IRAQI BULLETIN OF GEOLOGY AND MINING (IBGM)
IRAQ GEOLOGICAL SURVEY (GEOSURV-IRAQ)

Vol.20, No.1, 2024 ***p 53 – 73***

ASSESSMENT OF GROUNDWATER IN ERBIL CENTRAL BASIN, N IRAQ

Awaz K. Rasul[1*], Rebwar N. Dara[1], Masoud H. Hamed[1], and Sangar k. Kareem[1]

[1] Department of Earth Sciences and Petroleum, College of Science, Salahaddin University, Erbil, Iraq,
[*]Correspondence e-mail: awaz.rasul@su.edu.krd (AKR)
e-mail: rebwar.dara@su.edu.krd (RND); e-mail: masoud.hamed@su.edu.krd (MHH);
e-mail: Sangeokurdish89@gmail.com (SKK)

Type of the Paper: Article
Received: 29/ 10/ 2022
Accepted: 12/ 01/ 2023

Keywords: Erbil Basin; groundwater quality assessment; hydrochemistry; Piper Diagram; Water Quality Index.

ABSTRACT

The present effort is expected to consider the groundwater quality of the Erbil Central Basin. In this study, we compared the physiochemical properties and distribution of major cations and anions in groundwater to evaluate the quality assessment as a special usage (drinking and irrigation) and identify the sources and types of water quality variation and pollution. The mean richness of major cations are $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$, whereas the major anions are $HCO_3^- > SO_4^{2-} > NO_3^- > Cl^-$. The quality of water was evaluated using SAR, sodium (%), PI, TH, MH, PS, and WQI. When the chemical and physical characteristics were compared to Iraqi and public health standards (IQS) for drinking water, it was discovered that the majority of the wells' groundwater during both periods was within the acceptable range, and suitable for all human drinking and domestic purposes except for three wells exceed the maximum permissible limit of NO_3^-, which are Newroz, Rizgari, and Birayaty, while HCO_3^- is showed a maximum in Newroz, and in Rizgari well the total hardness (TH) doesn't lie within recommended standards. The Ca and Mg^- Bicarbonate type was the predominant form for the groundwater classified for both seasons, with only one well (Zanko) being Ca- Chloride type for the dry season. The majority of ionic species originated from alkaline earth metals that originate from interactions between weak acidic anions in groundwater and soil or rock. All samples were suitable for drinking water according to the WQI, only the Zanko well had poor water during the dry season.

1. INTRODUCTION

Climate change, as well as increasing disruptions in rainfall patterns, temperature, and soil moisture, have directly impacted water availability and quality for drinking, livestock use, agriculture, and a variety of other uses (Woodward, 2019). Natural processes and anthropogenic activities dominate the groundwater chemistry mechanism (Li et al., 2019; He et al., 2020; Zhou et al., 2020). Based on the significant role that water plays in economic growth (Al-Ozeer & Al-Abadi, 2022) and the fact that groundwater is the main source of water for both domestic and agricultural usage, the quality and availability of water are important indicators of sustainable development. Many researches on the suitability of water for various uses have been undertaken recently and will continue to be carried out (Awadh, 2018; Al-Kubaisi, 2020; Al-Kubaisi et al., 2021; Al-Dabbas et al., 2020; Al-Dulaimi & Al-Kubaisi, 2022.

Erbil City has seen a surge in construction projects over the last decade as the city's population has grown, resulting in increased water demand for industry, agriculture, and domestic use. Groundwater extraction has increased as a result of population growth, industrialization, urbanization, and agricultural activities, which reduces its availability and makes it more vulnerable to contamination. Thus, the evaluation and measurement of water resource quality is an important technique in improving water resources in the region. Since 2005, Iraq has suffered from desertification, frequent drought, and deteriorating living standards in significant parts of the country. In the Iraqi Kurdistan Region, as a consequence of climate change, declining precipitation events have remarkably resulted in decreasing groundwater levels, especially in the driest parts of Erbil governorates. Groundwater levels have declined by 40 – 50 meters (and in some areas up to 100 meters). Furthermore, the region's severe drought periods worsened the situation because precipitation is the only source of recharge for the Erbil Basin. Such frightening information demonstrates the Iraqi Kurdistan region’s vulnerability to environmental threats and the urgent need to implement mitigation measures. In Erbil City, more than 30% of the water supply comes from wells, while less than 70% comes from the Greater Zab River (Mohamed & Zangana, 1990).

Jawad & Hussien (1988) evaluated the groundwater monitoring network rationalization in the Erbil Basin, one of several earlier studies on the region. Al-Tamir (2008) investigated the Erbil Basin's fluctuating groundwater quality. Bapeer (2010) evaluated Erbil Basin Destiny's major sewage channel and how it matched up with irrigation needs. Dizayee (2014) investigated the Erbil Basin's groundwater sustainability and degradation. The environmental significance of major and trace elements in the soils of specific regions in the Erbil Basin was assessed by Mohammed et al. (2013). Gardi (2017) investigated the environmental impact assessment of the Erbil dumpsite region in the West Erbil Basin. The present study focuses on the Erbil Basin's Central sub-basin. The Erbil Basin receives the most groundwater in the province of Erbil, and a significant number of wells are drilled in the region to extract groundwater; all of this provides a permanent source of water for drinking and a variety of activities (Toma, 2006). Erbil's water resources are distinguished by the presence of several rivers, streams, springs, and groundwater sources, all of which are supplied by rainfall and snow melt.

The Erbil Basin is situated between 36°08'23" and 36°16'22"N latitude and 43°52'44" and 44°12'54"E longitude and an area of around 177 Km^2. Its altitude varies from 322 to 1073 m above mean sea level (a.s.l; Figure 1). It has semi-arid climatic characteristics, with cold winters and hot, dry summers, the average annual temperature is around 21°C (Hameed, 2017). The annual rainfall in Erbil is approximately 419.2 mm (Kareem et al., 2022). Erbil Basin is separated into three sub-basins, the first is the northern sub-basin named Kapran (915 Km^2), the second is the central sub-basin (1400 Km^2), and the third is the southern sub-basin named Bashtapa (885 Km^2) (Habib et al., 1990; Majeed & Ahmad, 2002; Figure 2).

Erbil Basin is situated within the foothill zone, which is part of Iraq's stable shelf tectonic unit. Geomorphologically, the area is flat-lying with sporadic low-lying hills. The area is bounded on the NE by the Pirmam anticline and on the SW by the Kirkuk anticline. Stratigraphically, the study area is covered by Quaternary and Pleistocene sediments, which are dominated by clays, silt, and sand (Figure 3; Jassim & Goff, 2006). The Quaternary sediments include river terraces, slope sediments, polygenetic sediments, and floodplains. The Bai-Hassan Formation (Pliocene), which is dominated by thick conglomerate units alternating with claystone, siltstones, and sandstones, exposed to the east of the investigated area, near Basstowra valley, is unconformably overlain by Quaternary sediments (Hassan, 1998).

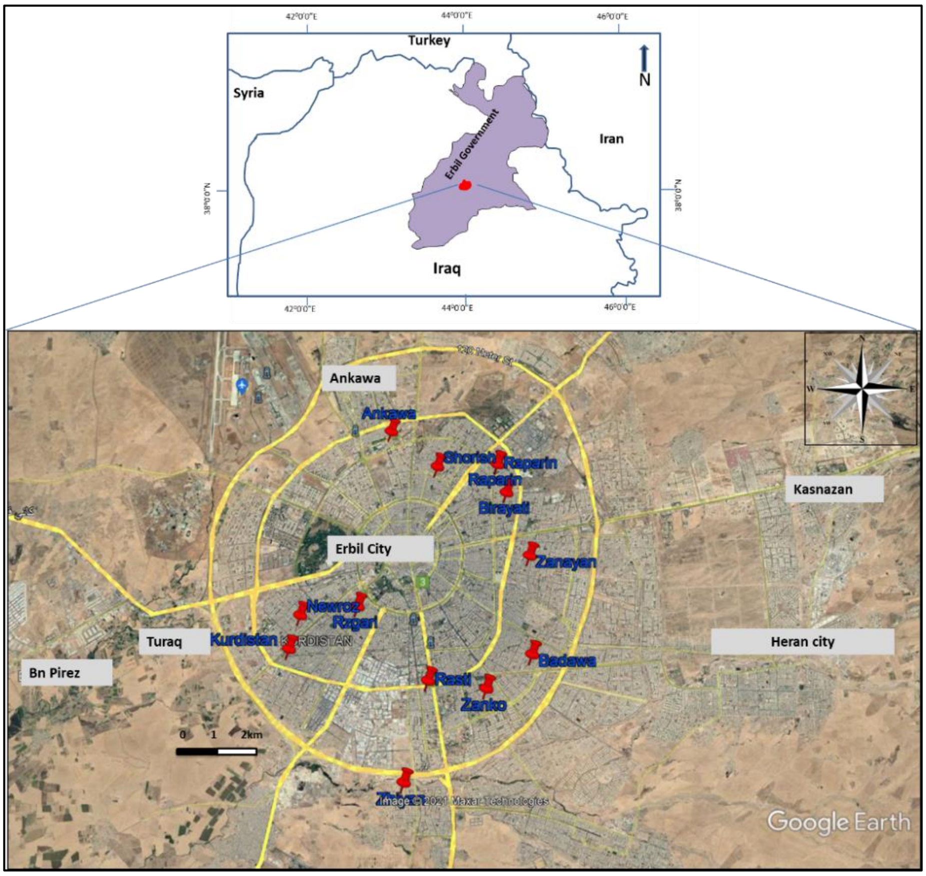


Figure 1: Google Earth map of Erbil Basin showing the studied areas and sample locations.

