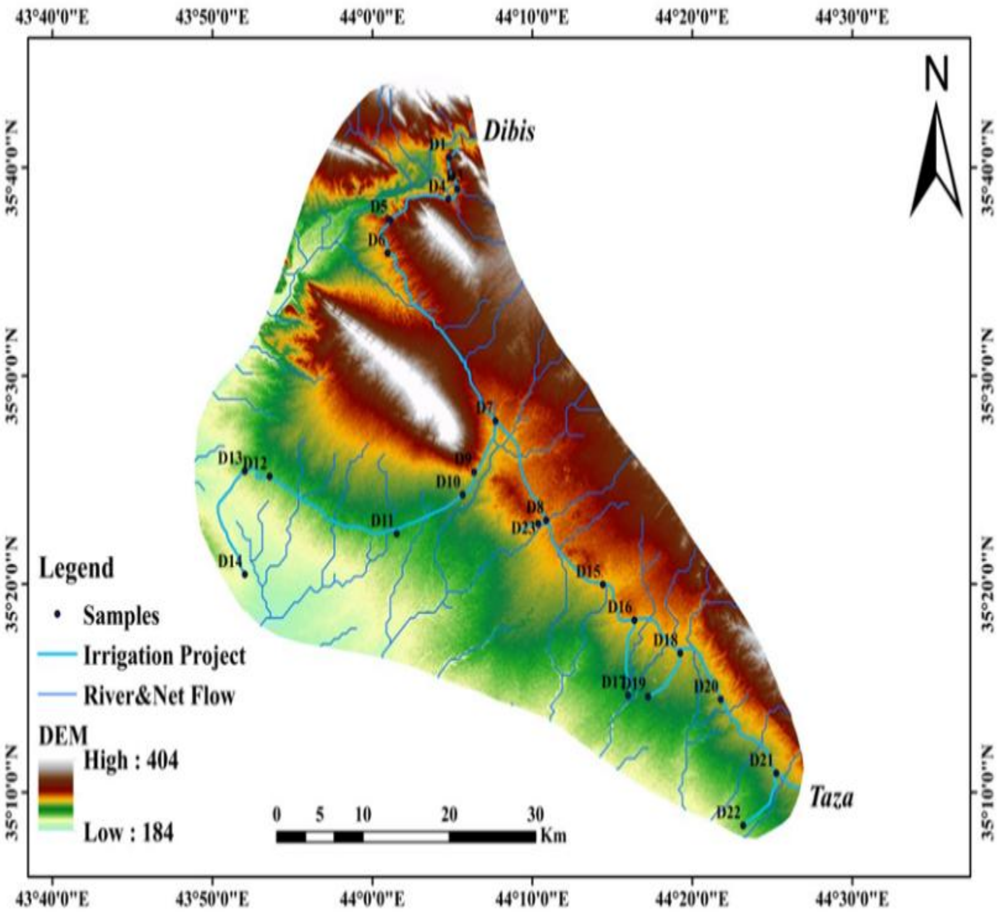

Fig. 2. Map of the DEM of the study area.

Geological and hydrogeological setting

Generally, the study area is mostly covered by Tertiary-age rock formations represented by exposed rocks of the Fatha, Injana, Muqdadiyah, and Bai Hassan formations, which are covered by Quaternary and Recent sediments. The stratigraphy is composed mainly of chemical sedimentary and clastic rocks dating back to the Cenozoic era, and these sedimentary rocks are represented by sandstone, siltstone, claystone, limestone, gypsum, and salt (Buday, 1980) of (Pliocene-Pleistocene- Middle Miocene) (Jassim and Goff, 2006). The surface of Kirkuk Governorate is characterized by a variety of terrain features, including hills, plateaus, and plains. Elevation varied between 212 m and 266 m (Stevanovic and Markovic, 2004). The study region is located within the unstable shelf in the low folded or foothill subzone (Makhul subzone) (Al-Kadhimi et al., 1996) (Fig. 3).

The hydrogeological water source for the project is the Lesser Zab River. Two dams were built on the Lesser Zab River, namely Dukan Dam and Dibis Dam. Dibs Dam is located 40 km north-west of Kirkuk, used to feed the Kirkuk Irrigation Canal. All the valleys in the region flow towards the Lesser Zab, while in the Taza and Daquq regions, they flow into the seasonal Khassa and Daquq rivers and from there into the Tigris River.

The described climate of the study area is a Mediterranean climate (Soran, 2008), as it is hot and dry in summer and cold and humid in winter. By monitoring the climate information of Kirkuk Governorate for the period between (1992-2022), it is characterized by the amount of precipitation falling at a rate in January (64.3mm) annually, and at a temperature in July (43.9 Cº) and a minimum in January (5.2 Cº), and at an annual rate of evaporation in July (427.3 mm) (Meteorological Authority - Kirkuk Station data) (Table 1).

