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Ground Water Quality Evaluation with Using WQI of Selected wells in Mandali Area, Diyala Governorate, East Iraq

Reham Basim Al-Mashhadani*, Qusai Y. Al-Kubaisi
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract

Groundwater is necessary to ensure the safety of Mandali's water supply. Groundwater samples were collected from various parts of the city for this study. Two aquifers have been identified: the first is a free bed made up of Quaternary deposits. The second is the primary bed that conveys water, belonging to the Bai Hassan Formation. Nineteen groundwater samples were collected from wells and examined for physicochemical parameters in the current study during October 2021. Samples were analyzed for main cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}; anions HCO^{3-} , SO_4^{2-} , Cl^{-} and NO_3^{-}, pH, Electrical Conductivity, and Total Dissolved Solids. Results indicated that the Samples water is neutral to slightly alkaline. The TDS classifications show that the groundwater samples are classified as fresh to slightly fresh water. All water samples are severely mineralized, except sample W17 which is highly mineralized due to the water feeding from the deep aquifer of Bai Hassan formation. Dominant cation is Na+ followed by Ca^{2+}, Mg^{2+} then K^{+}, whereas dominant anion $SO4^{2-}$ followed by Cl^{-} then HCO_3^{-}. The water type of 8 samples 42% is NaCl type, seven samples 37% is $MgSO_4$ type, three samples 16% is Na_2SO_4 type, and 1 sample 5% is $CaSO_4$. The diversity in water is because the sediments of the Quaternary age derived from neighboring formations such as Fatha and other formations. According to Piper's diagram, Groundwater samples are mostly earth alkaline water with an increased amount of alkali, high sulfate and chloride. The groundwater in the study area has a wide range of WQI ranging from excellent (W17) while classified as good water (W1, W3, W4, W5, W6, W7, W8, W9, W11, W12, W13, W14, W16, W18, W19) and classified as Poor water (W2, W10, W15) because of the high values of WQI values computed.

Keywords: Ground Water , Mandali Area , water Quality , Diyala , East Iraq

تقييم جودة المياه الجوفية لآبار مختارة في منطقة مندلي ، محافظة ديالى ، شرق العراق

ريهام باسم المشهداني* ، قصي ياسين الكبيسي
قسم علم الارض ، كلية العلوم ، جامعة بغداد ، العراق

الخلاصة

المياه الجوفية ضرورية لضمان بقاء إمدادات المياه في مندلي. لهذه الدراسة تم جمع عينات المياه الجوفية من أجزاء مختلفة من المدينة. تم تحديد خزانين للمياه الجوفية: الأول عبارة عن طبقة مكونة من الرواسب الرباعية ، بينما الثانية هي الطبقة الرئيسية التي تنقل المياه وتنتمي إلى تكوين باي حسن. تم جمع تسعة عشر

*Email: reham16994@gmail.com

عينة من المياه الجوفية من الآبار وفحصها لمعرفة المعلمات الفيزيائية والكيميائية في الدراسة الحالية خلال أكتوبر 2021. تم تحليل العينات لتحديد تركيزات الكاتيونات الرئيسية Ca^{2+} و Mg^{2+} و Na^{+} و K^{+} والأنيونات HCO_3^{-} و SO_4^{2-} و Cl^{-} و NO^{3-} بالإضافة إلى فحص الخواص الفيزيائية والكيميائية المتمثلة في رقم الهيدروجين ، والتوصيل الكهربائي ، وإجمالي المواد الصلبة الذائبة. أشارت النتائج إلى أن مياه العينات متعادلة إلى قلوية قليلاً ، وتبين تصنيفات المواد الصلبة الذائبة للمياه أن عينات المياه الجوفية تصنف على أنها مياه عذبة إلى مياه عذبة قليلاً. في منطقة الدراسة الحالية ، جميع عينات المياه عبارة عن مياه معدنية بشدة باستثناء W17 مياه معدنية عالية بسبب احتمال وجود مياه مغذية من طبقة المياه الجوفية العميقة التي يمثلها تكوين باي حسن. الكاتيون السائد هو Na^{+} يليه Ca^{2+} ، Mg^{2+}ثم K^{+} بينما الأنيون السائد SO_4^{2-} يليه Cl^{-} ثم HCO_3^{-} في منطقة الدراسة. نوع الماء (8) عينات 42٪ NaCl ، (7) عينات 37٪ نوع MgSO4 ، (3)العينات 16٪ من نوع Na2SO4 و (1) العينات 5٪من نوع CaSO4 ، هذا التنوع في الماء يرجع إلى حقيقة أن رواسب العصر الرباعي مستمدة من التكوينات المجاورة مثل الفتحة والتكوينات الأخرى. وفقًا لشكل بايبر ، فإن غالبية العينات عبارة عن ماء قلوي أرضي مع زيادة جزء من القلويات مع الكبريتات السائدة والكلوريد. المياه الجوفية في منطقة الدراسة لديها مدى واسع من WQI تتراوح بين ممتاز (W17)بينما تصنف على أنها مياه جيدة(W1 ، W3، W4، W5، W6، W7، W8، W9، W11، W12، W13، W14، W16، W18، W19)وتصنف على أنها مياه غير جيدة(W2 ، W10 ، W15) بسبب القيم العالية لقيم WQI المحسوبة.