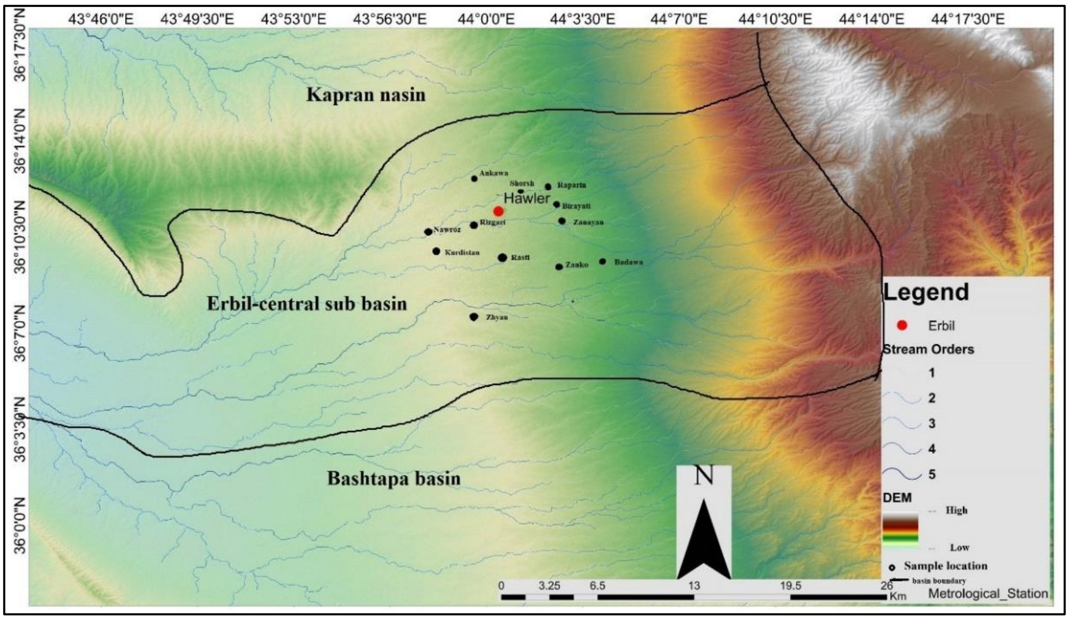


Figure 2: Erbil Basin map with the sub-basins labeled, and the locations of the wells of the study area.

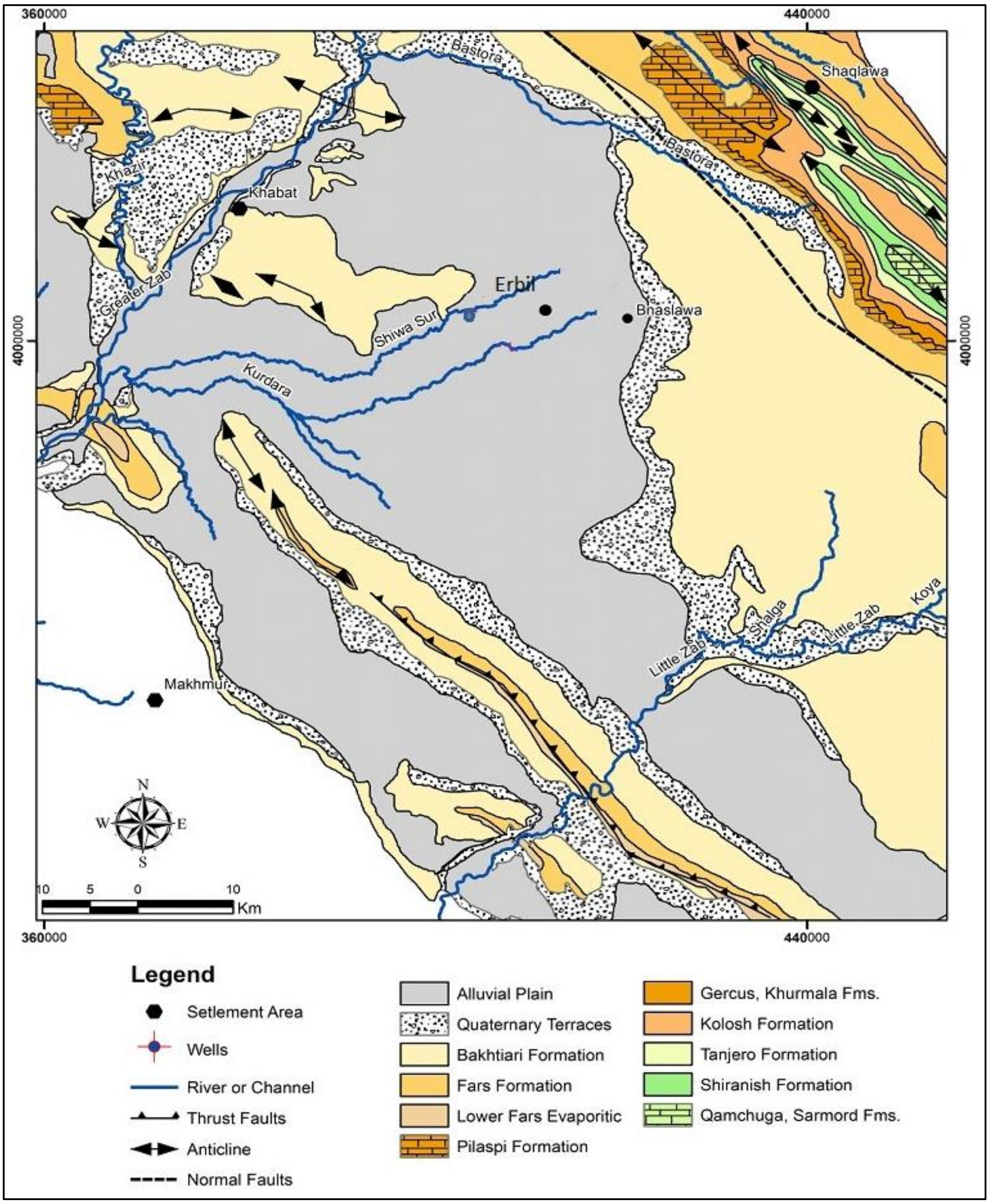


Figure 3: Geological map showing the location of the study area (Shukir, 2021).

This study is being conducted to assess the hydrochemical characteristics and formation mechanisms of the wells using descriptive and multivariate statistical methods. Several assessing methods Piper diagram, Gibbs diagram, and water quality index (WQI) are taken into account using specific purposes for drinking, agricultural purposes usages, and deduction of water-rock interactions. Major objectives of this study are grouped into the following categories: **1)** Demonstrate groundwater quality for different purposes, such as domestic and irrigation; **2)** determine WQI; **3)** determine groundwater types.

2. MATERIALS AND METHODS

2.1. Field Sampling and Laboratory Measurements

A total of twenty-four groundwater samples were collected from groundwater wells in the study area to evaluate the characteristics, quality, and assessment of groundwater (Table 1). All samples were collected for two different seasons representing pre-monsoon (wet season) in May 2020 and post-monsoon (dry season) in October 2021, taken from shallow and deep wells in the central of the basin. An ice box full of ice was used to store all collected water samples until transport to the laboratory and following water tests within 48h of sample collection. The samples collected exactly out of the well water tests are taken from the water fundamental outlet valve of the pump room. Prior to sampling, the wells were pumped for at least 10 minutes to remove stagnant water. The sample water was used to rinse each sample vial three times. All of the groundwater samples were analyzed for hydrochemical compositions in the Erbil central lab for water test and analysis, using a standard procedure of APHA (2005). Temperature (T), hydrogen ion concentration (pH), total hardness (T.H), electrical conductivity (EC), total dissolved solids (TDS), and main cations (e.g., Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), as well as significant anions (HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-), are some of the characteristics to consider. The pH, T, and EC were measured using pH meters. The measure of analytical accuracy for all samples over two periods, revealed results within acceptable limits (less than 5%) using the below equation (Baird, 2017).

$$U\% = \frac{r\Sigma \text{ cations} - r\Sigma \text{ anions}}{r\Sigma \text{ cations} + r\Sigma \text{ anions}} \times 100 \quad \ldots\ldots 1$$

$$A = 100 - U \quad \ldots\ldots 2$$

Where r is the ion concentration expressed in equivalents per million (epm) units, U is uncertainty or reaction error, and accuracy or certainty (A).

Table 1: Sampling locations in Erbil Basin.

	Coordinates		
Wells	**longitude (N)**	**Latitude (E)**	**Elevation (m)**
Zanko	36°09'11"	44º01'57"	422
Rasty	36º09'18"	44º00'54"	410
Zhiyan	36º07'51"	44º00'29"	340
Newroz	36º10'16"	43º58'33"	387
Kurdistan	36º 09'46"	43º58'22"	386
Rizgari	36º10'24"	43º59'36"	397
Badawa	36º09'41"	44º02'47"	434
Zanayan	36º11'10"	44º02'46"	431
Birayaty	36º12'09"	44º02'21"	433
Raparin	36º12'36"	44º02'11"	435
Shorish	36º12'34"	44º01'03"	421
Ankawa	36º13'08"	44º00'10"	412

2.2. Data Processing and Analysis

The statistical analysis for hydrochemical parameters was applied based on SPSS 22. The Piper diagram was created by Rockworks version 16, showing the hydrochemical type. As a result, primary assessing methodologies for groundwater quality assurance were used in this study for the following key items: SAR, Na (%), PI, TH, MH, Kelly's Ratio, PS, WQI, and all equations were shown in Table 2.

