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Hydrochemical Assessment and Groundwater Quality of Eastern and Western Catchments of Erbil City, Northern Iraq

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ABSTRACT

Groundwater quality and quantity are important factors for controlling the management of water. The significance of the hadrochemical analysis underlies the fact that the chemistry of the ground water can conventional be rated with the source of water, climate, and geology of the region. The study includes the hadrochemical characterization of groundwater in Eastern and Western catchments in Erbil city, Kurdistan Region, to achieve their chemistry, quality, suitability for drinking, irrigation, and industry purposes. Water well samples were collected from different wells during two periods, the first period is considered a minimum recharge period (dry) in November 2021 and the second period is considered a maximum recharge period (wet) in May 2022; 36 samples (18 from the eastern part, 18 from the western part) for each period. The physicochemical parameters, namely (ph), electrical conductivity (EC), total dissolved solids (TDS), Temperature, Salinity, major cations and anions) were analyzed to evaluate the present groundwater quality as well as the possible source of ions in the groundwater. The chemical composition of water is based primarily on the minerals which have dissolved in it and modified by ion-exchange equilibrium. Aquifer sediments and abundant soils are considered to be the major sources of cations and anions, whereas the fertilizers, municipal wastewater and irrigation-return flows are additional contributors of Mg2+, Na+, K+, Cl-, SO42- ions. The concentration of major ions decreases slightly in the wet season due to excess rainfall which normally dilutes dissolved elements. Generally, the concentration of physiochemical parameters, cations, and anions in the eastern part is lower than in the western part because the eastern part is considered a recharge zone of the Erbil basin it depends on the soil formation and depth of wells. The results reveal that the dominant types of groundwater in the eastern and western parts based on piper and schoellar diagrams are calcium bicarbonate water in both seasons. Gibbs ratio indicates that the groundwater in both parts is affected by the weathering of rock-forming minerals for the groundwater samples.

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التقييم الهيدروكيميائي وجودة المياه الجوفية لمستجمعات المياه شرق وغرب مدينة أربيل، شمال العراق

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الملخص

تعد نوعية المياه الجوفية وكميتها من العوامل المهمة للتحكم في إدارة المياه. تكمن أهمية التحليل الهيدروكيميائي في أنه يمكن تصنيف كيمياءالمياه الجوفية من حيث مصدر المياه والمناخ والجيولوجيا المنطقة. تتضمن الدراسة توصيف الهيدروكيميائي للمياه الجوفية في المستجمعات الشرقية والغربية في مدينة أربيل، إقليم كوردستان، للتحقق من كيميائيتها وجودتها وملاءمتها للشرب والري والصناعة. تم جمع عينات آبار المياه من آبار مختلفة خلال فترتين، تعتبر الفترة الأولى فترة التغذية الدنيا (الجافة) في نوفمبر 2021 والفترة الثانية تعتبر فترة التغذية القصوى (الرطبة) في مايو 2022؛ 36 عينة (18 من الجزء الشرقي، 18 من الجزء الغربي) لكل فترة. تم تحليل العوامل الفيزيائية والكيميائية وهي (ph) والتوصيل الكهربائي (EC) و المواد الصلبة الذائبة الكلية (TDS) و درجة الحرارةو الملوحة، الكاتيونات والأنيونات الرئيسية) لتقييم نوعية المياه الجوفية الحالية وكذلك المصدر المحتمل للأيونات في المياه الجوفية. يعتمد التركيب الكيميائي للمياه في المقام الأول على المعادن التي تذوب فيه وتتغير عن طريق توازن التبادل الأيوني. تعتبر رواسب طبقات المياه الجوفية والتربة الوفيرة المصادر الرئيسية للكاتيونات والأنيونات، في حين أن الأسمدة ومياه الصرف الصحي البلدية وتدفقات الري العائدة هي مساهمات إضافية في أيونات Mg^{2+}، Na^{+}، K^{+}، Cl^{-}، SO_4^{2-}. يتناقص تركيز الأيونات الرئيسية قليلاً في موسم الأمطار بسبب هطول الأمطار الزائدة التي تعمل عادة على تخفيف العناصر الذائبة. وبشكل عام فإن تركيز العوامل الفيزيوكيميائية والكاتيونات والأنيونات في الجزء الشرقي هي أقل من الجزء الغربي لأن الجزء الشرقي يعتبر منطقة تغذية لحوض أربيل ويعتمد على تكوين التربة وعمق الآبار.أظهرت النتائج أن الأنواع السائدة من المياه الجوفية في الأجزاء الشرقية والغربية حسب المخططات الأنبوبية والشولرية هي مياه غنية ببيكربونات الكالسيوم في كلا الموسمين. تشير نسبة جيبس التي اجريت لعينات المياه الجوفيةإلى أنها في كلا الجزأين تتأثر بتجوية المعادن المكونة للصخور.

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Introduction

Groundwater can be defined as water that occurs in the open space below surface of the earth. Useable groundwater occurs in voids or spaces in various layers of geological material such as sand, silt, sandstone and limestone (Toma, 2006). Groundwater is almost globally important for human and animal consumption, industrial, irrigation and other purposes (WHO, 1993). Groundwater has two major advantages over surface water resources; first, groundwater is of less pollution; and second, it is not a source of loss as it is the case in stream, lakes and reservoirs.

Groundwater is the main water source in some Kurdistan regions of Iraq. Because it is the main water source there, it is a key part of the region's social and economic stability. Groundwater meets almost all of the needs of the people who live there. People use this water for irrigation, drinking, and making things. To get the groundwater, wells are dug into the aquifers all over the Kurdistan Region. In Erbil, Iraq, the groundwater is the primary source of water. However, because of the tremendous changes that have occurred in the city over the last two decades at all levels, this resource is in danger of being depleted. In addition to fast development, population growth, industry, urbanization, and agricultural activities, Erbil province has received over one million displaced individuals seeking safety in the city as a result of the battles that began in 2014 and continue to this day (Majeed and Ahmad, 2002).