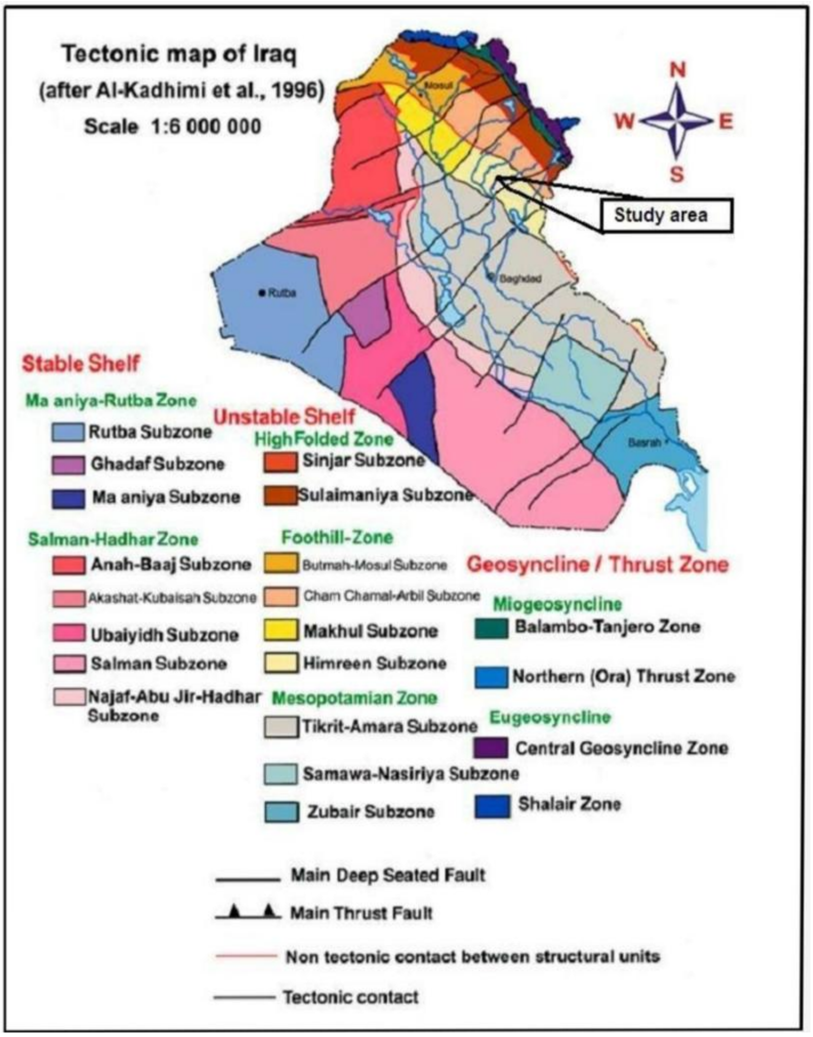

Fig. 3. Tectonic Map of Iraq (after Al-Kadhimi et al., 1996).

Table 1: Monthly and annual mean of climate elements from (1992-2022), Directorate of Meteorological - Kirkuk Station.

Months	Temperature (C°)	Rainfall (mm)	Evaporation (mm)
October	33.8	13.3	219.9
November	23	44.5	106
December	16.8	51.5	64.9
January	14.5	64.3	65.1
February	16.7	51.3	78.13
March	21	47.6	124.2
April	27.3	35.7	182.8
May	34.6	13.4	278.1
June	40.8	0.1	374.7
July	43.9	0.3	427.3
August	43.7	0	410.9
September	38.7	0.7	315.3
Mean	29.4	26.6	220.6

Materials and Methods

Sampling

The fieldwork included collecting water samples at the humid season from the Kirkuk Irrigation Project in December (2023) and the dry season in May (2024). Samples were collected from different places along the Kirkuk Irrigation Project for the purpose of conducting chemical and physical analyses to determine their suitability for their purpose, while the element concentrations were analyzed in the laboratory in Kirkuk, Iraq, and the heavy element and trace elements were analyzed by ICP-MS in the University Lab of Ankara, Turkey. The accuracy results indicate that there is a great convergence between the measured results and those of the analytical accuracy (Table 2).

Table 2: Analytical accuracy as a comparison between certified and measured concentration.

Elements (ppb)	Certified Concentration µg/l	Measurement Concentration µg/l
Al (ppb)	52	**50.3**
As (ppb)	26.67	**25.91**
B (ppb)	301.1	**300.6**
Cu (ppb)	85.2	**87.3**
Co (ppb)	20.28	**21.2**
Cr (ppb)	38.6	**37.7**
Fe (ppb)	34.3	**31.2**
Mn (ppb)	121.5	**119.6**
Ni (ppb)	27.4	**28.1**
Pb (ppb)	27.89	**28.8**

Water Quality Index (WQI) Calculation

It is calculated using the Canadian Council of Ministers for the Environment Water Quality Index (CCME-WQI, 2001) method along the Kirkuk Irrigation Project for assessment of the water quality for human drinking compared with Iraqi Standards (2009). The method is calculated through three factors: range F1, frequency F2, and amplitude F3. The equations are calculated through the following coefficients:

Factor 1, Scope, where, F1= Number of Failed Variables/Total Number of Variables x100 …1

Factor 2, Frequency, where, F2= Number of Failed Tests/Total Number of Tests × 100 …. 2

Factor 3, Amplitude:

Step 1 where, Excursions = (Failed Test /Value Objective)-1 ….3

Excursion = (Value Objective /Failed Test)-1 ….4

Step 2 where NSE= ∑Excursion /Total Number of Tests …5

F3= NSE /0.01NSE + 0.01 f, where, CCME WQI = 100- [√F1+F2 + F3/ 1.732] …6

The CCME WQI categorization scheme is given in Table 3 for aquatic.

Table 3: Classification of water quality according to CWQI (2001).