3. RESULTS

3.1. Physiochemical Parameters

In this study, T, pH, EC, and TDS were measured on-site. Groundwater samples were divided into three categories depending on their intended use: Agricultural, residential, and drinking water. They were further divided into two seasons: pre-monsoon and post-monsoon. The data of on-site measurements showed that the T was (19 – 20)°C for the wet season and (17 – 18.5)°C the for dry season. The ranges of EC were (348 – 819) μs/cm for the wet season and (400 – 1299) μs/cm for the dry season, and TDS were (250 – 532) mg/l and (260 – 844) mg/l. The results also showed that the pH is (7.2 – 7.5) the for wet and (7.1 – 7.8) the for dry season (Tables 3a and 3b). Little differences can be seen between each season, even though the Ec and TDS showed an increase in the dry season.

3.2. Distributions of Major Cations and Anions

In this study, we compare the distribution of four cations, Ca^{2+}, Mg^{2+}, Na^{+}, $K^{+,}$ and four anions, HCO_3^-, SO_4^{2-}, Cl^-, and NO_3^-, with a focus on the evaluation of groundwater quality described in the sampling period and groundwater usages. The results are shown Table 3a and 3b to be (62 – 109) mg/l during the wet season and (53 – 125) mg/l in the dry season for Ca^{2+}, also (23 – 36) mg/l and, (17.5 – 46) mg/l for Mg^{2+}, (11.5 – 32.7) mg/l and (15 – 112) mg/l for Na^{+}, and (0.6 – 1.3) mg/l and (0.9 – 3.3) mg/l for K^{+} in cation groups during wet and dry seasons respectively. Cation concentrations were somewhat higher in the dry season, according to the distribution characteristics for groundwater water utilization. And the distribution of anions, (200 – 330) mg/l and (210 – 370) mg/l for HCO_3^-, (18 – 73) mg/l and (24 – 76) mg/l for SO_4^{2-}, (18 – 49) mg/l and (11 – 200) mg/l for Cl^-, (30 – 60) mg/l and (1.6 – 60) NO_3^-, during wet and dry seasons, respectively. The results for anion groups were high in the dry season comparing the data for the wet season. All of the data of cation and anion groups are shown in Tables 3a and 3b.

3.3. Classifications of Groundwater

The characteristics of chemical and physical in groundwater represent the unique physiochemical characteristics caused by the groundwater's interaction with rock and soil while flowing in the aquifer. The aquifer represents the characteristics of different chemically composed bodies of water. As a result, such properties are referred to as groundwater hydrochemical facies. The hydrochemical facies is known to be affected by the rocks of the aquifer and the flow of groundwater, and groundwater can be classified using the Piper diagram using the distribution of cations and anions. In this study, we used the Piper diagram which is a major method for classifying groundwater to classify the samples for each sampling period and purposes of groundwater. Furthermore, the distribution of anions (Cl^-, HCO_3^-) and cations (Na^+ and Ca^{2+}) as well as the TDS value, were used to construct the Gibbs diagram to predict dominance types such as evaporation dominance, rock dominance, and precipitation dominance. Aside from the Piper diagram (Piper, 1944) and the Gibbs diagram (Gibbs, 1970), the Chadha diagram (Chadha, 1999) was used to compare the Piper diagram to see if it could be replaced and if it was well matched with the Piper diagram.

3.4. Suitability for drinking and agricultural purposes SAR, Na (%), PI, TH, MH, PS, WQI

The important hydrochemical parameters of groundwater used to determine its suitability for irrigation are EC, salinity, percent sodium (Na%), potential salinity (PS), sodium adsorption ratio (SAR), total hardness (TH), permeability index (PI), and magnesium ratio (MR). Also, the WQI can be applied to detect the acceptability of drinking water, which is very efficient since it is based on several digitally produced factors that include the influence of these variables on water quality (Awadh, 2018). As a result of applying the equations and classifications for evaluating groundwater (Table 2; 4a and 4b).

Table 2: Equations and classifications for evaluating groundwater.

Index	Equations	Value	Water Quality	References
Permeability Index (PI) (meq/l)	$PI = [(Na^+ + \sqrt{HCO_3}) / (Na^+ + Ca^{2+} + Mg^{2+})] * 100$	PI > 75%	Suitable	(Doneen, 1964)
		PI = 25 – 75%	Moderate	
		PI < 25%	Unsuitable	
Sodium Adsorption Ratio (SAR) (meq/l)	$SAR = Na^+/ \sqrt{[(Ca^{2+} + Mg^{2+})/ 2]}$	SAR < 10	Excellent	(Richards, 1954)
		SAR = 10 – 18	Good	
		SAR = 19 – 26	Doubtful/Fair Poor	
		SAR > 26	Unsuitable	
Sodium percent (Na%) (meq/l)	$Na\% = [(Na^+ + K^+)/ (Na^+ + K^+ + Ca^{2+} + Mg^{2+})] * 100$	Na% < 20	Excellent	(Wilcox, 1955)
		Na% = 20 – 40	Good	
		Na% = 40 – 60	Permissible	
		Na% = 60 – 80	Doubtful	
		Na% > 80	Unsuitable	
Magnesium Hazard (MH) (meq/l)	$MH = [Mg/ (Mg^{2+} + Ca^{2+})] * 100$	MH < 50%	Suitable	(Paliwal, 1972)
		MH > 50%	Unsuitable	
Potential Salinity (PS) (meq/l)	$PS = Cl^- + \sqrt{SO_4^{2-}}$	PS < 3.0	Excellent to good	(Doneen, 1954)
		PS = 3.0 – 5.0	Good to injurious	
		PS > 5.0	Injurious to unsatisfactory	
Total Hardness (TH) (meq/l)	$TH = 2.497\ Ca^{2+} + 4.115\ Mg^{2+}$	0 < TH ≤ 60	Soft	Todd (1980)
		61 < TH ≤ 120	Moderate	
		121 < TH ≤ 180	Hard	
		> 181	Very hard	
Water Quality Index (WQI)	$Wi = wi/ \Sigma wi$	WQI ≤50	Excellent	(Ramakrishnaiah et al., 2009)
Relative weight (Wi), the weight of each	$qi = (Ci/ Si) * 100$	WQI = 50 – 100	Good	
parameter (wi), number of parameters (n),	$SIi = Wi * qi$	WQI = 100 – 200	Poor	
quality rating (qi), the concentration of	$WQI = \Sigma SIi$	WQI = 200 – 300	Very poor	
each chemical parameter in milligrams per liter (Ci),		WQI ≥ 300	Unsuitable	
World Health Organization standard (Si), sub-index (SIi)				

Table 3a: Physical and chemical parameters analysis for 12 wells in the central Erbil Basin area during the wet season.

Well	T°C	pH	EC µs/cm	TH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-
				mg/l									
Zanko	20	7.4	162.5	249	250	62	23	22.6	1.1	245	19	20	30
Rasty	20	7.3	188.5	314	290	72	27	20.8	0.9	250	26	28	35
Zhiyan	20	7.4	536	285	348	64	23	30	1.2	252	18	27	33
Newroz	20	7.2	713	507	463	103	36	26.3	1.2	330	32	49	56
Kurdistan	20	7.5	558	360	363	90	32	32.7	1.2	290	65	32	43
Rizgari	20	7.4	819	540	532	109	36	22.6	1.3	291	55	55	60
Badawa	19	7.4	405	280	263	70	25	11.6	0.6	210	28	21	48
Zanayan	19	7.5	403	330	262	70	23	12.1	0.6	200	24	32	39
Birayaty	19	7.3	433	335	281	80	31	11.5	1.2	205	73	18	59
Raparin	20	7.5	633	420	411	95	33	18.4	0.9	290	45	35	43
Shorish	19	7.3	623	440	405	93	30	16.8	0.7	280	45	32	38
Ankawa	19	7.2	520	410	338	92	29	15.2	0.6	295	27	32	35

Table 3b: Physical and chemical parameters analysis for 12 wells in the central Erbil Basin area during the dry season.

Well	T°C	pH	EC µs/cm	TH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^-
				mg/l									
Zanko	18	7.8	1299	503	844	125	46.4	112	3.3	220	76	200	22
Rasty	18	7.7	400	271	260	67	25.2	15	0.9	250	30	18	35
Zhiyan	18	7.1	401	192	261	48	17.5	28	1	210	30	12	17
Newroz	18	7.4	525	289	341	72	26.5	23	1.3	250	70	17	18
Kurdistan	18.5	7.2	485	302	315	75	27.9	20	1	280	62	16	11
Rizgari	18	7.6	837	481	544	120	44.0	25	1.6	370	70	50	60
Badawa	17.5	7.7	408	242	265	60	22.4	18	1.3	211	32	18	40
Zanayan	17	7.6	419	214	272	53	19.8	25	1.1	212	24	15	29
Birayaty	17	7.4	458	291	298	72	27.0	12	1.4	250	74	11	1.6
Raparin	18	7.2	585	321	380	80	29.4	41	1.7	300	55	30	37
Shorish	17.5	7.7	481	280	313	70	25.5	25	1	260	73	14	2.1
Ankawa	17.5	7.1	588	276	382	59	31.2	20	1	290	26	25	30

Table 4a: The weight wi, Wi, Qi, SLi, and WQI of each chemical parameter during the wet season.