Moreover, groundwater is in danger of contamination in Erbil because of the discharge of industrial and municipal wastes and agricultural pollutants. The disposal of wastewater, including human waste, in septic tanks is a typical practice in metropolitan areas. In several areas of the city, the nitrate and alkali concentrations surpass Iraqi and WHO guidelines (Wali and Alwan, 2016).

Water's physical and chemical quality must be measured to determine if it is good for different uses. Most of the time, the quality of groundwater depends on the composition of the water that fills the aquifer, how the water reacts with the soil, how the soil reacts with gas, the rock it comes into contact with in the unsaturated zone, how long it stays there, and what happens inside the aquifer (Al-Sudani, 2019).

The aim of this paper is studying the physiochemical parameters and groundwater quality for both parts of Erbil City and implications for different purposes.

Study Area

The study area is located in the central part of Erbil basin which are eastern and western part. The study area is located between 36^{o} 00' 00" to 36^{o} 20' 00" north and between 43^{o} 40' 00" to 44^{o} 20' 00" east. The eastern and western watersheds cover an area about 525 km^2 and 980 km^2 respectively. The Erbil Basin is about 3,200 km^2 in size. Because it is close to the surface and has a lot of good-quality water, this basin is one of the most important groundwater basins in the Middle East (Ahmed, 2010) (Fig. 1).

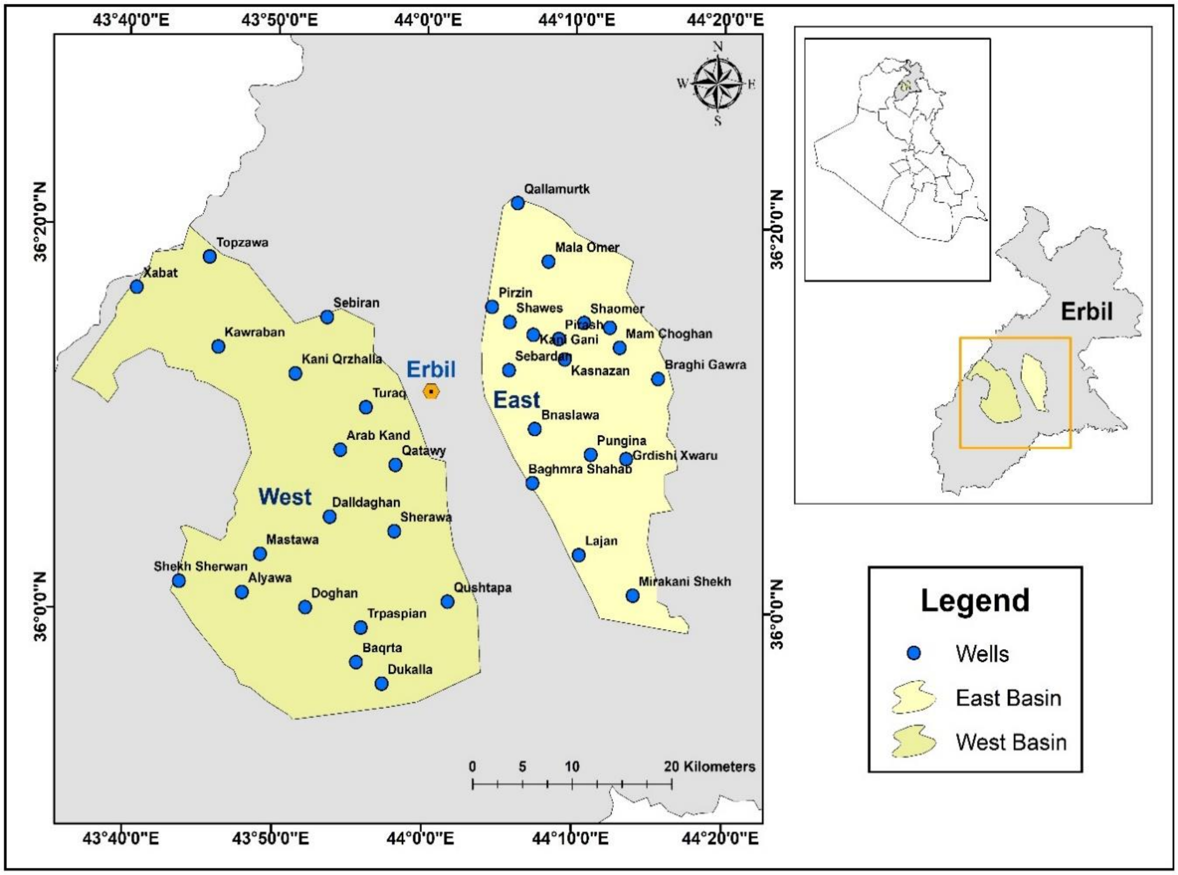

Fig. 1. Location map of the study area

Materials and Methods

The coordination of the wells from both east and west sides of the Erbil basin is recorded by A Global Positioning System (Garmin® GPS of UTM unit) (Table 1), and the border of the part of the basin in the studied area by the Arc GIS (version 10.8) program in the metric system of projection (WGS84-38N).

Groundwater samples are collected from deep wells in both East and west sides of the Erbil Basin for detailed chemical analysis. A total of 36 samples are collected and tested (18 from the eastern and 18 from the western parts). The samples are collected in two periods, the first period was in October 2021, which represents the minimum recharge period (drought), and the second period was in May 2022, which represents the maximum recharge period (wet) for the chemical analysis.

Chemical analysis of the collected water samples is carried out in the laboratory (Quality Control-Ministry of Municipality and Tourism -Directorate of Water and Sewerage) for dry and wet season. Physical parameters for the samples like temperature was measured in the field by thermometer model (Hanna HI8314), the pH and electric conductivity (EC) were recorded by the pH meter model (PHB-4), EC-meter model (Hanna HI8033) instruments. Total dissolved solids (TDS) are determined by (equation 6). Chemical parameters for the samples like calcium (Ca^{2+}) and magnesium (Mg^{2+}) are determined titrimetrically by the EDTA method. Sodium (Na^{+}) and potassium (K^{+}) are measured using the flame emission photometry. Chloride (Cl^{-}) is determined by Argent metric method. Nitrate-nitrogen (NO_3^-) is measured using the spectrophotometric technique. Sulfate (SO_4^{2-}) and bicarbonate (HCO_3^-) are determined volumetrically by titration.