Values	Water type
95-100	Excellent
80-94	Good
65-79	Fair
45-64	Marginal
0-44	Poor

Suitability of water for Irrigation purposes

To evaluate the suitability of water for irrigation and agriculture, the calculated indicators are: SAR, MH, salinity hazard, SP, KR, and Wilcox. The spatial distribution of various CWQls was carried out effectively to find water components suitable for human purposes and improve water quality (Abbas and Hassan, 2018). These indices are:

***Sodium Percentage* (Na%),** where all concentrations are expressed in meq/l and can be determined using the following formula of Todd (1995):

$$Na\% = rNa + rK / (rCa + rMg + rNa + rK) \times 100 \quad …..7$$

***Kelley ratio* (KR),** by which irrigation is evaluated following Kelley's (1940) measured level of sodium versus calcium-magnesium. All concentrations are expressed in meq/l determined using the following formula:

$$KR = Na+/(Ca^{+2} + Mg^{+2}) \quad …. 8$$

SAR Sodium Absorption Ratio ***(SAR),*** The sodium absorption ratio is used to evaluate whether it is suitable for irrigation. It is expressed in meq/l and is calculated using the formula shown below (Raghunath, 1987):

$$SAR = Na/(\sqrt[2]{\boldsymbol{Ca+Mg/2}}) \qquad .....9$$

Magnesium hazard ***(MH),*** by detecting Mg over Ca. used to determine whether project water is suitable for purposes (Raghunath, 1987). Magnesium hazard expressed as meq/l is calculated using the following formula:

$$MH = [Mg^{+2}/(Ca^{+2} + Mg^{+2})] \times 100 \qquad ..... 10$$

Results and discussion

Canadian Water Quality Index (CWQI)

It is noted that there is a variation in values between the average global quality index for the winter season, range of '62.61', and that in the summer season, '58.14' (Table 3). It is noted in the wet season that it falls into the third category 'Fair' and the dry season in the fourth category 'Marginal' according to the classification of CCME WQI (2001). As for the values of the remaining sites, they mostly fell between 'Fair, Marginal, and Poor' (Table 4) due to turbidity exceeding the permissible limit, increasing the pH to alkalinity, and high Ca values above the permissible limit. In the wet season, site W17 is within the 'Good' category.

During the dry season, in the final result, it is found through the index that the quality assessment is unsuitable and poor water with high risks for human use and drinking due to the presence of pollutant concentrations in the sites within the water project. The good category also needs simple treatment, while the rest of the categories need advanced treatment, and the last category is poor, which is unacceptable (Kennish, 1992) (Fig. 4). At present, anthropogenic inputs of pollutants have exceeded natural inputs. Turbidity in water results from suspended particles such as clay, silt, fine organic matter, plankton, and other microorganisms (Charles, 1970). When the water is clear, it refers to turbidity. Increased turbidity is indicative of most human activities occurring in the Irrigation project (WRC, 2003).

Table 4: Measurement value of CCME WQI in wet and dry seasons.

Sample No.	F1	F2	NSE	F3	CWQI	Classes	Sample No.	F1	F2	NSE	F3	CWQI	Classes
W1	18.18	18.18	1.96	66.33	40.7	poor	D1	18.18	18.18	1.22	55.036	47.2288	Marginal
W2	9.09	9.09	0.91	47.69	40.97	poor	D2	18.18	18.18	3.2	76.1904	35.015	poor
W3	18.18	18.18	0.09	9.15	73.71	Fair	D3	18.18	18.18	2.49	71.5787	37.6776	poor
W4	18.18	18.18	0.12	11	72.65	Fair	D4	18.18	18.18	1.007	50.36	49.9286	Marginal
W5	18.18	18.18	0.10	9.66	73.42	Fair	D5	27.27	27.27	1.73	63.6849	31.7377	poor
W6	18.18	18.18	0.65	39.72	56.07	Marginal	D6	18.18	18.18	0.84	45.6521	52.6468	Marginal
W7	18.18	18.18	0.82	45.07	52.98	Marginal	D7	18.18	18.18	1.57	61.1945	43.6731	Poor
W8	18.18	18.18	0.58	36.92	57.68	Marginal	D8	9.09	9.09	0.0109	1.0792	88.8793	Good
W9	18.18	18.18	1.61	61.99	43.21	poor	D9	18.18	18.18	0.48	32.6756	60.139	Fair
W10	18.18	18.18	0.69	40.96	55.35	Marginal	D10	18.18	18.18	0.68	40.4762	55.6352	Marginal
W11	18.18	18.18	0.46	31.91	60.58	Fair	D11	18.18	18.18	0.15	13.4347	71.248	Fair
W12	18.18	18.18	0.40	28.87	62.33	Fair	D12	18.18	18.18	0.098	9.0183	73.7979	Fair
W13	9.09	9.09	0.21	17.82	79	Fair	D13	9.09	9.09	0.0078	0.7722	89.0565	Good
W14	18.18	18.18	1.87	65.22	41.34	poor	D14	9.09	9.09	0.0085	0.8465	89.0136	Good
W15	18.18	18.18	0.31	23.92	65.19	fair	D15	18.18	18.18	1.52	60.3174	44.1795	poor
W16	9.09	9.09	0.40	28.7	72.93	fair	D16	18.18	18.18	1.107	52.4739	48.7081	Marginal
W17	18.18	18.18	0.25	20.53	67.14	fair	D17	18.18	18.18	1.572	61.1945	43.6731	poor
W18	9.09	9.09	0.71	42	65.24	fair	D18	9.09	9.09	3.72	78.9661	43.9099	poor
W19	9.09	9.09	0.003	0.37	89.28	Good	D19	9.09	9.09	0.45	31.3448	71.4049	Fair
W20	9.09	9.09	0.27	21.47	77.1	fair	D20	9.09	9.09	0.909	47.8421	61.8799	Fair
W21	18.18	18.18	0.12	11.03	72.63	fair	D21	27.27	27.27	5.0057	83.4283	20.3385	poor

W22	18.18	18.18	0.18	15.9	69.82	fair	D22	9.09	9.09	0.001	0.1	89.4411	Good
W23	18.18	18.18	0.97	49.29	50.54	marginal	D23	9.09	9.09	0.022	2.196	88.2345	Good
Average					62.61							58.14	