parameters	Units	WHO (2008) standard	Weight (Wi)	Relative Weight (Wi)	Mean of the observed value	quality rating (Qi)	Subindex (SIi)
pH		7.50	4.00	0.13	7.37	98.27	13.10
T.H	mg/l	200.00	2.00	0.07	373.00	186.50	12.43
E.C	µs/cm	1000.00	3.00	0.10	539.00	53.90	5.39
TDS	mg /l	500.00	3.00	0.10	351.00	70.20	7.02
Ca^{2+}	mg /l	100.00	2.00	0.07	83.00	83.00	5.53
Mg^{2+}	mg /l	30.00	2.00	0.07	29.00	96.67	6.44
Na^{2+}	mg /l	200.00	1.00	0.03	20.10	10.05	0.34
K^{+}	mg /l	10.00	1.00	0.03	0.99	9.90	0.33
HCO_3^-	mg/l	200.00	1.00	0.03	261.50	130.75	4.36
SO_4^{2-}	mg /l	250.00	4.00	0.13	38.10	15.24	2.03
Cl^-	mg /l	250.00	2.00	0.07	31.80	12.72	0.85
NO_3^-	mg /l	50.00	5.00	0.17	43.30	86.60	14.43
Sum			30	1			
WQI				72.26			

Table 4b: The weight wi, Wi, Qi, SLi, and WQI of each chemical parameter during the dry season.

parameters	Units	WHO standard	Weight (Wi)	Relative Weight (Wi)	Mean of the observed value	Quality rating (Qi)	Subindex (SIi)
pH		7.50	4.00	0.13	7.50	100.00	13.33
T.H	mg/l	200.00	2.00	0.07	305.20	152.60	10.17
E.C	µs/cm	1000.00	3.00	0.10	573.80	57.38	5.74
TDS	mg /l	500.00	3.00	0.10	373.00	74.60	7.46
Ca^{2+}	mg /l	100.00	2.00	0.07	75.08	75.08	5.01
Mg^{2+}	mg /l	30.00	2.00	0.07	28.58	95.27	6.35
Na^{2+}	mg /l	200.00	1.00	0.03	30.32	15.16	0.51
K^{+}	mg /l	10.00	1.00	0.03	1.38	13.80	0.46
HCO_3^-	mg/l	200.00	1.00	0.03	258.58	129.29	4.31
SO_4^{2-}	mg /l	250.00	4.00	0.13	51.83	20.73	2.76
Cl^-	mg /l	250.00	2.00	0.07	35.50	14.20	0.95
NO_3^-	mg /l	50.00	5.00	0.17	25.22	50.44	8.41
Sum			30.00	1.00			
WQI					65.45		

4. DISCUSSION

Groundwater hydrochemistry may be affected by one or more factors such as regional geological conditions, the chemical composition of precipitation, hydrogeological conditions, and water-rock interaction. Similarly, pesticide use, fertilizer use, groundwater extraction, groundwater recharge, and biological and microbial effects will also affect the composition of groundwater.

4.1. Physiochemical Characteristics

Basic statistics of major ions concentrations, EC, pH, TDS, T°C, and evaluation parameters of water quality are summarized in Tables 3a, 3b, and 5. According to Edition (2011), WHO (2008) guidelines, and IQS (2009), all the parameters of the study area allowable value and in a safe range for drinking water, except three wells Newroz, Rizgar, and Birayaty were the NO_3^- values higher than 50 mg/l during the wet season, while only Rizgari have a high value of Nitrate. HCO_3^- is shown maximum in Newroz and total hardness TH doesn’t lie with recommended standards in Rizgari well compared with the standards. The maximum allowable limit of TH for drinking water is specified as 450 – 500 mg/l (WHO and IQS), and the maximum hardness values reached 540 mg/l (Rizgari). The value of TH for all samples more than 180 mg/l is considered to be very hard water. There are several sources of groundwater nitrate, including improper waste disposal, animal farm waste (Burkholder et al., 2007), the use of nitrogenous fertilizers (Adimalla & Qian, 2019), vegetables, such as Chinese cabbage, kale, and carrots, and so on. Early research indicates that nitrate pollution in groundwater can come from a variety of sources, including point-source pollution, such as industrial pollution and intensive animal husbandry; and non-point-source pollution, such as fertilizers, fungicides, atmospheric deposition, and so on (Almasri, 2007). Groundwater pollution is very complex and often difficult to observe and has long-term effects (Shrestha et al., 2016). Groundwater, unlike surface water, is difficult to recover once polluted by certain pollutants (Rahmati et al., 2015). Therefore in the study area, the fertilizer and stormwater that percolate with the irrigation and rainwater to the groundwater can affect the variation of NO_3^- and SO_4^{-2} concentrations, therefore this component can reflect the agricultural and stormwater effects on the groundwater in the region. The presence of Na^+ and Cl^- in natural water is attributed to the dissolution of halite, HCO_3^-, and SO_4^{2-} from the dissolution of limestone and gypsum. However, may have other origins (natural or anthropogenic).

Table 5: Comparison of physicochemical parameters with (WHO, 2008), Guideline 2011 and (IQS, 2009) standards for both periods.

Parameters	Units	WHO (2008)	Guideline (2011)	IQS (2009)	Wet season (May 2020)			02		
					Range	Mean	SD	Range	Mean	SD
T	°C				19 – 20	19.6	0.5	17 – 18.5	17.8	0.45
pH	-	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5	7.2 – 7.5	7.4	0.1	7.1 – 7.8	7.5	0.26
EC	µS/cm				384 – 819	539.0	136.7	400 – 1299	573.8	259.25
TH	mg/l	500	450	500	249 – 540	373.0	91.8	192 – 503	305.2	94.7
TDS	mg/l	1000	1000	1000	250 – 532	351.0	88.9	260 – 844	373	169
Ca^{2+}	mg/l	100	75	150	62 – 109	83.0	15.7	53 – 125	75.08	24
Mg^{2+}	mg/l	125	50	100	23 – 36	29.0	4.8	17.5 – 46	28.58	8.68
Na^{+}	mg/l	200	200	200	11.5 – 32.7	20.1	7.1	15 – 112	30.32	26.7
K^{+}	mg/l	12	12		0.6 – 1.3	1.0	0.3	0.9 – 3.3	1.38	0.7
HCO_3^-	mg/l	300	500	600	200 – 330	261.5	41.3	210 – 370	258.58	46.8
SO_4^{2-}	mg/l	250	250	400	18 – 73	38.1	18.3	24 – 76	51.83	21.5
Cl^-	mg/l	250	250	350	18 – 49	31.8	11.0	11 – 200	35.5	52.9
NO_3^-	mg/l	50	50	50	30 – 60	43.3	10.3	1.6 – 60	25.22	16.9

4.2. Hydrochemical formula and type of water

Major cations and anions in epm%, their concentrations should be more than (%15) in the hydrochemical formula it can be utilized to determine water type, while hydrochemical formula as purposed according to Ivanov et al. (1968) formula:

Wet Season

$$TDS_{(351mg/l)} \; \frac{HCO_{3(65)} - SO_{4\,(12)}}{Ca_{(56)} - Mg_{(32)}} \; PH_{(7.4)}$$

Type of water: Ca, Mg-Bicarbonate

Dry season:

$$TDS_{(373mg/l)} \; \frac{HCO_{3(67)} - SO_{4(16)}}{Ca_{(51)} - Mg_{(32)} - Na_{(16)}} \; pH_{(7.5)}$$

Type of water: Ca, Mg-Bicarbonate

According to water type, the dominant cations are Ca^{+2} and Mg^{+2} and the dominant anion.is HCO_3^-. The three ions that exist in the groundwater are caused by the result of natural weathering and dissolving of carbonate rocks like limestone and dolomite.

4.3. Classifications of Groundwater

4.3.1. Piper Diagrams

The Piper diagram is a visual representation of the distribution of cations and anions in groundwater that can be used to classify it. The Piper diagram was created by categorizing the samples collected for this study based on their sampling seasons (wet and dry seasons). The Ca, Mg-Bicarbonate type was the dominant form for the groundwater classified for both seasons only one well (Zanko) was Ca, HCO_3^- Chloride type for the dry season (Figure 4a and 4b). The presence of Ca^{2+} and HCO_3^- in natural water is attributed to the carbonate rocks, while Na^+ and Cl^- are from the dissolution of halite. However, sodium chloride may have other origins (natural or anthropogenic).

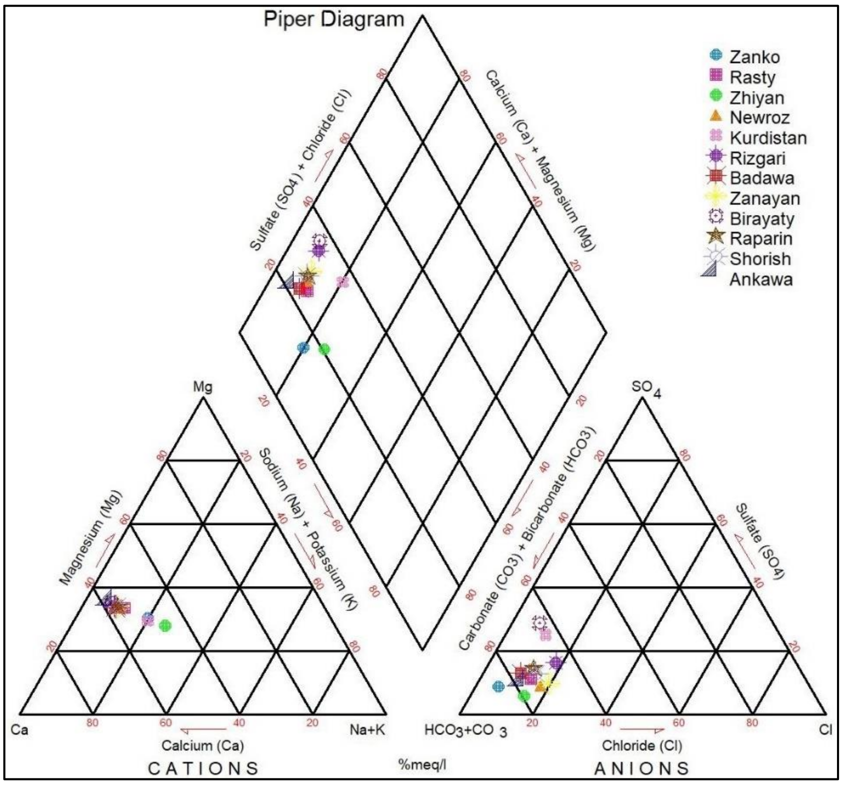


Figure 4a: Piper diagram of groundwater during the wet season.