Sodium percentage (Na%), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI) and magnesium hazard (MH) are calculated by the following formulas (Todd 1980; Eaton et al. 1995):

$$\%Na\ (in\ ppm) = [Na^{1+} + K^{1+} / Ca^{2+} + Mg^{2+} + Na^{1+} + K^{1+}] * 100 \quad \ldots (1)$$

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

$$RSC\ (in\ epm) = (CO_3 + HCO^{-}_3) - (Ca^{2+} + Mg^{2+}) \quad \ldots (3)$$

$$PI\ (in\ ppm) = 100 \times [([Na^{1+}] + [HCO^{-}_3]1/2) / [Na^{1+}] + [Ca^{2+}] + [Mg^{2+}] \quad \ldots (4)$$

$$MH\ (in\ ppm) = Mg^{2+} * 100 / Mg^{2+} + Ca^{2+} \quad \ldots (5)$$

By measuring a groundwater sample's electrical conductivity (EC), total dissolved solids may be quickly determined. Because it rises with salt concentration, conductance is preferred over its reciprocal and resistance. The equation used is:

$TDS = F * EC$ ……… (6); (where F is a factor that ranges between 0.55 – 0.75)

Table 1: The coordinates and total depth of the wells that have been studied from both parts (East and West) of the Erbil Basin

No.	Name of wells (East)	X (UTM)	Y (UTM)	Z (m)	Total Depth (m)	No.	Name of wells (West)	X (UTM)	Y (UTM)	Z (m)	Total Depth (m)
1	Bnaslawa	421,126	4,001,927	524	391	1	Kawraban	389,342	4,009,874	295	350
2	Shawes	418,627	4,012,212	538	400	2	Sebiran	400,267	4,012,698	359	380
3	Kasnazan	424,144	4,008,618	678	450	3	Qushtapa	412,357	3,985,341	398	540
4	Pirzin	416,841	4,013,677	510	350	4	Xabat	381,149	4,015,609	273	250
5	Braghi Gawra	433,526	4,006,754	625	400	5	Kani Qrzhalla	397,075	4,007,287	444	400
6	Qallamurtk	419,422	4,023,648	555	280	6	Dalldaghan	400,523	3,993,521	317	350
7	Mam Choghan	429,648	4,009,734	866	390	7	Arab Kand	401,402	4,000,313	346	180
8	Pungina	426,738	3,999,453	644	350	8	Alyawa	391,689	3,986,278	309	218
9	Shaomer	426,078	4,012,128	778	380	9	Qatawy	407,123	3,998,497	374	350
10	Sharaboti Gawra	428,669	4,011,671	910	420	10	Shekh Sherwan	385,405	3,987,276	317	250
11	Baghmra Shahab	420,885	3,996,730	510	350	11	Trpaspian	403,644	3,982,850	343	300
12	Pirash	423,548	4,010,588	652	325	12	Mastawa	393,521	3,989,951	305	250
13	Kani Gani	420,992	4,010,992	701	380	13	Sherawa	406,961	3,991,863	310	450
14	Sebardan	418,527	4,007,660	410	300	14	Doghan	398,056	3,984,813	324	233
15	Mala Omer	422,519	4,018,023	641	320	15	Turaq	404,159	4,004,031	375	330
16	Grdishi Xwaru	430,298	3,999,039	769	206	16	Dukalla	405,730	3,977,465	346	300
17	Lajan	425,547	3,985,940	575	305	17	Topzawa	388,479	4,018,519	283	320
18	Mirakani Shekh	430,946	3,985,868	410	330	18	Baqrta	403,163	3,979,538	325	315

Results and Discussion

Physiochemical Parameters of Groundwater

The physical characteristics and chemical analyses for the water samples in both wet and dry seasons from both eastern and western parts of Erbil basin are shown in (Tables 2, 3.1and2 and 4.1and2). The chemical analysis accuracy of water samples from both eastern and western parts in dry and wet seasons are between certain to probably certain types.

Table 2: Statistical results of chemical and physical variables of the groundwater samples from eastern and western parts of Erbil Basin in dry and wet seasons.

Variables	Eastern Part						Western Part					
	Dry Season			Wet Season			Dry Season			Wet Season		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Ca^{2+} (ppm)	90	57	75	88	50	72	90	46	66	87	40	63
Mg^{2+} (ppm)	33	7	16	34	6	14	59	13	31	55	14	27
Na^{1+} (ppm)	68	9	30	63	9	31	86	22	51	83	20	50
K^{1+} (ppm)	2.2	0.6	1	1.8	0.2	1	6	0.9	2	6.1	1	2
HCO_3^- (ppm)	272	130	210	269	164	205	386	180	243	380	174	235
SO_4^{2-} (ppm)	83	34	49	78	28	44	99	46	66	97	35	63
Cl^{1-} (ppm)	49	18	28	38	12	22	62	22	41	54	17	34
NO_3^{1-} (ppm)	48	18	31	43	14	27	67	30	42	62	25	40
T.H. (ppm)	364	135	279	330	190	238	402	180	289	370	160	267
TDS (ppm)	586	250	332	582	218	315	715	309	504	704	307	477
EC (µS/cm)	902	385	511	896	335	485	1100	476	782	1083	472	734
pH	8.2	7.5	8	8.1	7	7.7	8.5	7.3	7.9	8.1	7.4	7.8
Turbidity (NTU)	5	0.3	1.0	2.5	0.3	0.8	5	0.5	1.8	5	0.5	1.8
T°C.	24.8	19.2	22.4	23.4	20.2	22.2	26.2	23	22.8	26.2	19.2	23.1

Table 3.1: Laboratory results of chemical and physical parameters from the eastern part of Erbil Basin (dry season).