1. Introduction

Groundwater is a vital natural water resource that serves the population for various purposes, including household, agricultural, and industrial uses, accounting for almost half of all freshwater consumed globally. [1]. groundwater is resorted to as it is an important resource for drinking, domestic use, and irrigation of crops and livestock, so managing this resource is critical to meet the increasing water demand. Natural factors such as rock type, groundwater velocity, geochemical processes, soluble salts, the quality of water recharged into aquifers, and human-induced factors, such as agricultural operations and industrialization, influence the physical and chemical properties of groundwater [2]. The study of water's hydrochemical properties can aid in determining the mechanics and type of chemical interactions that occur between water and water-bearing rocks, allowing for better and easier protection and the use of water for drinking and irrigation. [3].

Location of the study area

The study area is located east of the Diyala governorate along the Iraqi-Iranian borders. It is bordered to the south by Qazaniya district, to the north by Khanaqin district, and to the west by Baladrouz district, between the latitudes 33° 40′ 17″.34 -33° 54′ 14″.33N, longitudes 45° 24′ 55″.27 - 45° 38′ 51″.53E. The total area is expanded over about 334 km^2 with an elevation of 58 -168 m above sea level (Figure1).

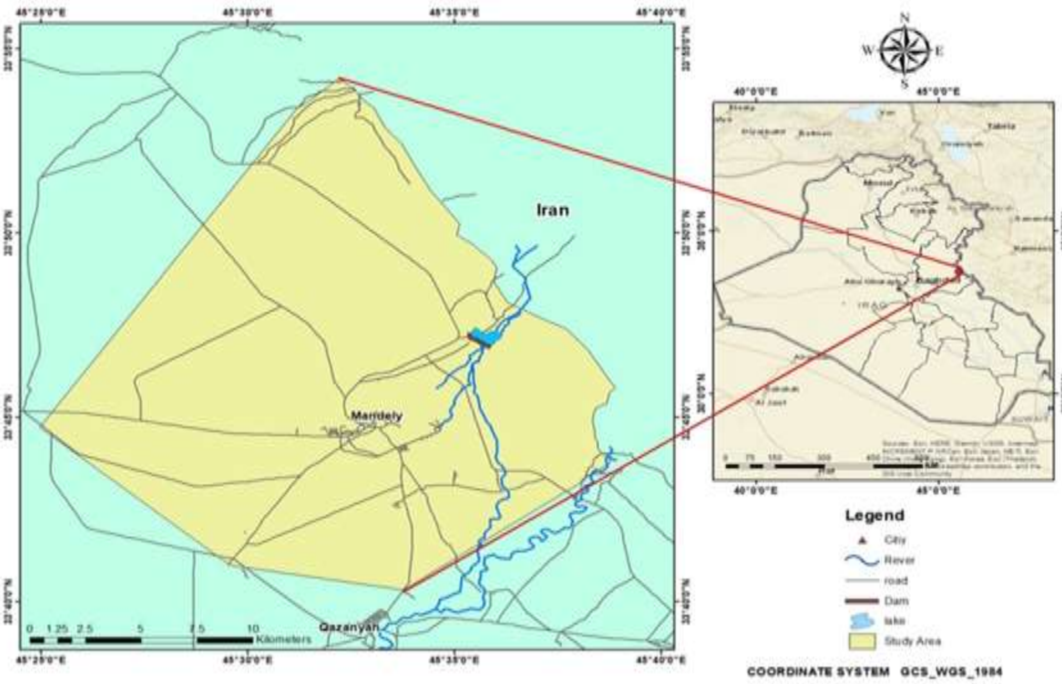

Figure 1: Location of the study area

Many studies have dealt with groundwater in the Mandali area. Buringh conducted research on soil in 1960 [4], and concluded that soils are mainly sedimentary transported from the border areas by torrential rains. The Mendelian fan was studied geophysically by [5]. The study comprised the interpretation of vertical electric survey data using the electrical specific resistance method in 58 electric points throughout the study area, which are contemporary sediments made up of variable proportions of gravel, sand, and clay that change over time in numerous areas [6] hydrochemical and hydrogeochemical studied of the deep wells, hand-dug wells and springs Mandali district [7]. They studied water balance of the basin of Mandali, eastern Iraq From the study of climate reality of the basin.
According to a study of the Mandali area's climate realities between 1994 and 2020, as well as an assessment of the climate; the yearly rate of rainfall is 248.6 mm, evaporation is 268.05 mm, the temperature is 24.4^{o}C, the relative humidity is 43.89%, the wind speed is 2.0 m/sec, sunshine is 8.3 hr/day.

The current study aims to understand the hydrochemistry parameters and water quality and evaluate groundwater wells in Mandaly for various uses.