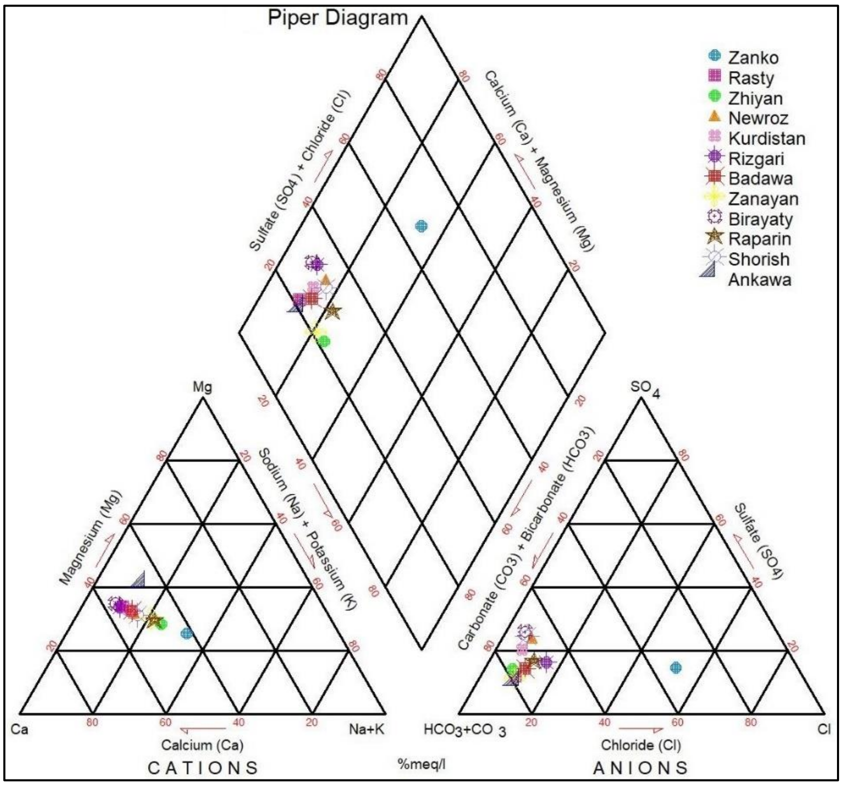


Figure 4b: Piper diagram of groundwater during the dry season.

4.3.2. Gibbs Diagram and Chadha Diagram

The Gibbs diagram is a method for estimating the source of ions in groundwater by focusing on the relationship between them. concentration of cations (Na^+ and Ca^{2+}) and anions (Cl^- and $3HCO^-$), and TDS. The majority of the cations and anions in groundwater have a rock-dominance origin, as illustrated in Figures 5a and 5b. This characteristic suggests that ion dissolution in groundwater occurs more frequently as a result of interactions between groundwater and rock or soil than as a result of precipitation or other sources. Unlike Gibbs, Chadha provided a modified diagram that classified ion origins into eight categories. In a Chadha diagram, the square or rectangle field reflects the overall ion distribution and character of groundwater and is used to show geochemical categorization and hydrochemical processes. To define the primary character of groundwater, the rectangular field is divided into eight sub-fields, each of which represents a water type. The tracing study of an ion based on the Chadha diagram (Figure 6) indicated that there are alkaline earth metals that originate from soil or rock interactions with weak acidic anions in groundwater.

4.3.2. Gibbs Diagram and Chadha Diagram

The Gibbs diagram is a method for estimating the source of ions in groundwater by focusing on the relationship between them. concentration of cations (Na^+ and Ca^{2+}) and anions (Cl^- and $3HCO^-$), and TDS. The majority of the cations and anions in groundwater have a rock-dominance origin, as illustrated in Figures 5a and 5b. This characteristic suggests that ion dissolution in groundwater occurs more frequently as a result of interactions between groundwater and rock or soil than as a result of precipitation or other sources. Unlike Gibbs, Chadha provided a modified diagram that classified ion origins into eight categories. In a Chadha diagram, the square or rectangle field reflects the overall ion distribution and character of groundwater and is used to show geochemical categorization and hydrochemical processes. To define the primary character of groundwater, the rectangular field is divided into eight sub-fields, each of which represents a water type. The tracing study of an ion based on the Chadha diagram (Figure 6) indicated that there are alkaline earth metals that originate from soil or rock interactions with weak acidic anions in groundwater.

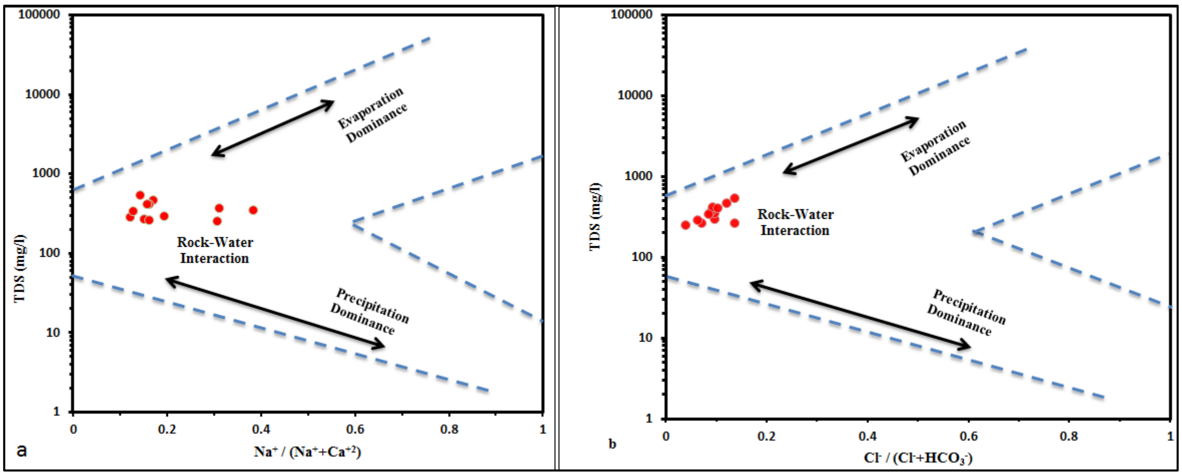


Figure 5: **a)** Gibbs diagram by cations; **b)** Gibbs diagram by anions.

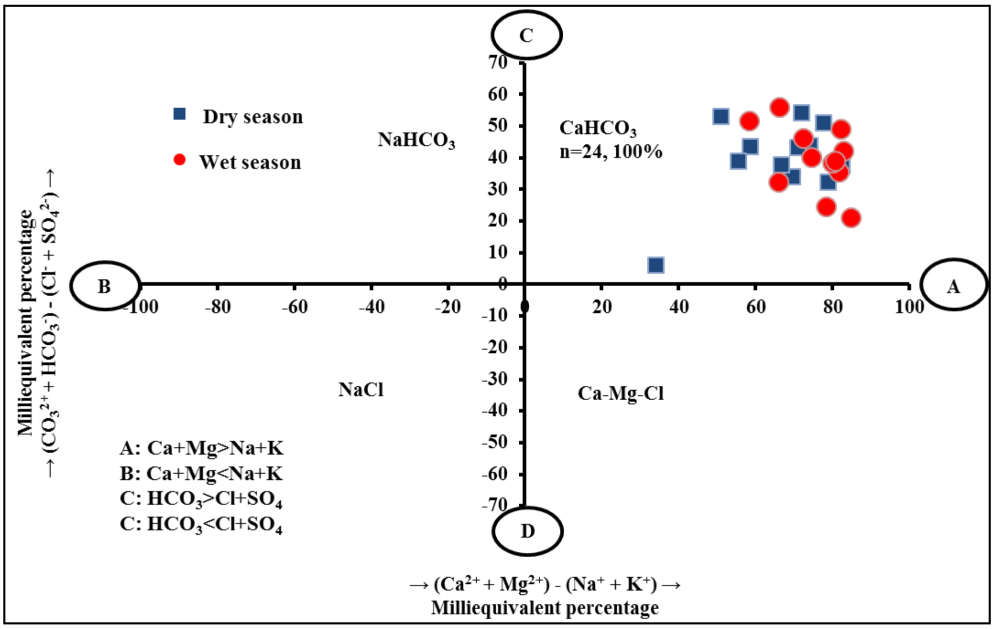


Figure 6: Geochemical classification and hydrochemical parameters of groundwater b using the Chadha diagram during wet and dry seasons.