No.	Name of wells	Physical						Cations				Anions			
		Temp.	EC	pH	TDS	T.H.	Turbidity	Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	HCO_3^-	SO_4^{2-}	NO_3^{1-}	Cl^{1-}
1	Bnaslawa	21.2	420	7.7	273	220	0.4	70	19	38	1.2	220	54	39	15
2	Shawes	21.8	575	7.5	374	335	5	88	33	18	0.9	270	40	45	32
3	Kasnazan	20.2	430	7.9	280	255	1.5	59	20	24	0.7	195	41	48	20
4	Pirzin	21.6	552	7.6	359	364	1	77	29	19	0.6	230	36	35	27
5	Braghi Gawra	23.6	536	7.9	348	349	0.3	80	17	37	1	202	56	28	42
6	Qallamurtk	23.4	492	8.2	320	234	0.3	90	13	33	1	185	67	28	47
7	Mam Choghan	23.9	488	8.1	317	293	0.5	62	10	55	1.5	220	46	19	32
8	Pungina	21.8	385	7.9	250	256	0.4	57	11	9	0.7	130	42	32	18
9	Shaomer	23.4	463	8.1	301	300	0.9	87	8	30	1	230	47	25	25
10	Sharaboti Gawra	21.4	557	8.2	362	361	0.6	75	33	32	1	272	52	48	49
11	Baghmra Shahab	20.6	415	7.9	270	225	1.1	77	9	13	2.2	150	42	25	30
12	Pirash	23.7	479	8.1	311	316	0.5	70	13	68	1.5	214	52	38	22
13	Kani Gani	23.4	470	7.9	306	317	0.6	73	7	30	0.9	220	38	28	20
14	Sebardan	24.8	513	7.6	333	241	1.4	77	12	32	1.5	210	65	18	25
15	Mala Omer	21.9	506	7.8	329	252	2.8	82	10	30	0.6	225	34	25	23
16	Grdishi Xwaru	23.8	443	7.9	288	289	0.3	83	16	30	1.4	215	54	30	24
17	Lajan	19.2	478	7.6	311	214	1.1	67	20	12	1.1	213	41	28	21
18	Mirakani Shekh	24.2	902	7.9	586	135	1.2	63	15	40	1.7	196	83	20	21

Table 3.2: Laboratory results of chemical and physical parameters from the western part of Erbil Basin (dry season).

No.	Name of wells	Physical						Cations				Anions			
		Temp.	EC	pH	TDS	T.H.	Turbidity	Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	HCO_3^-	SO_4^{2-}	NO_3^{1-}	Cl^{1-}
1	Kawraban	24.4	608	7.9	395	219	1.8	56	21	48	2	220	77	29	24
2	Sebiran	19.6	805	8.0	523	263	0.8	53	37	61	1	265	48	41	38
3	Qushtapa	19.2	637	8.0	414	211	0.5	64	18	38	1	195	46	35	32
4	Xabat	22.8	795	7.3	517	240	1	48	29	33	0.9	191	55	38	28
5	Kani Qrzhalla	24.4	908	7.7	590	255	0.5	82	18	66	1.5	238	88	40	62
6	Dalldaghan	22.6	890	8.5	579	260	4.4	82	13	38	1	180	52	30	60
7	Arab Kand	21.8	815	8.0	530	350	1.6	52	59	51	1.5	280	88	48	50
8	Alyawa	22.1	658	7.9	428	261	2.5	54	33	28	1.3	205	60	38	28
9	Qatawy	23.6	709	8.0	461	335	0.9	90	32	58	2.5	270	88	48	38
10	Shekh Sherwan	21.6	670	8.0	436	228	1	62	22	47	1	215	70	41	28
11	Trpaspian	26.2	678	8.3	361	180	0.7	46	18	71	2	225	62	33	39
12	Mastawa	22.6	1100	7.7	715	369	1	81	40	32	1	277	51	45	39
13	Sherawa	23.8	884	7.9	575	240	1.7	50	30	65	2.2	210	67	46	45
14	Doghan	21.8	951	7.9	618	380	2.3	70	46	38	1	210	79	43	56
15	Turaq	21.9	729	7.3	474	402	1.8	84	25	63	2.4	280	70	45	40
16	Dukalla	26.1	764	7.8	497	328	5	76	33	86	2.4	320	54	45	42
17	Topzawa	22.8	476	7.9	309	241	5	46	33	22	1.5	190	53	31	22
18	Baqrta	22.6	830	8.1	540	375	0.5	90	36	73	6	386	99	67	52

Table 4.1: Laboratory results of chemical and physical parameters from the eastern part of Erbil Basin (wet season).

No.	Name of wells	Physical						Cations				Anions			
		Temp.	EC	pH	TDS	T.H.	Turbidity	Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	HCO_3^-	SO_4^{2-}	NO_3^{1-}	Cl^{1-}
1	Bnaslawa	21.8	415	7.5	270	206	0.7	68	11	34	1.1	210	31	32	17
2	Shawes	22.4	574	7	373	330	0.6	78	33	20	1	250	35	38	30
3	Kasnazan	23	389	7.7	253	200	1.3	50	18	26	0.5	165	37	30	17
4	Pirzin	22.8	548	7.1	356	300	0.9	75	27	15	0.6	227	37	31	26
5	Braghi Gawra	21.8	533	7.9	346	265	0.6	80	15	35	1.4	200	57	23	37
6	Qallamurtk	23.1	515	8.1	335	245	0.3	85	7	32	1.3	165	66	22	38
7	Mam Choghan	22.2	423	8	275	190	0.4	62	8	57	1.8	215	46	15	27
8	Pungina	21.3	390	7.9	254	224	0.9	76	8	13	0.6	164	34	36	12
9	Shaomer	23.4	450	8	293	245	0.7	88	6	32	1	240	37	28	16
10	Sharaboti Gawra	22.5	553	7.9	359	316	0.8	70	34	29	1.5	269	40	43	30
11	Baghmra Shahab	21.8	335	7.7	218	215	1.2	73	7	13	0.5	171	36	17	22
12	Pirash	23.2	476	7.9	309	200	0.4	62	11	63	1.8	190	59	34	23
13	Kani Gani	22	462	7.7	300	204	0.7	72	6	34	0.9	218	30	28	14
14	Sebardan	22.1	509	7.8	331	235	0.3	80	8	36	1.4	200	69	15	18
15	Mala Omer	22.4	405	7.8	263	230	2.5	76	9	27	0.2	215	28	22	18
16	Grdishi Xwaru	21.4	436	7.7	283	250	0.4	78	13	33	1.5	217	50	31	17
17	Lajan	20.2	420	7.7	273	246	1.2	67	19	8.6	0.7	211	29	28	15
18	Mirakani Shekh	22.1	896	7.8	582	190	0.9	60	10	45	1.8	166	78	14	18

Table 4.2: Laboratory results of chemical and physical parameters from the western part of Erbil Basin (wet season).