Geological of the study area

The Quaternary and Tertiary sediments that emerge along the margin of the Hamrin mountain range cover the study region. The incompatible geological layer structures characterize the quadrilateral and Tertiary periods. It is notably prominent at the Iraqi-Iranian border, where Miocene and Pliocene sediments are represented by the Euphrates, Fatha, Injana, Mukdadiyah, and Bai Hassan formations. Quaternary sediments are represented by multiple units that differ based on geomorphological and lithological characteristics. The Pleistocene sediments represent by alluvial fans and terraces [6] (Fig.2). The studied groundwater existed within the Quaternary age.

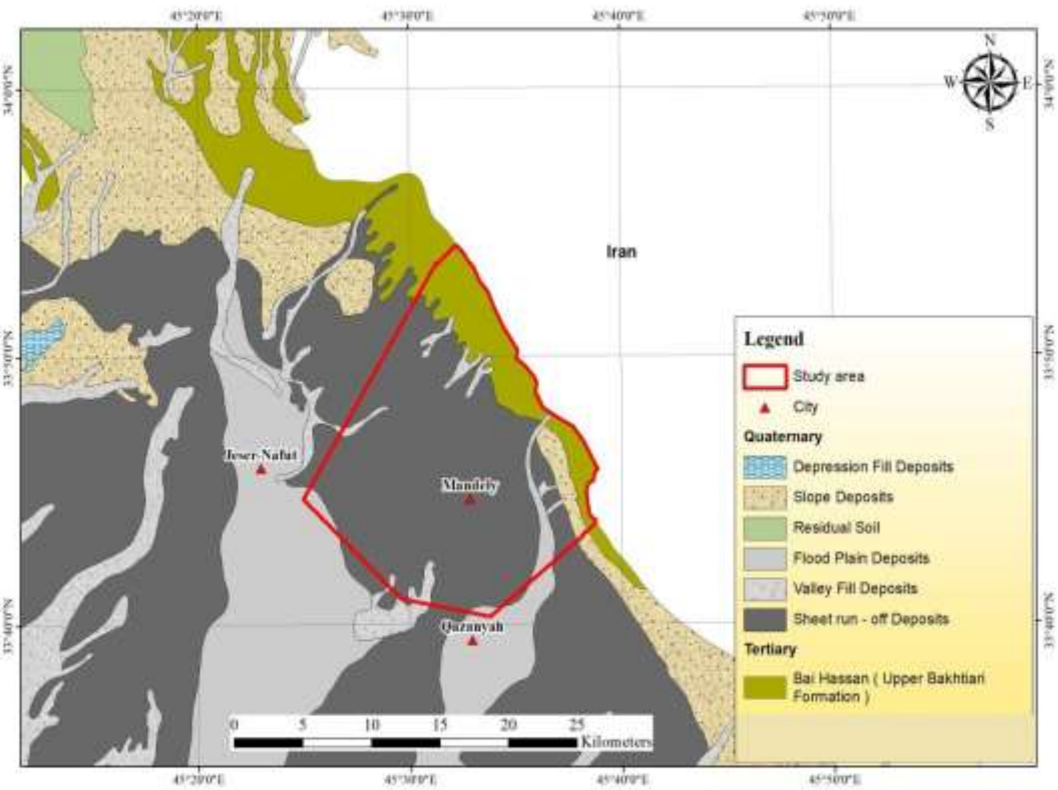

Figure 2: Geological map of the Mandali region (GEOSURV, 1996)

2. Materials and Methods

In October 2021, 19 wells were chosen to gather water samples. The positions of the samples on a handheld GPS device dropped, and the sites from where the samples were taken were picked using the GIS software ArcMap once the study area's boundaries were defined (Fig.3. The analysis is to determine the concentration of cations (K^+ , Na^+ , Mg^{2+}, Ca^{2+}) , anions (Cl^- , $SO4^{2-}$, HCO3) , minor ions ($NO3^-$) additionally to the parameters of pH, TDS and EC . Water samples were analyzed in the General Commission of Groundwater (GCGW) laboratory by devices (Table 1).

Table 1: The parameter and method used to analyzed the water samples

Parameter	Method of Analysis
EC, pH	**Field electrode meter**
Total Dissolved Solid (TDS)	**Evaporation and drying method**
Sodium (Na^+) and Potassium (K^+)	**Flame photometer**
Calcium (Ca^+), Magnesium ($Mg^{+)}$	**Titration with 0.02 N (EDTA-Na salt) using erichrome black T indicator**
Chloride Ions (Cl^-)	**Titration with 0.02N (AgNO,), using potassium dio-chromate indicator**
Sulphate (SO_4^{2-})	**Gravimetric method by using wavelength (430nm)**
Nitrate (NO_3^{2-})	**UV- Spectrophotometer by using wave length(270nm)**
Bicarbonate (HCO_3^-)	**Titration with (0.02N)H2SO and phenoephtaline indicator**