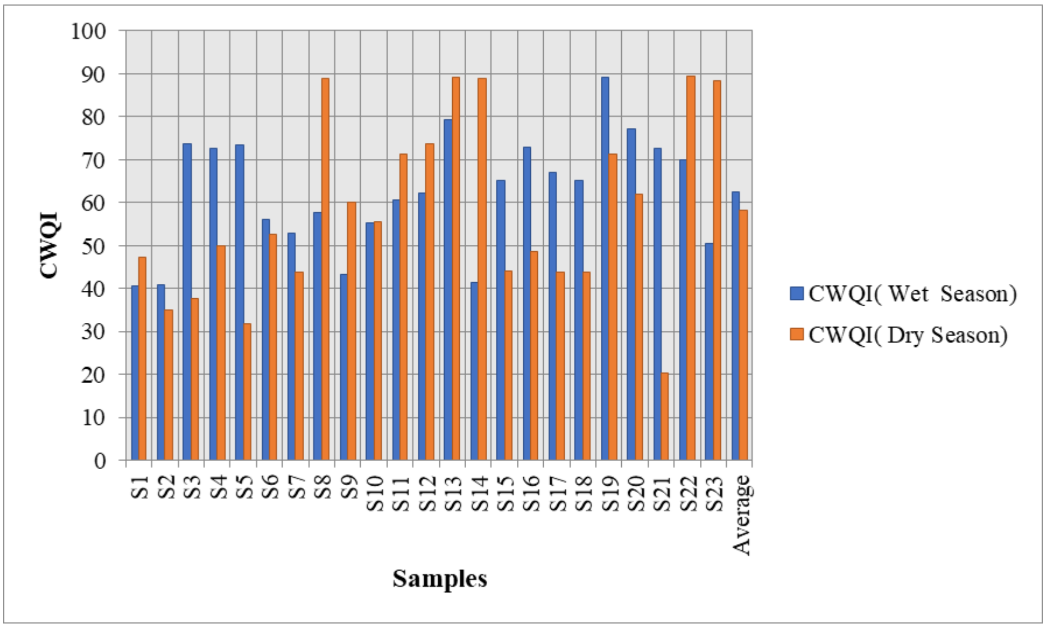

Fig. 4. CWQI for human purposes in an irrigation project.

Physicochemical Characteristics for Irrigation

Descriptive statistics of the physical and chemical parameters of river water samples, including mean, range, and standard deviation, are performed as shown in Tables 5 and 6. The average pH in the wet and dry seasons is 8.44 and 8.48, respectively, with ranges of 7.2-9.6 and 7.7-10.6, respectively. This refers to the water sample that is almost neutral to alkaline and, in some locations, is alkaline in nature. TDS is within the permissible limits for irrigation. Salts possess an effect on soil structure for plant growth as well as directly influencing it (Matthess, 1982). It is found that wet and dry period samples classified as ‘Good’ are permissible according to Don (1995), as shown in Table 9. Most of the values are higher than the permissible limit according to the IQS (2009) and WHO (2017) standards of 5 NTU. Turbidity was classified following, and it is found that they are all bad because irrigation water is affected by agricultural and human activities, pollutants, rain in the winter season, and the project is fed from the dam, so it is in a state of continuous impurity. Total hardness is one of the main parameters for determining the quality of water if we rely on the classifications of Al-Safawy et al. (2018). It is found in both seasons that it has ‘hard-very hard’ classes. The temperature in the wet season was 14.5 C° with a range between (13-16 C°). In the dry season, it was 24.21 C° with a range between 20-27°C. As shown in Figure 2 and Tables 5 and 6, it is clear that there is a variation in the temperatures, and there is no abnormal temperature recorded. Some of the major and minor elements exceed the limits of WHO (2017); some of the heavy metals (As, Cr, Pb, Ni) are also more than the standard of WHO (2017) and IQS (2009), caused by the pollution from the agriculture and industrial activities (Kadhim et al., 2018).

Table 5: Descriptive statistics in the wet season, physical-chemical parameters.

wet	PH	EC	TDS	Turb.	T.H	Ca	Mg	Na	K	HCO3	SO4	CL	NO3
N Valid	23	23	23	23	23	23	23	23	23	23	23	23	23
Mean	8.4	382.21	248.34	40.31	168.73	45.52	24.82	7.99	1.02	110.13	74	32.17	5.03
Median	8.3	381	248	36.89	170	48	19.5	8.6	1	104	82	32	4.20
Mode	8.1[a]	302[a]	196	.00[a]	170[a]	60	4.90[a]	2.90[a]	.80	97.60	78.00[a]	32	4
Std. Deviation	.505	68.47	44.470	29.48	24.88	17.20	18.63	3.49	.33	23.1	29.74	7.77	1.97
Kurtosis	1.192	2.06	2.06	1.01	1.98	-1.19	.79	-.749	.485	-.60	-1.15	.16	2.23

Std. Error of Kurtosis	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93
Range	2.40	295.00	192.	112	120	56	73.50	11.90	1.50	83	94.00	30.00	8.00
Sum	194.2	8791	5712	927.1	3881	1047	570.8	183.9	23.6	2533	1702.2	740	115.80

Table 6: Descriptive statistics in dry season, physical-chemical parameters.