No.	Name of wells	Physical						Cations				Anions			
		Temp.	EC	pH	TDS	T.H.	Turbidity	Ca^{2+}	Mg^{2+}	Na^{1+}	K^{1+}	HCO_3^-	SO_4^{2-}	NO_3^{1-}	Cl^{1-}
1	Kawraban	24	584	7.9	380	214	1.2	53	20	50	1.9	200	67	30	17
2	Sebiran	20.5	790	7.9	514	260	2.3	47	34	60	2	265	36	40	38
3	Qushtapa	20.1	630	7.8	410	208	2	60	14	38	2	180	35	30	29
4	Xabat	23.2	566	7.5	368	244	0.5	50	30	30	1	180	47	35	30
5	Kani Qrzhalla	24.8	818	7.8	532	250	0.6	75	15	72	2.6	240	97	35	52
6	Dalldaghan	23	880	7.8	572	252	1	77	14	30	1	174	40	25	47
7	Arab Kand	25	808	8	525	346	0.5	48	55	48	1.3	300	81	45	54
8	Alyawa	22.5	645	8.1	419	258	2.1	49	32	28	1	200	45	38	18
9	Qatawy	24	704	7.5	458	320	1	80	29	52	2	258	91	47	34
10	Shekh Sherwan	23	562	7.5	365	235	5	58	22	51	1.4	210	72	43	19
11	Trpaspian	25	660	7.9	429	160	1.5	40	15	83	2.3	230	83	35	24
12	Mastawa	23.1	1083	8	704	365	1	75	43	33	1	280	47	49	36
13	Sherawa	24.1	879	8	571	224	1.2	45	27	69	2	201	78	44	34
14	Doghan	23.4	940	7.9	611	280	1	81	24	36	1	200	58	43	44
15	Turaq	23.8	694	7.4	451	300	1.4	75	28	48	1.7	240	74	43	35
16	Dukalla	21.5	680	7.5	442	280	5	84	17	81	3	300	45	47	39
17	Topzawa	23.5	472	7.9	307	236	5	42	32	20	2	193	36	29	19
18	Baqrta	21	822	7.4	534	370	0.6	87	38	76	6.1	380	94	62	46

During two periods, temperature was measured in each station for determining T°C value. T°C in first period which is water deficit period from the eastern part ranges from 19.2 -24.8 °C, while from the western part ranges from 19.2 - 26.2 °C. In second period, which is water surplus period, from the eastern part it ranges from 20.2 -23.4.3 °C, while from the western part it ranges from 20.1 -25 °C. This seasonal variation in the value of temperature from both parts is because the temperature in the dry season (October) is higher than in the wet season (May) (Tables 2, 3.1and2 and 4.1and2) (Fig. 2). The pH-value of the collected water samples, in first period from the eastern part, ranges between 7.5- 8.2, and from the western part ranges between 7.3 - 8.5; while in the second period from the eastern part ranges between 7 - 8.1, and from the western part ranges between 7.4 - 8.1. This very slightly seasonal variation in pH-value from both parts is attributed to the temperature rise, and increasing in human activity (irrigation, and farm land), (Tables 2, 3.1and2 and 4.1and2) (Fig. 3). The highest EC value is recorded in Mastawa well for both dry and wet season 1100 μS/cm and 1083 μS/cm respectively. This suggests that the localized destructive of soil formation and abundant of sand deposits in the area which may cause less filtration processes. Generally, the EC value from the eastern part is less than in the western part because the eastern part is a good recharge zone also, the soil formation and depth of wells have an important role (Tables 2, 3.1and2 and 4.1and2) (Fig. 4). Total dissolved solid concentrations from the both parts for two studied periods are recorded, during first period the TDS value from the eastern part ranges between 250 - 586 ppm, and from the western part ranges between 309 - 715 ppm. While during second period the TDS value from the eastern part ranges between 248- 590 ppm, and from the western part ranges between 307 - 704 ppm. The concentration of TDS in the western boreholes are higher than in the eastern boreholes in both periods, (Tables 2, 3.1and2 and 4.1and2) (Fig. 5).

According to Gorrel (1958), Altoviski (1962) and Drever (1997), water samples are classified as fresh water from both parts of Erbil basin for both seasons (Table 5).

Table 5. Classifications of water according to TDS content in ppm

Water Class	Gorrel (1958)	Altoviski (1962)	Drever (1997)
Fresh water	0 – 1000	0 – 1000	< 1000
Slightly brackish water	--	1000 – 3000	--
Brackish water	1000 – 10,000	3000 – 10,000	1000 – 20,000
Salty water	10,000 – 100,000	10,000 – 100,000	--
Saline water	--	--	35,000
Brine water	100,000	> 100,000	> 35,000

U.S.D.A. (1954) classified water according to EC (Table 6). Generally, the water samples from the eastern part for both periods are of medium salinity, except (Mirakani Shekh) is of high salinity water; while generally, the water samples from the western part are of high salinity for both periods.