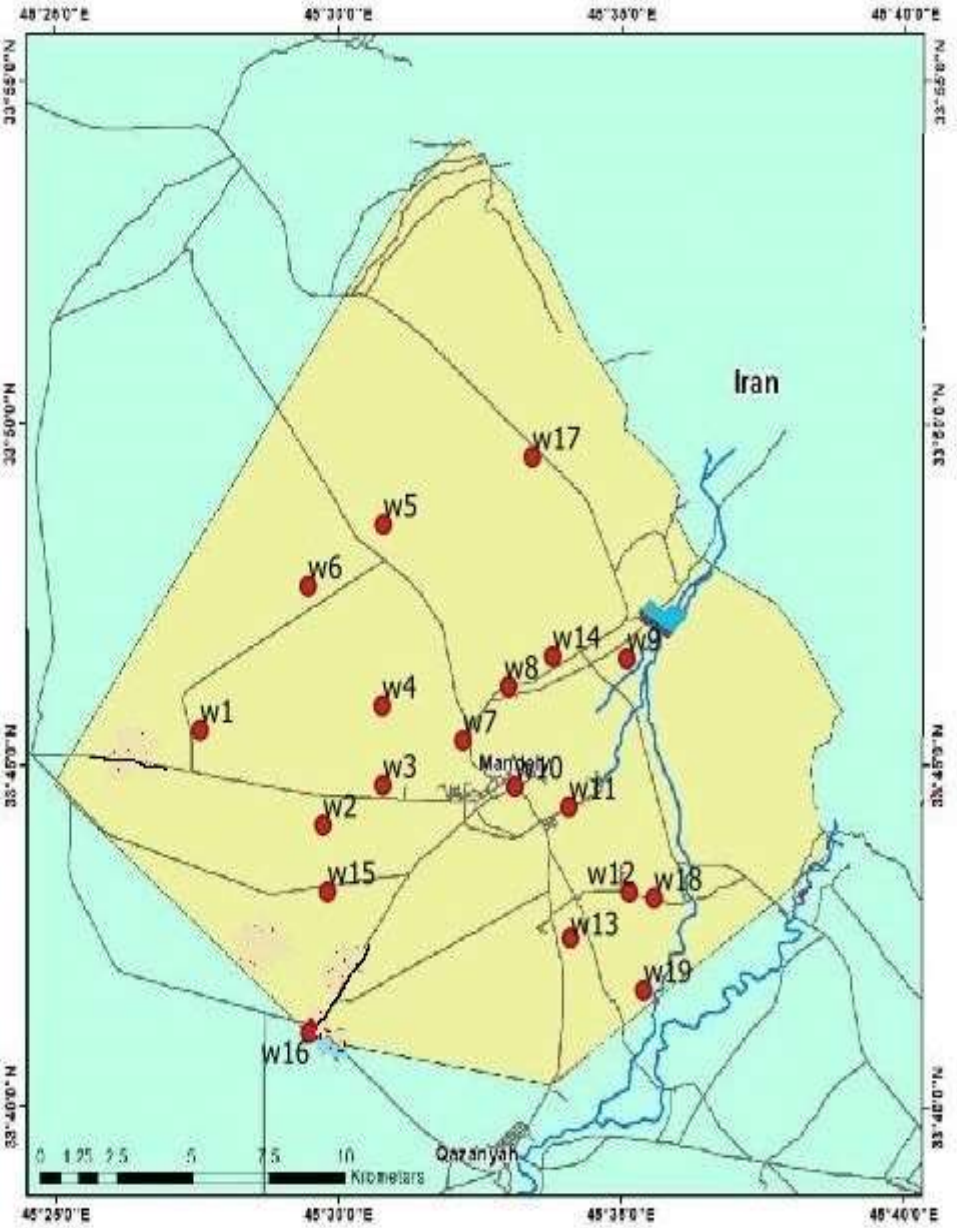

Figure 3: the locations of wells in the study area

Table 2: Physico-Chemical parameter of water sampling for the study area

NO.	depth	EC	TDS	PH	TH	Ca^{2+}		Mg^{2+}		Na^{1+}		K^{+}		Cl^{-}		SO_4^{2-}		HCO_3^{-}		NO_3^{-}
						ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	ppm	epm	
W1	80	1357	880	7.25	455.76	82	4.09	61	5	130	5.65	2	0.05	252	7.11	244	5.08	79	1.29	1.3
W2	84	2680	1732	7.18	869.05	175	8.73	105	8.60	251	10.91	5	0.12	408	11.52	525	10.93	228	3.73	1.2
W3	72	1968	1272	7.14	707.72	145	7.23	84	6.88	155	6.73	4	0.10	236	6.66	526	10.95	95	1.55	1.1
W4	78	2120	1371	7.2	767.69	141	7.03	101	8.27	149	6.47	13	0.33	274	7.74	587	12.22	89	1.45	1.4
W5	90	1305	848	7.13	441.66	78	3.89	60	4.91	127	5.52	2	0.05	249	7.03	239	4.97	76	1.24	1.3
W6	72	2070	1340	7.22	734.63	136	6.78	96	7.86	144	6.26	13	0.33	269	7.59	580	12.07	84	1.37	1.2
W7	90	2350	1522	7.14	405.09	65	3.24	59	4.83	238	10.34	5	0.12	264	7.45	318	6.62	181	2.96	1.1
W8	90	1635	1058	7.12	653.67	125	6.23	83	6.80	107	4.65	7	0.17	203	5.73	450	9.36	68	1.11	1.3
W9	90	2320	1500	7.1	658.20	140	6.98	75	6.14	243	10.56	4	0.10	240	6.77	578	12.03	205	3.36	1.4
W10	90	2560	1654	7.16	770.29	175	8.73	81	6.63	247	10.73	3	0.07	318	8.98	592	12.32	185	3.03	1.2
W11	84	2100	1359	7.13	794.14	145	7.23	105	8.60	152	6.60	12	0.30	268	7.57	578	12.03	81	1.32	1.1
W12	84	1337	868	7.19	457.38	81	4.04	62	5.08	126	5.47	2	0.05	257	7.25	251	5.22	79	1.29	1.3
W13	102	1776	1150	7.17	708.18	132	6.58	92	7.54	112	4.86	5	0.12	226	6.38	475	9.88	87	1.42	0.6
W14	60	1324	860	7.25	445.78	78	3.89	61	5	126	5.47	2	0.05	250	7.06	240	4.99	80	1.31	0.4
W15	60	2520	1626	7.16	703.57	173	8.63	66	5.40	247	10.73	9	0.23	340	9.60	562	11.70	213	3.49	0.8
W16	75	2090	1355	7.15	787.52	144	7.18	104	8.52	152	6.60	12	0.30	267	7.54	576	11.99	80	1.31	1.1
W17	150	822	540	7.28	269.01	55	2.74	32	2.62	70	3.04	4	0.10	144	4.06	180	3.74	37	0.60	1.1
W18	84	1595	1035	7.14	627.22	121	6.03	79	6.47	103	4.47	7	0.17	199	5.62	445	9.26	64	1.04	1.3
W19	72	1266	822	7.18	412.72	73	3.64	56	4.59	123	5.34	3	0.07	248	7.00	230	4.78	75	1.22	1.1

To assess and confirm the analyses' accuracy, the relative difference between the summation of cation and anion concentrations divided by the summation of the concentration in epm%, the relative difference (R.D) results illustrate the correctness of the chemical analysis [8]. The results are within the acceptable limit, as shown in Table 3.