	PH	EC	TDS	Turb.	T.H	Ca	Mg	Na	K	HCO3	SO4	CL	NO3
N Valid	23	23	23	23	23	23	23	23	23	23	23	23	23
Mean	8.54	920	644	70.45	208.43	50.43	19.97	12.07	.69	137.56	88.95	17.17	7.3874
Median	8.4	920	644	55	200	54	17.6	13.8	.80	138	90	18	8.8000
Mode	8.3	590[a]	413.00[a]	4.00	200	56	14.00[a]	3.00[a]	0.0	146.40[a]	78[a]	18.00	10.00
Std. Deviation	.58	203.46	142.42	72.88	30.47	12.92	7.91644	5.34	.67	38.51	30.59	2.55	3.32299
Kurtosis	6.37	-1.2	-1.2	2.07	-.55	-.45	1.756	-.66	-1.6	-.233	-.60	-.84	-.379
Std. Error of Kurtosis	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93	.93
Range	2.90	660	462.00	280	112	47	34.00	17	1.90	155.4	116	8	11.27
Sum	196.44	21160	14812.00	1620.52	4794	1160	459.50	277.7	16	3164	2046	395	169.91

Water Suitability for Agricultural Purposes

It is found that the Kirkuk irrigation project, which represents the study area, can use its water because it is suitable for growing most types of crops (Table 7).

Table 7: Suitability of using the project's water for agricultural purposes according to Ayres and Westcot (1994) classification.

Crop Department	Low salt tolerance EC(µs/cm)	Medium salt tolerance EC (µs/cm)	High salt tolerance EC(µs/cm)
Fruit crops	3000-0 Avocado, Lemon, Strawberry, Peach, Orange, Apple, Grapefruit.	4000-3000 Date, Olive, Fig.	**00010-4000 Date palm.**
Vegetable crops	4000-3000 Green beans. Celery.	10000-4000 Cucumber, Peas, Onion, Potatoes, Broccoli. Tomato, Bell pepper, Sweet corn.	**10000-12000 Spinach, Asparagus, and Garden Beet.**
Field crops	6000-4000 Field beans	10000-6000 Castor beans, Sunflower, Corn, Rice, Wheat	**16000-10000 Cotton, Sugar beet, Rape.**

Hydrochemical facies

Piper Diagram: This diagram is shown in figure (5 A-B) that the predominant waters are alkaline terrestrial with bicarbonate dominance, and a few are alkaline terrestrial with bicarbonate dominance and little sulfate. The water samples fall into the bicarbonate types in the anion triangle, while calcium-magnesium is the predominant type in the cation triangle. The order is $Ca^+ > Mg^+$, Na^+, K^+, although the anions order is $HCO_3 > SO_4$, Cl^-.

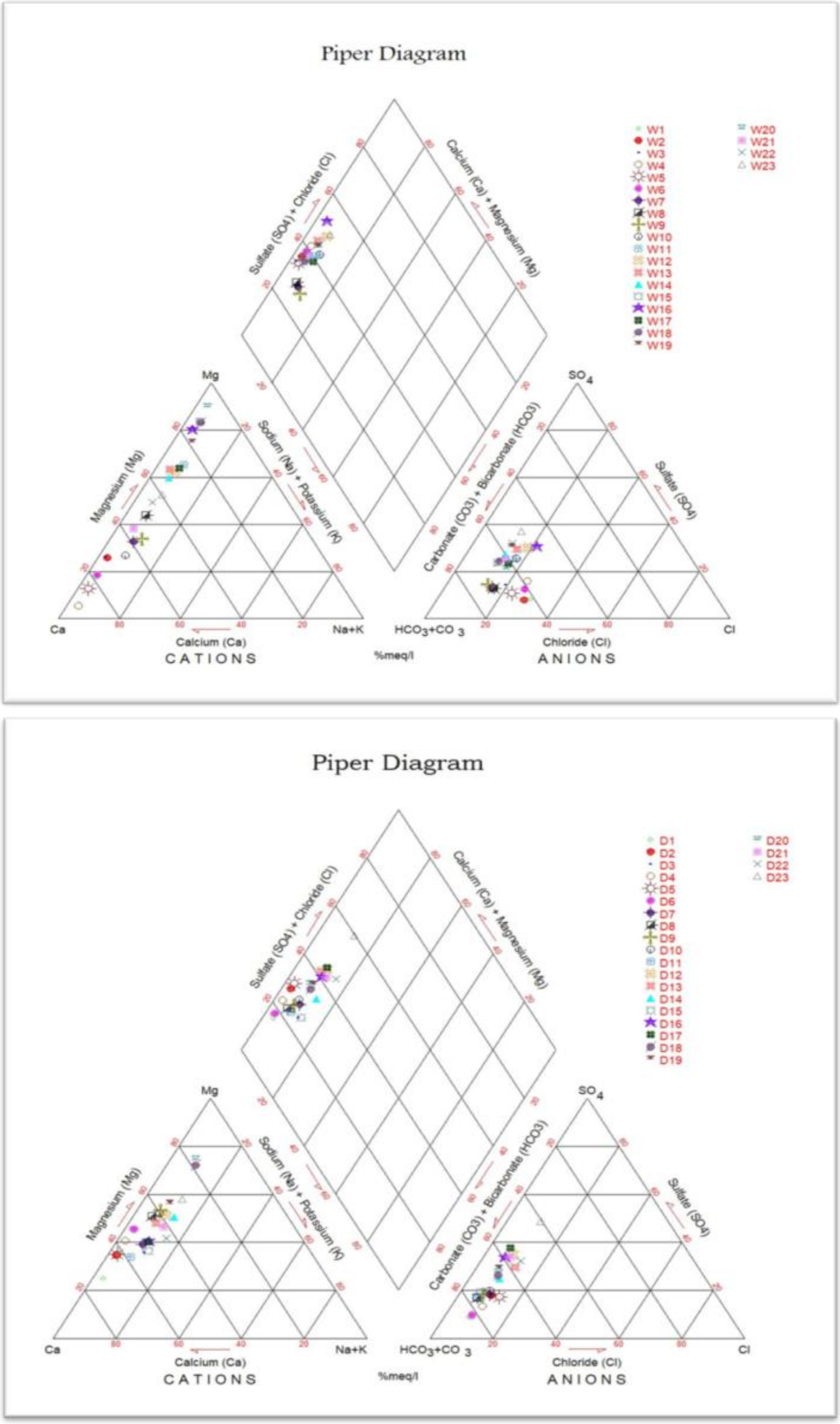

Fig. 5. Piper Diagrams, (Top) for the wet season, (Bottom) for the dry season.