Table 6: Water type depends on EC value from both the Eastern and Western parts of Erbil Basin according to U. S. D. A. (1954)

EC (µs/cm)	Mineralization	Eastern Part		Western Part	
		Dry Season	Wet Season	Dry Season	Wet Season
< 100	Very weakly mineralized water (granite terrains)	-	-	-	-
100 – 200	Weakly mineralized water	-	-	-	-
200 – 400	Slightly water (limestone terrains)	385 (8)	335 - 390 (3, 8, 11)	-	-
400 – 600	Moderately mineralized water	415 - 575 (1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17)	405 - 574 (1, 2, 4, 5, 6, 7, 9, 10, 12, 13, 14, 15, 16, 17)	476 (17)	472 - 584 (1, 4, 10, 17)
600 – 1000	Highly mineralized water	902 (18)	896 (18)	608 - 908 (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13,14, 15, 16, 17, 18)	630 - 940 (2, 3, 5,6,7, 8, 9, 11, 13, 14, 15, 16,18)
1000 <	Excessively mineralized water	-	-	1100 (12)	1083 (12)

Detay (1997) estimated the relationship between electrical conductivity and water mineralization (Table 7).

Table 7: Relationship between EC and water mineralization from both the eastern and western parts of Erbil Basin according to Detay (1997).

Class of water	EC value (µs/cm)	Eastern Part		Western Part	
		Dry season (range)	Wet season (range)	Dry season (range)	Wet season (range)
Low salinity water	100<EC<250	385- 902 µS/cm (All 18 samples)	335 - 896 µS/cm (All 18 samples)	476 - 1100 µS/cm (All 18 samples)	472 - 1083 µS/cm (All 18 samples)
Medium salinity water	250<EC<750				
High salinity water	750<EC<2250				
Very high salinity water	2250<EC<5000				

The Turbidity of water samples of the wells in the first period from the eastern part ranges between 0.3 - 5 NTU, and in the western part between 0.5 - 5 NTU, while in the second period from the eastern part ranges between 0.3 - 2.5 NTU, and in the western part ranges between 0.5 - 5 NTU. Because of the samples turbidity is not greater than 5 NTU, so the water is pure (Tables 2, 3.1and2 and 4.1and2) (Fig. 6).

Chemical analysis

Major Cations and Anions

Calcium and magnesium are the most abundant in water; the concentration of Ca^{2+} of the studied water samples in the first period from the eastern part ranges between 57 - 90 ppm, and from the western part between 46 - 90 ppm. While in the second period from the eastern part ranges between 50 - 88 ppm, and from the western part between 40 - 87 ppm. Generally, the Ca^{2+} concentration in second period from both parts of Erbil basin is lower than the first period due to dilution by rainfall, bacterial effective, and decrease in pH, which affect the dissolved rocks containing calcium (Tables 2, 3.1and2 and 4.1and2) (Fig. 7). The concentration of Mg^{2+} of the studied water samples in the first period from the eastern part ranges between 7 - 33 ppm, and from the western part between 13 - 59 ppm. While in the second period from the eastern part ranges between 6 - 34 ppm, and from the western part between 14 - 55 ppm. Generally, the concentration of Mg^{2+} in the western boreholes is higher than that in the eastern boreholes in both periods; the reasons of these values are to human contamination, agricultural crops and using insecticide in the soils to prevent the bacterial effective (Tables 2, 3.1and2 and 4.1and2) (Fig. 8). The concentration of the sodium ions of water samples in the first period from the eastern part ranges from 9 - 68 ppm, and from the western part from 22 - 86 ppm. While in the second period from the eastern part ranges from 9 - 63 ppm, and from the western from 20 - 83 ppm. Generally, concentration of Na^{1+} in both periods from the western boreholes is higher than that in the eastern boreholes, may be due to the mineral deposits in the sediment and the surrounding soil, industrial waste, sewage, fertilizers, human impacts, and animal wastes (Tables 2, 3.1and2 and 4.1and2) (Fig. 9). The K^{1+} concentration of the water samples in the first period from the eastern part ranges from 0.6 - 2.2 ppm, and from the western part from 0.9 - 6 ppm. While in the second period from the eastern part ranges from 0.2 - 1.8 ppm, and from the western part from 1 - 6 ppm. Generally, the K^{1+} concentration in both periods from the western boreholes is higher than in the eastern boreholes. Low concentration of K^{1+} in the eastern part might be due to limited dissolving and weathering in its bonding structure (Tables 2, 3.1and2 and 4.1and2) (Fig. 10). The value of total hardness in the first period from the eastern part ranges from 135- 364 ppm, and from the western part from 180 - 402 ppm. While in the second period from the eastern part ranges from 190 - 330 ppm, and from the western part from 160 - 370 ppm (Tables 2, 3.1and2 and 4.1and2) (Fig. 11).

The waters are classified with regard to the hardness using Sawyer and McCarthy (1967) classification (Table 8).

Table 8. Classification of water based on hardness by Sawyer and McCartly (1967), from the eastern and western parts of Erbil Basin

Hardness as $CaCO_3$	Water Class	Eastern Part		Western Part	
		Dry Season Samples	Wet season Samples	Dry Season Samples	Wet season Samples
0-75	Soft	………	……..	………	……..
75-150	Moderate Hard	135 (1Sample)	……..	……….	……….
150-300	Hard	214 - 293 (11 Samples)	190 - 300 (16 Samples)	180 - 263 (11 Samples)	160 - 300 (14 Samples)
>300	Very Hard	316 - 364 (6 Samples)	316 - 330 (2 Samples)	328 - 402 (7 Samples)	320 - 370 (4 Samples)

HCO_3^- concentration in the first period from the eastern part ranges from 130- 272 ppm, and from the western part from 180 - 386 ppm. While in the second period from the eastern part ranges from 164 - 296 ppm, and from the western part from 174 - 380 ppm. The high HCO_3^- content in both periods in the western part may be related to soil formation as a result of chemical fertilizers-free, herbicides, and pesticides that entering the soil (Tables 2, 3.1and2 and 4.1and2) (Fig. 12).

SO_4^{2-} concentration in first period from the eastern part ranges from 34- 83 ppm, and from the western part from 46 - 99 ppm. While in the second period from the eastern part ranges from 28 - 78 ppm, and from the western part from 35 - 97 ppm. Generally, the concentration of SO_4^{2-} in the western boreholes is higher than that in the eastern boreholes in both periods due to human contamination and agricultural activities and fertilizer (Tables 2, 3.1and2 and 4.1and2) (Fig. 13).