Table 3: Accuracy of chemical analysis of the water samples

Sample No	R.D	A%	Decision
W1	4.5	95.4	Certain
W2	4.0	95.9	Certain
W3	4.4	95.5	Certain
W4	1.6	98.3	Certain
W5	4.0	95.9	Certain
W6	0.4	99.5	Certain
W7	4.2	95.7	Certain
W8	4.8	95.1	Certain
W9	3.5	96.4	Certain
W10	3.6	96.3	Certain
W11	4.1	95.8	Certain
W12	3.0	96.9	Certain
W13	3.8	96.1	Certain
W14	3.7	96.2	Certain
W15	0.4	99.5	Certain
W16	4.0	95.9	Certain
W17	0.5	99.4	Certain
W18	3.7	96.2	Certain
W19	2.3	97.6	Certain

Weighted Arithmetic Index Method (WQI) was calculated using the calculations below to determine if it is suitable for human consumption [9] :

$$WQI = \sum QiWi / \sum Wi \qquad \text{.............. (1)}$$

Where:

(Qi) The quality rating scale for each parameter is calculated by using this expression:

$$Qi = (V_i - V_0 / Si - V_0) * 100 \qquad \text{.............. (2)}$$

Where:

Vi is the oncentration of each parameter in each water sample in mg/l, V_o is the parameter's optimum value in pure water (V_0=0 except for pH =7), and Si is the Iraqi standard for drinking of each chemical parameter in mg/l according to the guidelines of the [10].

The unit weight (Wi) for each water quality parameter is calculated by using the following formula.

$$Wi = K / Si \qquad \text{.................. (3)}$$

Where, K = proportionality constant and can also be calculated by using the following equation:

$$K = \frac{1}{\sum (1/Si)} \qquad \text{..................... (4)}$$

Parameters pH, TDS, Ca^{2+}, Mg^{2+}, Na^{+}. K^{+}. Cl^{-}, $SO_4{}^{2-}$, $NO_3{}^{-}$, and TH used to calculate WQI for water samples.

Table 4: standard values and weighted arithmetic for parameters according to [10]

Chemical parameter (mg/l)	*Si* (Iraqi standard) (2009)	1/Si	K	Relative weight (*wi*)
pH	6.5-8.5	0.1176		0.410
TDS	1000	0.001		0.003
TH	500	0.002		0.006
Ca^{2+}	75	0.013		0.046
Mg^{2+}	50	0.02		0.069
Na^{+}	200	0.005		0.017
k^{+}	10	0.1		0.3489
Cl^{-}	250	0.004		0.013
SO_4^{2-}	250	0.004	3.4891	0.013
NO_3^{-}	50	0.02		0.069
Total		0.2866		$\sum = 0.994$

Hydrochemical formula and water type:

The water type of the samples was determined using the hydrochemical formula (Kurolov Formula) [11] :

$$\text{TDS (g/l)} \frac{\text{Anions epm\% descending order}}{\text{Cations epm\% descending order}} \text{pH} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

The results of the water type are shown in Table 5.