Irrigation Water Quality Analysis

There are many classifications used to assess the quality of water for irrigation purposes by means of several variables (Qanam, 2003)**,** including cations, anions, electrical conductivity, total salts, pH, SAR, (Na%)**,** and SP and KR, MH (Al-Manmi, 2008), as follows:

SAR: The results in Table 8 display that all values are less than 10 and categorized as ‘excellent’ for irrigation, as listed in Table 9.

Sodium Percentage (Na%): Table 8 shows the sodium percentage values of water samples based on Don's (1995) classification. The sodium percentage was in the wet period ‘Good-Excellent’ category (Table 9). It is observed in the dry season ‘Excellent-Good’ category, then classified as having ‘good’ for irrigation.

KR: The result shows that all samples for both seasons are less than 1, and the sample sites are suitable for irrigation.

MH: It is observed that the results show a difference and variation in values; it is found that in the wet season from the site (W1-W10) were less than 50, suitable for irrigation, while the sample sites (W12-W23) show that these sites had an increase in magnesium risk values that were more than 50. As for the dry season, most of them are suitable for irrigation, ranging from (17.5-45.9), while the rest (D18, D19, D20, D23) have more than 50, which are not suitable according to the classification of Raghunath (1987) as shown in Tables (8,9). If water contains high levels of magnesium that degrade soil alkalinity, it will reduce crop productivity. Magnesium concentrations affect crops more seriously than calcium concentrations.

Table 8: Results of Irrigation parameters (wet and dry) seasons.

Sample No.	SAR	KR	SP (%)	MH	Sample No.	SAR	KR	SP%	MH
W1	0.103	0.0396	4.15	11.85	D1	0.085	0.0374	5.04	17.57
W2	0.097	0.0371	4.04	18.09	D2	0.068	0.0377	5.24	24.21
W3	0.07	0.0238	3.57	18.17	D3	0.294	0.1588	21.12	29.03
W4	0.153	0.046	4.39	3.52	D4	0.078	0.0378	6.76	29.92
W5	0.132	0.0387	4.06	8.47	D5	0.082	0.0401	6.42	25.62
W6	0.115	0.0407	3.98	12.56	D6	0.073	0.0423	8.11	35
W7	0.202	0.1023	13.73	25.16	D7	0.299	0.1714	16.55	31.43
W8	0.168	0.0981	14.12	35.14	D8	0.161	0.1161	13.94	41.77
W9	0.211	0.1518	19.92	26.94	D9	0.184	0.135	15.61	45.43
W10	0.205	0.1158	14.79	20.19	D10	0.184	0.1481	15.55	44.14
W11	0.186	0.1448	22.95	60.17	D11	0.163	0.223	13.72	26.17
W12	0.168	0.1162	21.24	55.12	D12	0.227	0.1863	22.64	44.67
W13	0.121	0.0741	17.65	54.65	D13	0.227	0.1666	18.79	40.59
W14	0.151	0.0984	17.17	51.65	D14	0.311	0.24	27.71	45.97
W15	0.091	0.0798	18.84	81	D15	0.232	0.3076	21.75	30
W16	0.082	0.0657	18.42	75.09	D16	0.243	0.2411	20.51	33.84
W17	0.161	0.1287	22.51	57.56	D17	0.245	0.2396	20.32	32.52
W18	0.086	0.089	22.63	77.17	D18	0.199	0.1565	24.57	67.03
W19	0.105	0.1083	22.74	70.79	D19	0.242	0.1607	23.29	50.15
W20	0.075	0.0719	22.12	89.91	D20	0.154	0.1197	29.06	71.87
W21	0.168	0.0752	6.68	29.25	D21	0.211	0.2261	21.86	43.21
W22	0.142	0.0906	10.34	40.15	D22	0.233	0.2226	22.89	36.85
W23	0.192	0.1187	15.46	44.55	D23	0.227	0.1471	24.09	56.23

Table 9: Irrigation parameters indices and percentage of water samples.

Parameters	Values	Water type
Na% (Wilcox 1955)	<20	Excellent
	20-40	Good
	40-6	Permissible
	60-8	Doubtful
	>80	Unsuitable
MH (Raghunath 1987)	<50	Suitable
	>50	Unsuitable
SAR	<10	Excellent
	10-8	Good
	18-26	Doubtful
	>26	Unsuitable
EC (Don 1995)	250	Excellent
	250-750	Good
	750-2000	Permissible
	2000-3000	Doubtful
	>3000	Unsuitable
KR (Killyes 1963)	<1	Good
	>1	Unsuitable

Wilcox Diagram: Surface water samples collected from both seasons assess the suitability for irrigation based on their Wilcox chart (Fig. 6, A-B).