4.3.3. Chemical Processes and Ion Chemistry

Major ions, as we know, make up a considerable portion of total dissolved solids in groundwater, and their concentrations in groundwater are influenced by hydrogeochemical processes in the aquifer system. When the concentration of main ions in groundwater approaches equilibrium, certain activities occur. As a result, measurements of the concentrations of various main ions in groundwater have been utilized to identify geochemical processes. We concentrated on a comparative analysis to assign weight to two or three key ion groups, such as calcium and magnesium, sodium and potassium, and chloride and sulfate, in this study. Because the interaction of two or three ions is critical for studying weathering types of solutes (calcite, gypsum, and dolomite), the dominant type of ions in solution, influence the type for mutual interaction between one ion and the other ion (Hwang et al., 2017).

a. Weathering Mechanisms

In all of the groundwater samples, calcium is the most prevalent ion. Minerals such as montmorillonite, illite, and chlorite are commonly associated with Ca^{2+}, Na^{+}, and Mg^{2+} abundance (Garrels, 1976). The calcium ion found in the groundwater samples could have come from the dissolution of $CaCO_3$ and $CaMg(CO_3)_2$ precipitates during recharge. The ionic concentrations falling above the line in the ($Ca^{2+} + Mg^{2+}$) vs. ($4H_2CO_3^- + SO_4^{2-}$) scatter plot are caused by carbonate weathering, while those falling along the line are caused by both carbonate and silicate weathering, according to Datta & Tyagi (1996). Such a ($Ca^{2+} + Mg^{2+}$) vs. ($H_2CO_3^-$ + SO_4^{2-}) scatter diagram (Figure 7a) of samples during the wet season shows that half of the sample lies above the line and half lies down the line which indicates that carbonate weathering and silicate weathering are the main physical action for making the source for calcium ion in the groundwater. While in the dry season, only two samples above the line and all others down indicate that silicate weathering is the main source. Carbonic acid (from CO_2 dissolution in soil and groundwater) and calcium carbonate in soil react to form bicarbonate and calcium ions in this reaction (Equations (3) through (7); Lakshmanen et al., 2003):

$CO_2 + H_2O \Rightarrow H_2CO_3$ (formation of carbonic acid) ………. 3

$CaCO_3 + H_2CO_3 \Rightarrow Ca^{+2} + 2HCO_3^-$ (calcite dissolution) …………..……. 4

$2NaAlSi_3O_8$ (albite) + $2H_2CO_3 + 9H_2O \Rightarrow Al_2Si_2O_5(OH)_4$ (kaolinite) $2Na^+ + 4H_4SiO_4 + 2HCO_3^-$ …. 5

$CaMg(CO_3)_2$ (dolomite) $2H_2CO_3 \Rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$ (magnesium calcite dissolution) ….. 6

$H_2O + CaSO_4 \cdot 2H_2O \Rightarrow Ca^{+2} + SO_4^{-2} + 3H_2O$ (gypsum dissolution) ……. 7

Carbonate weathering is an intense process in which carbonic acid water saturated with CO_2 dissolves the carbonate minerals present in its flow path. This process has increased the soluble ion content of groundwater, such as chloride, potassium, sodium, magnesium, and bicarbonate ions.

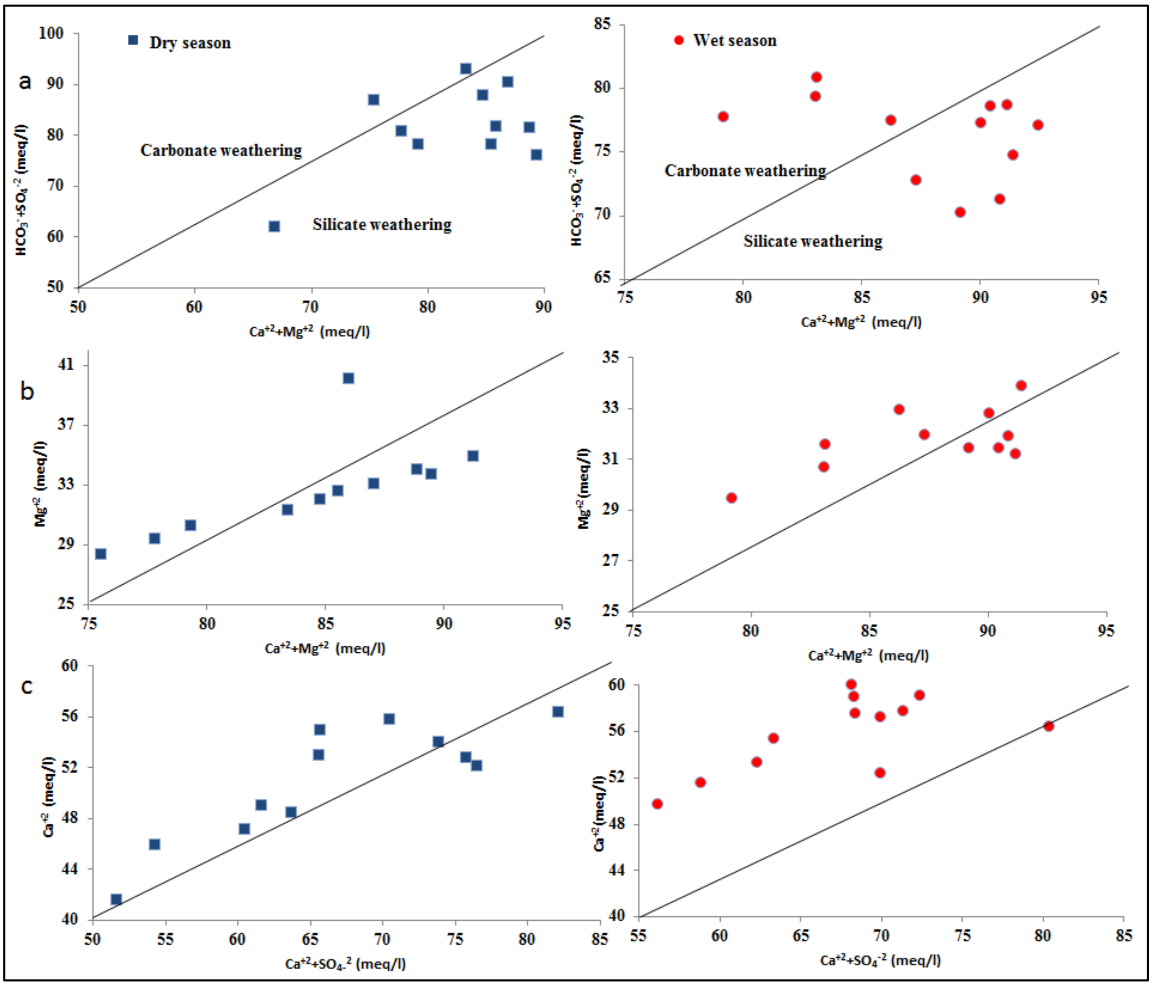


Figure 7: scatter diagram showing: **a)** The ($Ca^{2+} + Mg^{2+}$) vs. ($HCO_3^- + SO_4^{2-}$) show carbonate dissolution and silicate weathering; **b)** The Mg^{+2}/ ($Ca^{2+} + Mg^{2+}$) diagram for dolomite weathering type; **c)** The Ca^{2+}/ ($Ca^{2+} + SO_4^{2-}$) diagram for the gypsum weathering type.

b. Deduction of Source-Rock

The source rock deduction is to gain insight into the possible origin of water analysis. When the source of groundwater is unknown, it can be used as both an analytical check and an investigation process. It is derived from a simplistic mass-balance approach to water quality data (Garrels & MacKenzie, 1967). The quantity of cations is determined by the mineralogy of the rock, and the composition of different cations and anions may change throughout rock weathering. The source rock deduction is important in explaining groundwater quality since it is frequently possible to establish source rock minerals from groundwater composition. Under moderate TDS conditions, the dissolution of Mg^{2+} and Ca^{2+} in groundwater is critical for understanding the source rock for dolomite. However, if the Mg^{+2} to Ca^{+2} ratio approaches one, the Ca^{+2} has most likely been removed from the solution, a process known as dedolomitization. According to Hounslow (1995), if Mg^{2+} is greater than (equal to, or less than) Ca^{2+}, there are four possibilities: **1)** Gypsum dissolution (= 0.5); **2)** Limestone-dolomite weathering (< 0.5); **3)** Dolomite dissolution, calcite precipitation. In Figure 7b, we can understand that there are all possibilities as mentioned above during the weathering and dissolution processes. We can also deduce gypsum-type source rock by applying the Hounslaw equation to the categories: **1)** Gypsum dissolution (= 0.5); **2)** Pyrite oxidation (< 0.5 and pH < 5.5); **3)** Ion exchange (< 0.5 and pH = neutral); **4)** Calcium source other than gypsum-carbonates or silicates (Figure 7c).

4.4. Geostatistical assessment of water quality

Classification of the groundwater samples from Erbil Basin is shown in Tables 2; 4a; 4b; 6 and 7. The SAR values of groundwater vary between (1.04 – 3.23) meq/l during the wet season and (1.21 – 5.61) meq/l during the dry season. It demonstrates that all of the groundwater samples are suitable for use with salt-tolerant crops, organic soils, and irrigation. The Richards (1954) Reversed graphic shows that the EC is assumed to represent salinity hazard and SAR is taken to represent alkalinity hazard. All of the water samples are classified as S2S1 in Figure 8, however, only the Zanko and Rizgari samples are S3S1. The S3S1 indicates high salty and low Na, which requires drainage or is dangerous, whereas S2S1 shows medium salty and low Na, which should drain well. Spatial development of sodium percentage (Na%) was (7.51 – 16.94) meq/l during wet season and (8.75 – 33.01) meq/l excellent in most of Erbil Basin and Zanko is good. Magnesium hazard (MH) value ranges between (34.2 – 38.98) meq/l for the wet season and (37.57 – 46.61) meq/l for the dry season, less than 50%. This shows that the groundwater is not harmful for irrigation and it is suitable. PI ranges from (14.41 – 28.9) meq/l during the wet season and (16.57 – 39.88) meq/l. Table 2 shows that the Erbil Basin has a moderate PI indicating that the groundwater from this area is good. Table 4 shows that the PS values range from (12.91 – 19.36) meq/l during the wet season and (10.27 – 38.93) meq/l during the dry season. A value of more than 5 meq/l falls into injurious to unsatisfactory.