Table 5: The prevailing water type's percentage ratio in water samples

Water type	Frequency	(%)
NaCl	**8**	**42**
$MgSO_4$	**7**	**37**
Na_2SO_4	**3**	**16**
$CaSO_4$	**1**	**5**

3. Results and Discussion

The pH of groundwater samples ranged around 7.1-7.2 with an average of 7.17, indicating that the water is neutral to slightly alkalin . The EC in the groundwater samples ranged from 822 to 2680 µS/cm with an average of 1852 µS/cm. The water samples are of the type of excessively mineralized water, except sample no W17 is Highly Mineralized water because of the possibility that there is water feeds from the bottom aquifer, Bai Hassan (Table 6), according to an earlier documented link between EC and the degree of water mineralization [12]. In the studied area, the concentration values of TH in the groundwater samples ranged between 269.01and 869.05 ppm, with an average of (614.17) ppm, Groundwater is classified as very hard water. By comparing the values of TH with the classification of water hardness of [13 and 14] as shown in Table 7

Table 6: the relationship between electrical conductivity and the degree of water mineralization according to [12]

EC µS/cm	Mineralization	Sample No
<100	Very Weakly Mineralized water	
100-200	Weakly Mineralized water	
200-400	Slightly Mineralized water	
400-600	Moderately Mineralized water	
600-1000	Highly Mineralized water	W17
>1000	Excessively Mineralized water	all water samples except W17

Table 7: Water classification based on the total hardness

Type of water	Boyd (2000)	Todd (2007)
Soft	0-50	0-6
Moderate	50-150	60-120
Hard	150-300	120-180
Very Hard	>300	>180

The TDS for groundwater is of fresh to slightly freshwater type as the TDS ranged between 540 and 1732 ppm, with an average of 1193.52 ppm. The water classifications according to TDS values are shown in Table 8 [14, 15, and 16].

Table 8: Classifications of water samples depending on the TDS value

Water class	(Altoviski, 1962)	(Drever, 1997)	Todd, (2007)
Fresh water	0 - 1000	< 1000	10 – 1000
Slightly fresh water	1000 – 3000	1000 - 2000	-------
Slightly-brackish water	3000 – 10 000	2000 - 20 000	1000- 10 000
Brackish water	10 000 – 100 000	-------	10 000-100 000
Saline water	----------	35 000	-----
Brine water	> 100 000	> 35 000	> 100 000
All units are ppm			

The use of a previously published diagram was used to arrive at this conclusion [17], All of the water samples were classified as class (e), which denotes earth alkaline water with a high alkaline content and a high sulfate and chloride content except W7 in class (g) where alkaline water with prevailing sulfate and chloride Figure (4).