Chloride concentration in the first period from the eastern part ranges from 18- 49 ppm, and from the western part from 22 - 62 ppm. While in the second period from the eastern part ranges from 12 - 38 ppm, and from the western part from 17 - 54 ppm. Generally, the concentration of Cl^- in the western boreholes is higher than that in the eastern boreholes in both periods. The weathering of soils, salt-bearing geological formations, deposition of salt spray, salt used for road de-icing, and the influence of domestic sewage may be the result of this high concentration of Cl (Tables 2, 3.1and2 and 4.1and2) (Fig. 14).

NO_3^- in water samples in first period from the eastern part ranges from 18 - 48 ppm, and from the western part from 30 - 67 ppm. While in the second period from the eastern part ranges from 14 - 43 ppm, and from the western part from 25 - 62 ppm. Generally, the concentration of NO_3^- in the western boreholes is higher than that in the eastern boreholes in both periods. The reasons of this increasing value of nitrate in this part are human contamination, agricultural activities and using insecticides for agricultural crops, also may be many of wells are old and the casing pipes may be rusty and easily affected by the contaminant materials and going into the well and polluted the water (Tables 2, 3.1and2 and 4.1and2) (Fig. 15).

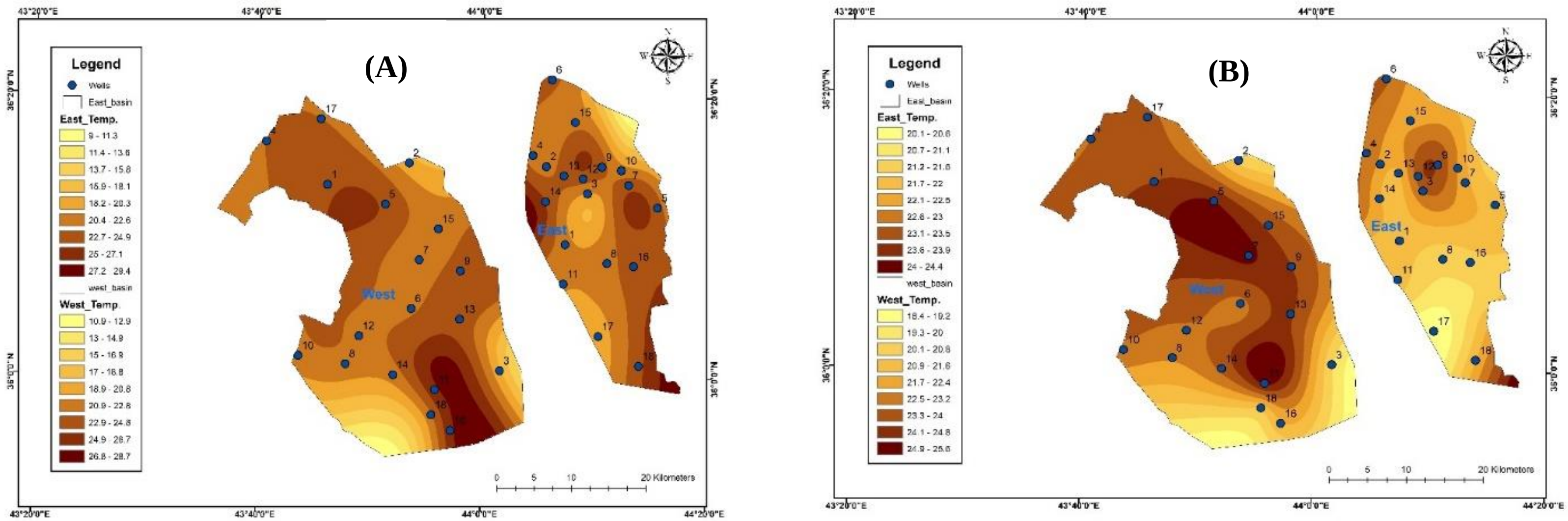

Fig. 2. Distribution of TºC in the study area for: (A) dry season and (B) wet season

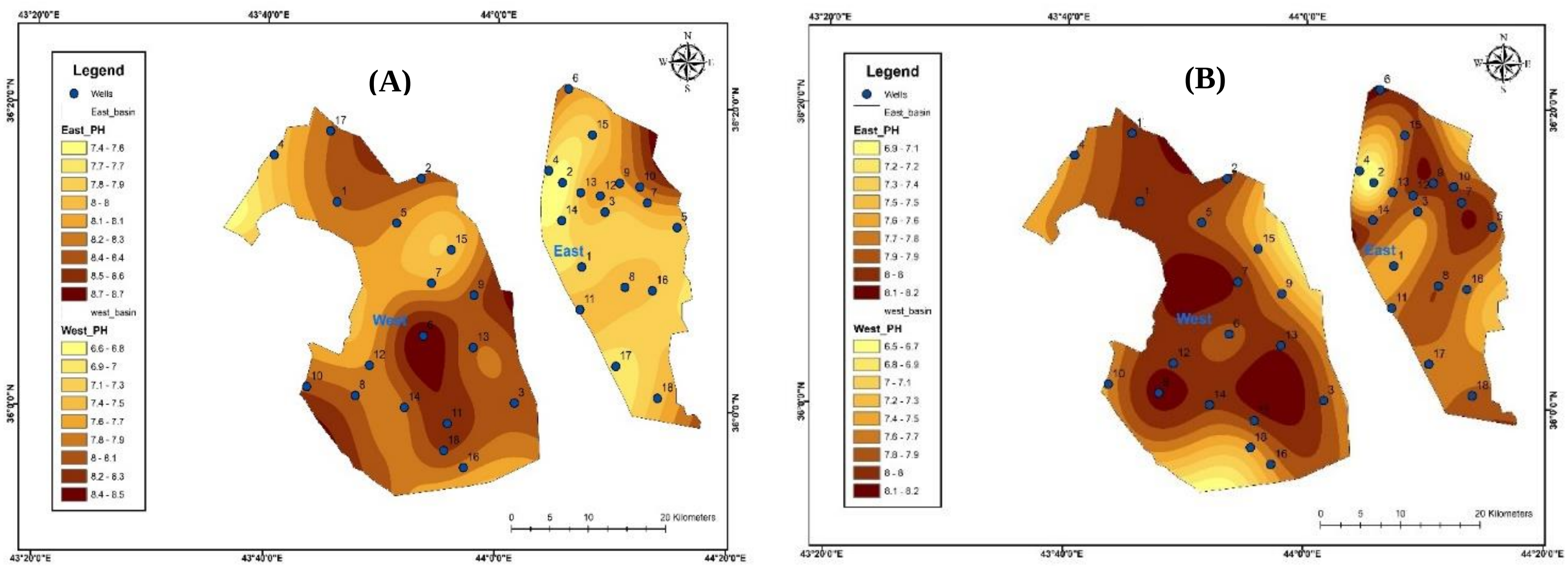

Fig. 3. Distribution of pH in the study area for: (A) dry season and (B) wet season