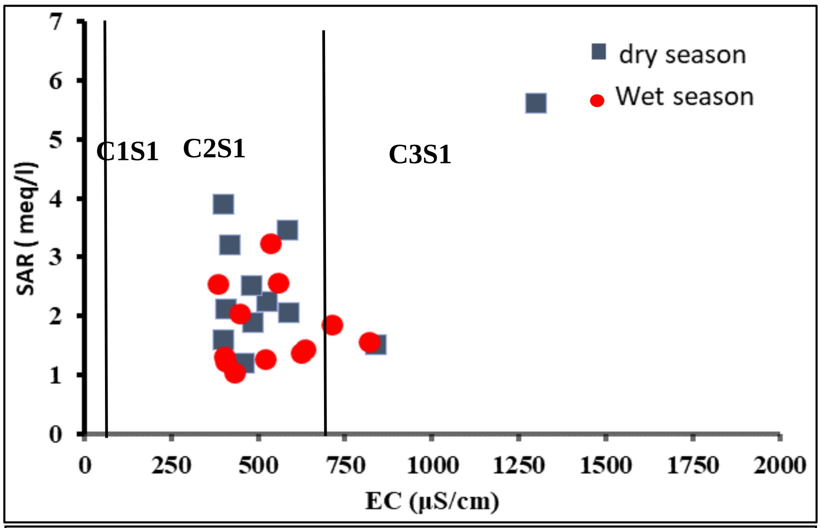
The WQI is considered to be an important indicator of water quality because that provides a general idea of water problems in any area (M. H. Al-Kubaisi, 2020). The results of groundwater WQI in Erbil Basin are shown in Table 7. Among the 24 wells of groundwater samples during both periods, all samples were "good water", only one well (Zhiyan) was "excellent water" during the dry season, and one well (Zanko) was "poor water" during the dry season. The calculation results of WQI show that the groundwater in the study area are suitable for drinking purposes, while the groundwater in Zanko well is not suitable for drinking (Eslami et al., 2017; Li & Wu, 2019; Solangi et al., 2019).

Table 6: The SAR, Na (%), MH, PI.and PS values of groundwater during wet and dry seasons.

Wells	Wet season (May 2020)in (meq/l)					Dry season (October 2021) in (meq/l)				
	SAR	Na%	MH	PI	PS	SAR	Na%	MH	PI	PS
Zanko	2.54	16.86	37.95	25.09	13.03	5.61	33.01	37.94	39.88	38.93
Rasty	2.04	13.76	38.21	21.76	16.18	1.61	11.09	38.26	19.19	12.05
Zhiyan	3.23	20.80	37.21	28.90	15.68	3.90	24.48	37.57	32.72	10.89
Newroz	1.87	12.66	36.56	20.44	19.36	2.26	15.18	37.78	22.85	12.38
Kurdistan	2.57	16.94	36.96	24.53	15.91	1.90	12.92	37.98	21.03	11.39
Rizgari	1.56	10.79	35.26	18.02	22.08	1.51	10.51	37.68	18.02	18.08
Badawa	1.23	8.57	37.06	16.34	14.28	2.12	14.44	38.08	22.08	13.17
Zanayan	1.32	9.14	35.14	16.78	20.07	3.20	20.69	38.15	28.42	13.14
Birayaty	1.04	7.51	38.98	14.41	12.91	1.21	8.75	38.21	16.57	10.27
Raparin	1.44	9.95	36.42	17.75	16.96	3.47	22.17	37.76	29.89	15.18
Shorish	1.38	9.53	34.72	17.41	16.47	2.51	16.59	37.57	24.59	11.31
Ankawa	1.28	8.84	34.20	17.07	16.01	2.07	13.97	46.61	22.22	13.77

Table 7: Classification of water quality according to the WQI values (Ramakrishnaiah et al., 2009).

Wells	WQI (Wet season)	Rank	WQI (Dry season)	Rank
Zanko	51.86	Good water	102.5	Poor Water
Rasty	56.35	Good water	60.45	Good water
Zhiyan	63.21	Good water	47.23	Excellent
Newroz	91.66	Good water	60.73	Good water
Kurdistan	66.55	Good water	57.95	Good water
Rizgari	98.61	Good water	98.77	Good water
Badawa	59.86	Good water	59.88	Good water
Zanayan	57.72	Good water	53.88	Good water
Birayaty	74.47	Good water	53.8	Good water
Raparin	77.98	Good water	71.15	Good water
Shorish	78.48	Good water	54.48	Good water
Ankawa	69	Good water	63.78	Good water



C1S1: Low salty and low Na and used for every soil
C2S1: Medium salty and low Na, drainage should be good
C3S1: High salty and low Na, require drainage or dangerous

Figure 8: Evaluation of groundwater samples for salinity and sodium hazards (after US Salinity Laboratory, 1954).

5. CONCLUSIONS

This study provides a thorough analysis of the groundwater physicochemical features in the Erbil Basin, the groundwater in the study area is weakly alkaline. For major cations, the abundance is in the following order: $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$, and for anions, $HCO_3^- > SO_4^{2-} > NO_3^- > Cl^-$. Comparing the data with WHO and IQS standards for drinking purposes indicated that most of the groundwater in the study area is chemically suitable for drinking uses, except three wells polluted by NO_3^- which are Newroz, Rizgari, and Birayaty. The fact that Ca, Mg-Bicarbonate is the most common form of water during both the dry and wet seasons shows that anthropogenic activities and natural geochemical processes like mineral weathering and mixing have an impact on groundwater's chemical composition, only one well (Zanko) have Ca, HCO_3^- Chlorid type for the dry season. The hydrochemistry of groundwater proposes according to Chadha that all the water samples are alkaline metals with weak acidic anions. Gibbs diagram also indicated that the major process controlling the water quality is the weathering of rocks which means rock-dominant groundwater. All samples were suitable for drinking water from good to excellent water according to the WQI, only the Zanko well had poor water during the dry season.

ACKNOWLEDGMENTS

We would like to thank the employees of these organizations for having allowed us to go and experience their everyday practices at their offices and laboratories: Erbil Water Directorate and Erbil Central Water Laboratory.

REFERENCES

A Mohammed, F., Q Smail, S., & A Kettanah, Y. (2013). Environmental Significance of Major and Trace Elements in the Soils of Selected Areas in Erbil City, Kurdistan Region, Northern Iraq. *Iraqi National Journal of Earth Science*, *13*(2), 15–32.

Adimalla, N., & Qian, H. (2019). Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. *Ecotoxicology and Environmental Safety*, *176*, 153–161.

Al-Dabbas, M. A., Kreamer, D. K., Al-Shammari, A. A., & Jwad, A. M. (2020). Management of Bai Hassan unconfined aquifer, Lesser Zab River basin, Kurdistan Region, Iraq using a modeling approach. *Iraqi Geological Journal*, *53*(2), 1–23. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85090218517&partnerID=40&md5=7820759fb943cae23b2f09c35f59de1e

Al-Dulaimi, A. M. S., & Al-Kubaisi, Q. Y. (2022). Hydrochemistry and Water Quality Index of Groundwater in Abu-Jir Village in Al-Anbar, Western Iraq. *The Iraqi Geological Journal*, 73–84.

Al-Kubaisi, M. H. (2020). Hydrochemical facies description to assess the water quality of Habbaniya Lake, Iraq. *The Iraqi Geological Journal*, 94–107.

Al-Kubaisi, M. H. D., Al-Heety, E. A. M. S., & Yousif, Y. M. (2021). Application of organic indicators and overall index to assess the level of water pollution in Habbaniya Lake, Iraq. *The Iraqi Geological Journal*, 93–102.

Al-Ozeer, A. Z. A., & Al-Abadi, A. M. (2022). Groundwater Quality Index Assessment using the Entropy Method on the Nineveh Plain in Northern Iraq. *The Iraqi Geological Journal*, 128–138.

Al-Tamir, A. (2008). Interpretation of groundwater quality data variation in Erbil city, Northern Iraq. *Al-Rafidain Engineering Journal (AREJ)*, *16*(2), 24–30.

Almasri, M. N. (2007). Nitrate contamination of groundwater: a conceptual management framework. *Environmental Impact Assessment Review*, *27*(3), 220–242.

APHA. (2005). *Standard method for the examination of water and waste water* (21st ed.). American public health Association.

Awadh, S. M. (2018). A preliminary assessment of the geochemical factors affecting groundwater and surface water quality around the rural communities in Al-Anbar, Western Desert of Iraq. *Environmental Earth Sciences*, *77*, 1–18.

Baird, R. B. (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). Water Environment Federation, American Public Health Association, American Water Works Association.

Bapeer, U. H. (2010). A study on the main sewage channel in Erbil city Destiny and its matching to irrigation purpose. *Journal of Kirkuk University-Scientific Studies*, *5*(2), 61–75.

Burkholder, J., Libra, B., Weyer, P., Heathcote, S., Kolpin, D., Thorne, P. S., & Wichman, M. (2007). Impacts of waste from concentrated animal feeding operations on water quality. *Environmental Health Perspectives*, *115*(2), 308–312.

Chadha, D. K. (1999). A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data. *Hydrogeology Journal*, *7*, 431–439.

Datta, P. S., & Tyagi, S. K. (1996). Major ion chemistry of groundwater in Delhi area: chemical weathering processes and groundwater flow regime. *Geological Society of India*, *47*(2), 179–188.

Dizayee, R. H. (2014). Groundwater Degradation and Sustainability of the Erbil Basin, Erbil, Kurdistan Region, Iraq. *Master, Texas Christian University*.

Doneen, L. D. (1954). Salination of soil by salts in the irrigation water. *Eos, Transactions American Geophysical Union*, *35*(6), 943–950.

Doneen, L. D. (1964). Notes on water quality in Agriculture, Paper 4001 ed. *Department of Water Sciences and Engineering, University of California: Published as a Water Science and Engineering*.