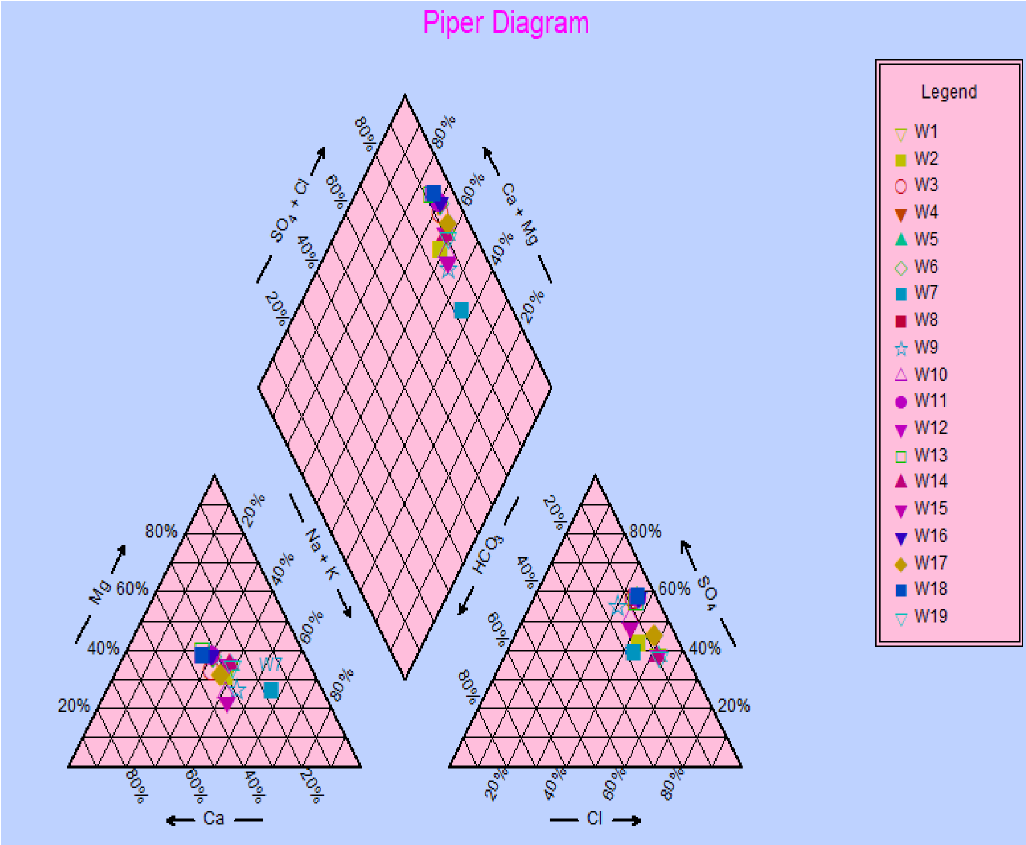

Figure 4: Piper diagram of the water samples in the study area

Table 9: Hydrochemical formula for samples in the study area

Well No.	Hydrochemical formula	Water type
W-1	TDS (880) $\frac{Cl_{(52.75)}\ SO_{4(37.64)}\ HCO_{3(9.59)}}{Na_{(38.20)}\ Mg_{(33.79)}\ Ca_{(27.65)}\ K_{(0.34)}}$ pH (7.25)	Ca-Mg- Sodium – SO_4-Chloride NaCl
W-2	TDS (1732) $\frac{Cl_{(44.0)}\ SO_{4(41.72)}\ HCO_{3(14.26)}}{Na_{(38.45)}\ Ca_{(30.77)}\ Mg_{(30.32)}\ K_{(0.45)}}$ pH (7.18)	Mg-Ca- Sodium – HCO_3-SO_4-Chloride NaCl
W-3	TDS (1272) $\frac{SO_{4(57.11)}\ Cl_{(34.76)}\ HCO_{3(8.12)}}{Ca_{(34.51)}\ Mg_{(32.8)}\ Na_{(32.14)}\ K_{(0.48)}}$ pH (7.14)	Na-Mg-calcium –Cl-Sulphate $CaSO_4$
W-4	TDS (1371) $\frac{SO_{4(57.05)}\ Cl_{(36.13)}\ HCO_{3(6.81)}}{Mg_{(37.41)}\ Ca_{(31.80)}\ Na_{(29.27)}\ K_{(1.50)}}$ pH (7.2)	Na-Ca-Magnesium – Cl-Sulphate $MgSO_4$
W-5	TDS (848) $\frac{Cl_{(53.06)}\ SO_{4(37.53)}\ HCO_{3(9.3)}}{Na_{(38.39)}\ Mg_{(34.19)}\ Ca_{(27.06)}\ K_{(0.35)}}$ pH (7.13)	Ca-Mg-Sodium –SO_4-Chloride NaCl
W-6	TDS (1340) $\frac{SO_{4(57.36)}\ Cl_{(36.09)}\ HCO_{3(6.5)}}{Mg_{(37.03)}\ Ca_{(31.93)}\ Na_{(29.46)}\ K_{(1.5)}}$ pH (7.22)	Na-Ca –Magnesium- Cl-Sulphate

		$MgSO_4$
W-7	TDS (1522) $\frac{Cl_{(43.76)}\ SO_{4(38.84)}\ HCO_{3(17.40)}}{Na_{(55.76)}\ Mg_{(26.06)}\ Ca_{(17.48)}\ K_{(0.6)}}$ pH (7.14)	**Ca-Mg-Sodium –HCO_3-SO_4-Chloride** **NaCl**
W-8	TDS (1058) $\frac{SO4_{(57.76)}\ Cl_{(35.35)}\ HCO_{3(6.8)}}{Mg_{(38.06)}\ Ca_{(34.90)}\ Na_{(26.03)}\ k_{(1)}}$ pH (7.12)	**Na-Ca-Magnesium –Cl-Sulphate** **MgSO4**
W-9	TDS (1500) $\frac{SO_{4(54.27)}\ Cl_{(30.57)}\ HCO_{3(15.15)}}{Na_{(44.38)}\ Ca_{(29.35)}\ Mg_{(25.82)}\ K_{(0.42)}}$ pH (7.1)	**Mg-Ca-Sodium – HCO3-Cl-Sulphate** **Na2SO4**
W-10	TDS (1654) $\frac{SO_{4(50.63)}Cl_{(36.90)}\ HCO_{3(12.45)}}{Na_{(41)}\ Ca_{(33.34)}\ Mg_{(25.35)}\ K_{(0.29)}}$ pH (7.16)	**Mg-Ca-Sodium –Cl-Sulphate** **Na2SO4**