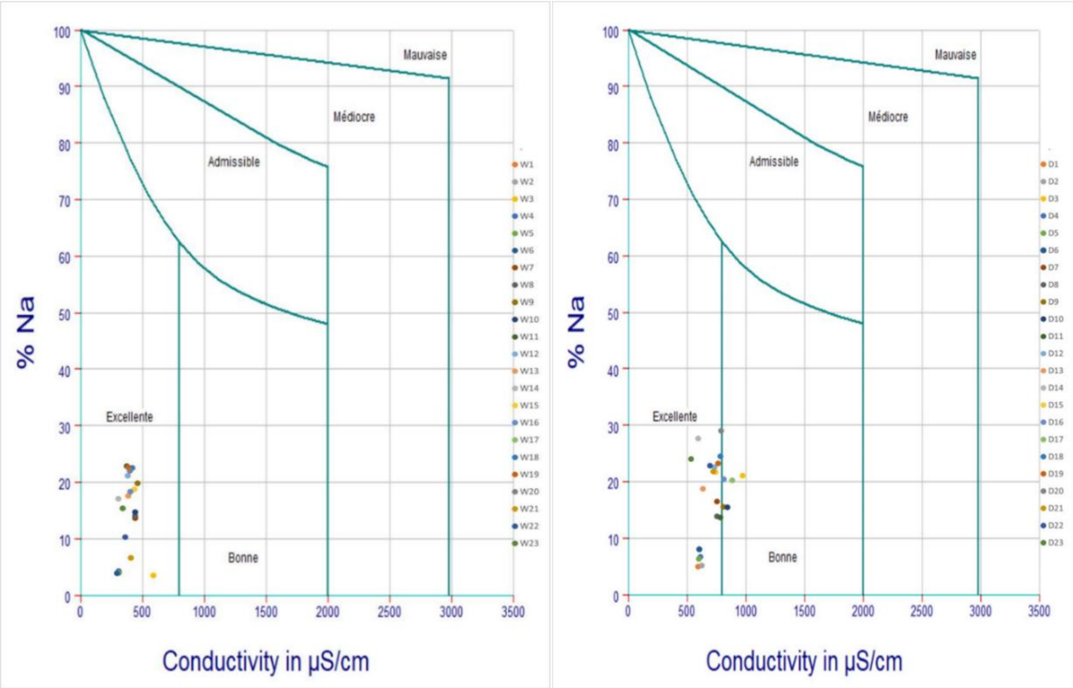

Fig. 6. Wilcox Diagrams, (Left) for the wet season, (Right) for the dry season.

Correlation Coefficient Analysis

Wet season: Fig. (7) shows strong negative correlations between Al and each of Fe (−0.614), Mn (−0.687), Fe (−0.677), and Mn (−0.635), respectively, suggesting that as Al concentration increases, Fe and Mn concentrations tend to decrease. This may suggest that higher Al levels may inhibit the presence or availability of Fe and Mn, which may impact overall water quality and ecosystem health (Hodge and Krenitsky, 2020). Boron has a strongly positive wet period correlated with sodium (0.712), potassium (0.427), HCO_3 (0.630), SO_4 (0.562), electrical conductivity (0.789), and total dissolved solids (0.791). This may be due to the presence of geochemical associations between them, or they are from the same sources. In the wet period, a strong positive correlation between chromium and iron is found. Chromium shows a strong positive correlation with iron (0.828) and manganese (0.703). A moderate positive correlation is also found between chromium and copper (0.445). This suggests a strong relationship that could reflect similar environmental or geological processes. This may indicate common sources or similar geochemical behaviors (Hubert and Wolkersdorfer, (2015).

Dry season: Iron is positively correlated strongly with manganese in wet (0.784) and in dry season (0.773); iron is moderately correlated with bicarbonate (0.459) (Table 8), Fe in the dry season with Zn (0.512), K (0.542) and HCO_3 (0.554) moderately positive; increased levels of zinc, potassium and bicarbonate are associated with higher levels of iron. Iron is negatively correlated moderately with sodium (-0.529) and negatively correlated strongly with SO_4 (-0.643) and with pH (-0.640), EC (-0.640), and TDS (-0.640). Iron solubility decreases under alkaline conditions, limiting its availability (Baker, 1987). Manganese has a moderate positive correlation with zinc (0.461). Simultaneous increases in manganese and zinc may indicate pollution or changes in agricultural land use practices that affect both minerals. Nickel and pH correlation of 0.659 reveals a strong positive relationship. Positive correlations between them suggest that these elements may originate from similar sources or be affected by similar environmental conditions. This is particularly important in agricultural runoff (Es-sahbany et al., 2019). Pb has a moderately negative correlation with zinc (-0.462). The inverse relationship may indicate competition between lead and zinc for uptake in biological systems, such as plants or aquatic organisms. High levels of lead may inhibit the uptake of zinc, which is essential for many biological functions. The negative correlation may mean that lead and zinc originated from different sources or underwent different movement processes in the environment (APHA et al., 2017). The correlation coefficient in the dry period indicates a moderate negative relationship between the other (Senthilkumar et al., 2019).

Persones Correlations (W.)