Edition, F. (2011). Guidelines for drinking-water quality. *WHO Chronicle*, *38*(4), 104–108.

Eslami, F., Shokoohi, R., Mazloomi, S., Darvish Motevalli, M., & Salari, M. (2017). Evaluation of water quality index (WQI) of groundwater supplies in Kerman Province in 2015. *Journal of Occupational and Environmental Health*, *3*(1), 48–58.

Gardi, S. Q. S. (2017). Environmental Impact Assessment of Erbil Dumpsite area-West of Erbil City-Iraqi Kurdistan Region. *Journal of Tethys*, *5*(3), 194–217.

Garrels, R. M. (1976). A survey of low temperature water-mineral relations. In *Interpretation of environmental isotope and hydrochemical data in groundwater hydrology*.

Garrels, R. M., & MacKenzie, F. T. (1967). *Origin of the chemical compositions of some springs and lakes*. ACS Publications.

Gibbs, R. J. (1970). Mechanisms controlling world water chemistry. *Science*, *170*(3962), 1088–1090.

Habib, F. K., Maddy, S. Q., & Gelly, K. J. (1990). Characterisation of receptors for 1, 25-dihydroxyvitamin D3 in the human testis. *Journal of Steroid Biochemistry*, *35*(2), 195–199.

Hameed, H. M. (2017). Estimating the effect of urban growth on annual runoff volume using GIS in the Erbil sub-basin of the Kurdistan region of Iraq. *Hydrology*, *4*(1), 12.

Hassan, E. O. (1998). *Urban Hydrogeology of Erbil City Region*. University of Baghdad- Iraq.

He, S., Li, P., Wu, J., Elumalai, V., & Adimalla, N. (2020). Groundwater quality under land use/land cover changes: a temporal study from 2005 to 2015 in Xi'an, northwest China. *Human and Ecological Risk Assessment: An International Journal*, *26*(10), 2771–2797.

Hounslow, A. (1995). *Water Quality Data: Analysis and Interpretation* (1st ed.). CRC press.

Hwang, J. Y., Park, S., Kim, H.-K., Kim, M.-S., Jo, H.-J., Kim, J.-I., Lee, G.-M., Shin, I.-K., & Kim, T.-S. (2017).

Hydrochemistry for the assessment of groundwater quality in Korea. *Journal of Agricultural Chemistry and Environment*, *6*(01), 1.
IQS. (2009). *Iraqi Guidelines standard for drinking water (in Arabic).*
Ivanov, V. V, Barabanov, L. N., & Plotnikova, G. N. (1968). *THE MAIN GENETIC TYPES OF THE EARTH'S CRUST MINERAL WATERS AND THEIR DISTRIBUTION IN THE U. S. S. R*.
Jassim, S. Z., & Goff, C. J. (2006). Geology of Iraq, Published by Dolin, Prague and Moravian. *Museum, Brno, 341*.
Jawad, S. B., & Hussien, K. A. (1988). Groundwater monitoring network rationalization using statistical analyses of piezometric fluctuation. *Hydrological Sciences Journal*, *33*(2), 181–191.
Kareem, D. A., M Amen, A. R., Mustafa, A., Yüce, M. I., & Szydłowski, M. (2022). Comparative analysis of developed rainfall intensity–duration–frequency curves for Erbil with other Iraqi Urban areas. *Water*, *14*(3), 419.
Lakshmanen, E., Kannan, R., & Kumar, M. S. (2003). Major ion chemistry and identification of hydrochemical processes of groundwater in a part of Kancheepuram District, Tamil Nadu, India. *Environmental Geosciences*, *10*(4), 157–166.
Li, P., He, X., & Guo, W. (2019). Spatial groundwater quality and potential health risks due to nitrate ingestion through drinking water: a case study in Yan'an City on the Loess Plateau of northwest China. *Human and Ecological Risk Assessment: An International Journal*, *25*(1–2), 11–31.
Li, P., & Wu, J. (2019). Drinking water quality and public health. *Exposure and Health*, *11*(2), 73–79.
Majeed, R. A., & Ahmad, M. A. (2002). Brief References on Hydrogeological Characters of Erbil Basin. *Unpublished Report, Erbil-Iraq*.
Mohamed, F. Y., & Zangana, J. M. (1990). Quality of groundwater in Erbil city. *Sadam Dam Research Center, 2nd Sci.*
Paliwal, K. V. (1972). Irrigation with saline water, Monogram no. 2 (New series). *New Delhi, IARI*, *198*.
Piper, M. (1944). A graphic procedure in the geochemical interpretation of water-analyses. *Eos, Transactions American Geophysical Union*, *25*(6), 914–928. https://doi.org/https://doi.org/10.1029/TR025i006p00914
Rahmati, O., Samani, A. N., Mahmoodi, N., & Mahdavi, M. (2015). Assessment of the contribution of N-fertilizers to nitrate pollution of groundwater in western Iran (Case Study: Ghorveh–Dehgelan Aquifer). *Water Quality, Exposure and Health*, *7*, 143–151.
Ramakrishnaiah, C. R., Sadashivaiah, C., & Ranganna, G. (2009). Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. *E-Journal of Chemistry*, *6*(2), 523–530.
Richards, L. A. (1954). *Diagnosis and Improvement of Saline Alkali Soils, Agriculture, 160, Handbook 60. US Department of Agriculture, Washington DC.-References-Scientific Research Publishing*.
Shrestha, S., Semkuyu, D. J., & Pandey, V. P. (2016). Assessment of groundwater vulnerability and risk to pollution in Kathmandu Valley, Nepal. *Science of the Total Environment*, *556*, 23–35.
Shukir, J. (2021). *Hydrology and hydrochemistry of Erbil subbasin*. Van ozongul University -Turkey.
Solangi, G. S., Siyal, A. A., Babar, M. M., & Siyal, P. (2019). Evaluation of drinking water quality using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools in Thatta district, Pakistan. *Desalination and Water Treatment*, *160*, 202–213.
Todd, D. K. (1980). Groundwater Hydrology. In *Geological Magazine* (2nd ed.). John Wiley. https://doi.org/DOI: 10.1017/S0016756800032477
Toma, J. J. (2006). Study on some of physico-chemical properties in Shaqlawa groundwater (some wells), Erbil. Iraq. *J. of Zanco*, *18*(3).
US Regional Salinity Laboratory. (1954). *Diagnosis and improvement of saline and alkali soils* (Issue 60). US Department of Agriculture.
WHO. (2008). *Guidelines for drinking-water quality* (3rd ed.).
Wilcox, Lv. (1955). *Classification and use of irrigation waters* (Issue 969). US Department of Agriculture.
Woodward, A. (2019). Climate change: Disruption, risk and opportunity. *Global Transitions*, *1*, 44–49.
Zhou, Y., Li, P., Xue, L., Dong, Z., & Li, D. (2020). Solute geochemistry and groundwater quality for drinking and irrigation purposes: A case study in Xinle City, North China. *Geochemistry*, *80*(4), 125609.

About the authors

Awaz Kareem Rasul is an assistant professor in geochemistry and hydrochemistry at the Department of Earth Sciences and Petroleum, College of Science, Salahuddin University-Hawler. She was awarded her B.Sc. in geology in 1992, an M.Sc. in geochemistry in 2003, and a Ph.D. in hydrogeochemistry in 2013 from the same university. Currently, she is working as an assistant professor and researcher at the Department of Earth Sciences and Petroleum. She has supervised some M.Sc. students in her field of research area.

e-mail: awaz.rasul@su.edu.krd

Rebwar Nasir Dara is a lecturer in Hydrogeology at the Department of Earth Sciences and Petroleum, College of Science, Salahuddin University-Hawler. He was awarded her B.Sc. in geology in 2005, an M.Sc. in hydrogeology and hydrochemistry in 2011 from the same university, and a Ph.D. in hydrogeophysics and environment from the University of Birmingham – UK in 2017. He did a short-term postdoc at Lebniz Institute for Freshwater Ecology and Inland Fisheries (IGB Inland Fisheries in the field of groundwater and surface water interactions in 2020. In 2023, he had a sabbatical at the University of Birmingham - UK, and I worked on Microplastic pollution in rivers and sediments. Currently, he is working as a lecturer and researcher at the Department of Earth Sciences and Petroleum. He has supervised some M.Sc. students in his field of research area.

e-mail: rebwar.dara@su.edu.krd

Dr. Masoud Hussein Hamed graduated from the Geological Department, College of Science at Salahaddin University in 2002. After graduation. He worked as a Demonstrator in the Geology Department from January/19/2003 to Oct/1/2005 in the Department. He worked as a laboratory demonstrator at the Department of Geology. In October 2005. He was accepted into the Master's Program at Salahaddin University in the specialty of Environmental. In April 2007. He has gotten a master's degree in Environmental Geology and became an assistant lecturer for an Environmental course in the Department of Geology at Salahaddin University. In 2013, he got Ph.D. in hydrogeology and groundwater modeling, at Salahaddin University. He has 22 years of experience working in the fields of Environmental Impact Assessment, Hydrogeology, Hydrochemistry, Water management, and GIS. He has published 6 articles on different geological aspects. He has wide experience in the environmental field. He has been a lecturer at the University of Salahaddin, College of Science, Department of Earth Sciences and Petroleum for the past 20 years, and supervised 2 M.Sc. students inside Iraq, and 3 students outside Iraq.

e-mail: masoud.hamed@su.edu.krd

Sangar Khalid Karim is a geologist who was awarded a B.Sc. in 2011 and a high diploma in 2021 in general geology from Salahaddin University-Erbil, College of Science. He worked as a geologist at Oli service company from 2011 to 2013 and now his employer serves in the Kurdistan region government.

e-mail: sangeokurdish89@gmail.com