Well No.	Hydrochemical formula	Water type
W-11	TDS (1359) $\frac{SO_{4(57.48)}\ Cl_{(36.16)}\ HCO_{3(6.34)}}{Mg_{(37.81)}\ Ca_{(31.79)}\ Na_{(29.03)}\ K_{(1.34)}}$ pH (7.13)	**Na-Ca-Magnesium –Cl -Sulphate** **MgSO4**
W-12	TDS (868) $\frac{Cl_{(52.68)}\ SO_{4(37.92)}\ HCO_{3(9.39)}}{Na_{(37.38)}\ Mg_{(34.68)}\ Ca_{(27.58)}\ K_{(0.34)}}$ pH (7.19)	**Ca-Mg-Sodium –SO_4-Chloride** **NaCl**
W-13	TDS (1150) $\frac{SO_{4(55.87)}\ Cl_{(36.06)}\ HCO_{3(8.05)}}{Mg_{(39.42)}Ca_{(34.44)}\ Na_{(25.46)}\ K_{(0.66)}}$ pH (7.17)	**Na-Ca-Magnesium –Cl-Sulphate** **$MgSO_4$**
W-14	TDS (860) $\frac{Cl_{(52.81)}\ SO_{4(37.37)}\ HCO_{3(9.80)}}{Na_{(37.98)}\ Mg_{(34.67)}\ Ca_{(26.98)}\ K_{(0.35)}}$ pH (7.25)	**Ca-Mg-Sodium – SO_4-Chloride** **NaCl**
W-15	TDS (1626) $\frac{SO_{4(47.18)}\ Cl_{(38.73)}\ HCO_{3(14.08)}}{Na_{(42.93)}\ Ca_{(34.51)}\ Mg_{(21.62)}\ K_{(0.92)}}$ pH (7.16)	**Mg-Ca-Sodium –Cl-Sulphate** **Na_2SO_4**
W-16	TDS (1355) $\frac{SO_{4(57.52)}\ Cl_{(36.18)}\ HCO_{3(6.29)}}{Mg_{(37.67)}Ca_{(31.75)}\ Na_{(29.20)}\ K_{(1.35)}}$ pH (7.15)	**Na-Ca-Magnesium –Cl-Sulphate** **$MgSO_4$**
W-17	TDS (540) $\frac{Cl_{(48.29)}\ SO_{4(44.49)}\ HCO_{3(7.20)}}{Na_{(35.74)}Ca_{(32.23)}\ Mg_{(30.81)}\ K_{(1.20)}}$ pH (7.28)	**Mg-Ca-Sodium – SO_4-Chloride** **NaCl**
W-18	TDS (1035) $\frac{SO_{4(58.14)}\ Cl_{(35.27)}\ HCO_{3(6.58)}}{Mg_{(37.71)}\ Ca_{(35.16)}\ Na_{(26.08)}\ K_{(1.04)}}$ pH (7.14)	**Na-Ca-Magnesium –Cl-Sulphate** **MgSO4**
W-19	TDS (822) $\frac{Cl_{(53.79)}\ SO_{4(36.76)}\ HCO_{3(9.44)}}{Na_{(39.15)}\ Mg_{(33.60)}\ Ca_{(26.67)}\ K_{(0.56)}}$ pH (7.18)	**Ca-Mg-Sodium – SO_4-Chloride** **NaCl**

According to the hydrochemical formula, four hydrochemical facies were identified that water type of 8 samples 42% of all samples is NaCl type, seven samples represent 37% of all samples is $MgSO_4$ type, three samples represent 16% is Na_2SO4 type and only one sample represent 5% is CaSO4 (Table 9). The WQI values are classified into five classes according to [9] (Table 10). The standard was used to assess the groundwater samples' water quality; groundwater has a wide range of WQI varying from 27.252 to 78.749. Therefore; WQI is considered to differ from good water (W1, W3, W5, W7, W9, W10, W12, W13, W14, W17, W18, and W19) to poor water (W2, W8, W11, W15, and W16) and very poor water (W4 and W6).

Table 10: Water quality classification according to the WQI values [9]

WQI value	Water quality	Sample No.
0-25	Excellent	
26-50	Good water	W1,W3,W5,W7,9.W10,W12,W13,W14,W17,W18,W19
51-75	Poor water	W2, W8, W11, W15, W16
76-100	Very poor water	W4, w6
Above 100	Unsuitable water	

4.CONCLUSIONS

This research evaluated the physicochemical parameters of groundwater in the Mandali district of Diyala Province, Eastern Iraq. The pH values show that the water samples are neutral to slightly alkaline. The TDS classifications of water show that the groundwater samples are classified as fresh to slightly fresh water. All water samples are overly mineralized except W17 is highly mineralized water due to the possibility of water coming from Bai Hassan. Dominant cation is Na^+ followed by Ca^{2+}, Mg^{2+} then K^+, whereas SO_4^{2-} is common and followed by Cl^- then HCO_3^-. Eleven samples represent 58% of the total water samples have a sulfate as a dominant anion ($MgSO_4$, Na_2SO_4, $CaSO_4$). Chloride is dominant in eight samples which represent 42% of the total samples. Eighteen samples were classified as class (e), which denotes earth alkaline water with high alkaline content and a high sulfate and chloride content and one sample (W7) was classified as class (g) in the piper diagram which denotes alkaline water with prevailing sulfate and chloride. Groundwater in the study area has a wide range of WQI ranging from good water (W1, W3, W5, W7, W9, W10, W12, W13, W14, W17, W18, W19) to poor water (W2, W8, W11, W15, W16). Samples w4 and w6 were classified as very poor water, because of the high values of WQI.

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