W.	Al	As	B	Cu	Co	Cr	Fe	Mn	Ni	Pb	Zn	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3	PH	EC	TDS
Al	1																					
As	-.255	1																				
B	-.389	-.042	1																			
Cu	-.223	.290	-.188	1																		
Co	-.087	.370	.404	-.047	1																	
Cr	-.343	.311	.082	.445*	.095	1																
Fe	-.614**	.343	.292	.392	.218	.828**	1															
Mn	-.687**	.213	.396	.282	.143	.703**	.784**	1														
Ni	-.283	-.002	.188	-.184	-.171	.238	.177	.269	1													
Pb	.221	.431*	-.231	-.043	.079	-.254	-.164	-.285	-.061	1												
Zn	-.386	-.266	-.070	.236	-.052	.355	.314	.461*	-.017	-.462*	1											
Ca	.146	.158	-.216	.050	.119	-.051	-.012	-.174	-.372	.205	-.070	1										
Mg	.418*	-.391	.169	-.254	-.008	-.275	-.271	-.339	-.012	-.003	-.286	-0.648	1									
Na	-.269	-.177	.712**	-.246	-.076	.045	.076	.348	.575**	-.134	-.049	-.436*	.152	1								
K	-.173	.025	.427*	-.237	.257	.295	.323	.257	.448*	-.228	-.020	-.260	.185	.271	1							
HCO3	-.268	.022	.630**	-.020	.183	.300	.459*	.329	-.265	-.244	.094	.004	.086	.308	.205	1						
SO4	-.327	-.283	.562**	-.311	.112	-.278	-.154	.214	.438*	-.213	.048	-.622**	.335	.642**	.382	-.050	1					
Cl	.125	.130	-.328	.085	.054	-.076	.037	-.271	-.455*	.270	-.069	.373	.030	-.579**	-.278	-.059	-.582**	1				
NO3	-.268	-.018	.295	-.009	-.246	-.051	.219	.110	-.274	-.073	-.034	-.195	.218	.147	.108	.602**	.137	-.040	1			
PH	.067	.019	-.006	-.200	-.262	-.051	-.303	.071	.659**	.212	-.147	-.441*	.081	.591**	.115	-.381	.463*	-.542**	-.290	1		
EC	-.324	.013	.789**	-.010	.464*	.119	.370	.394	-.340	-.195	.076	.053	.002	.294	.241	.715**	.241	-.075	.418*	-.429*	1	
TDS	-.321	.013	.791**	-.013	.466*	.117	.368	.393	-.339	-.193	.074	.050	.006	.296	.242	.714**	.244	-.077	.417*	-.427*	1.000**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Persons Correlations D.

D.	Al	As	B	Cu	Co	Cr	Fe	Mn	Ni	Pb	Zn	Ca	Mg	Na	K	HCO3	SO4	Cl	NO3	PH	EC	TDS
Al	1																					
As	-.336	1																				
B	.186	-.245	1																			
Cu	.088	.254	-.088	1																		
Co	-.132	-.231	-.094	-.070	1																	
Cr	.038	-.052	-.108	-.080	.088	1																
Fe	-.677**	.165	-.535**	-.120	.257	.053	1															
Mn	-.635**	.192	-.279	.171	.164	.052	.773**	1														
Ni	.555**	-.263	-.150	-.014	-.162	.266	-.211	-.112	1													
Pb	.201	-.127	.014	.401	.159	-.048	.069	.130	.348	1												
Zn	-.480*	.274	-.043	-.274	.208	-.211	.512*	.486*	-.454*	-.263	1											
Ca	.028	.001	-.062	.120	.185	-.060	.393	.331	.170	.390	.224	1										
Mg	-.105	.024	.048	-.151	-.127	-.036	-.224	-.072	-.002	-.305	.019	-.551**	1									
Na	.239	-.153	.175	.223	-.220	-.107	-.529**	-.249	.416*	.133	-.455*	-.184	.508*	1								
K	-.084	-.091	-.310	-.144	.281	.318	.542**	.539**	.125	-.028	.380	.520*	-.317	-.540**	1							
HCO3	-.251	.108	-.406	.155	.222	-.048	.554**	.579**	.084	.191	.306	.601**	.082	-.088	.600**	1						
SO4	.287	-.128	.498*	-.075	-.288	-.137	-.643**	-.434*	.216	-.079	-.245	-.235	.557**	.804**	-.615**	-.357	1					
Cl	-.170	.079	-.351	-.267	.164	.324	.362	.083	.058	-.192	.133	.024	.084	-.227	.329	.127	-.220	1				
NO3	-.366	.119	.052	.144	.205	-.215	.215	.226	-.394	.018	.365	.244	.298	-.048	.042	.449*	.076	.053	1			
PH	.263	-.256	.158	-.182	-.200	.195	-.483*	-.500*	-.050	-.212	-.277	-.626**	.028	.079	-.365	-.780**	.247	-.281	-.476*	1		
EC	-.010	-.071	.190	.073	-.014	-.046	-.023	.222	.373	.204	-.047	.394	.396	.657**	.032	.507*	.523*	-.002	.271	-.537**	1	
TDS	.157	-.034	.291	.077	-.302	-.200	-.640**	-.529**	-.071	-.208	-.254	-.600**	.536**	.679**	-.798**	-.569**	.787**	-.226	.068	.479*	.090	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Fig.7. Pearson's correlation of parameters of irrigation in the, (Top) for the wet Season, (Bottom) for the dry Season.

Conclusions

To assess the quality of water in the Kirkuk irrigation project for drinking purposes and irrigation, agricultural lands are assessed on several physical and chemical criteria, and analyses of heavy and trace elements. The water in the two wet and dry seasons varied between neutral, sub-alkaline, and alkaline, and it is shown that the pH is neutral in the north and gradually changed to alkaline towards the southern part, indicating that the dissolution processes were prevalent in the northern part. Most of the physical parameters are within their standard limits except for turbidity, which exceeded the permissible limit, and the pH in the southern areas of the project water is increasing towards alkalinity. Calcium is somewhat exceeded and magnesium. Fertilizers are another source of calcium, and from carbonate sedimentary rocks, it is found that all heavy elements are within the permissible limits. The Pearson correlation coefficient is used in continuous bivariate data to determine whether there are strong positive and strong negative relationships, and some are neutral positive and negative. As for drinking applications, they were not suitable. As for irrigation applications, it is generally predicted that the indicators show that they are suitable, 'excellent', and 'good' except for MH, which is found to be exceeded and became unsuitable for irrigation, as irrigation water containing high levels of magnesium leads to deterioration and reduces crop productivity. Piper and Wilcox's are suitable for irrigation in all types of soils.

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