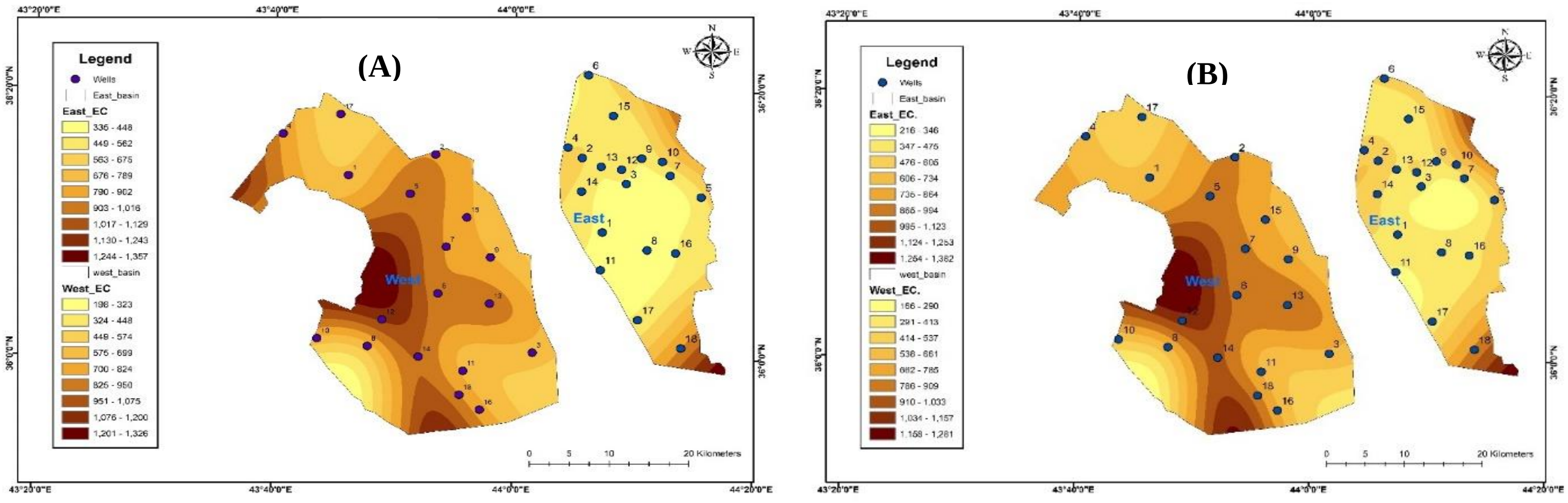

Fig. 4. Distribution of EC in the study area for: (A) dry season and (B) wet season

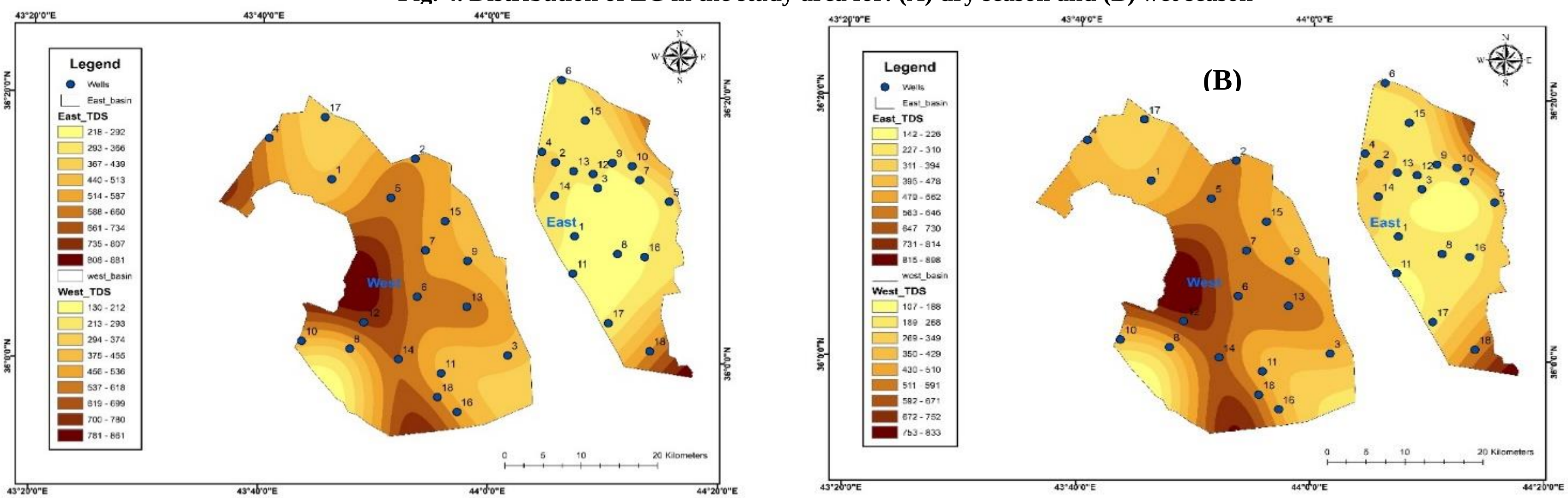

Fig. 5. Distribution of TDS in the study area for: (A) dry season and (B) wet season

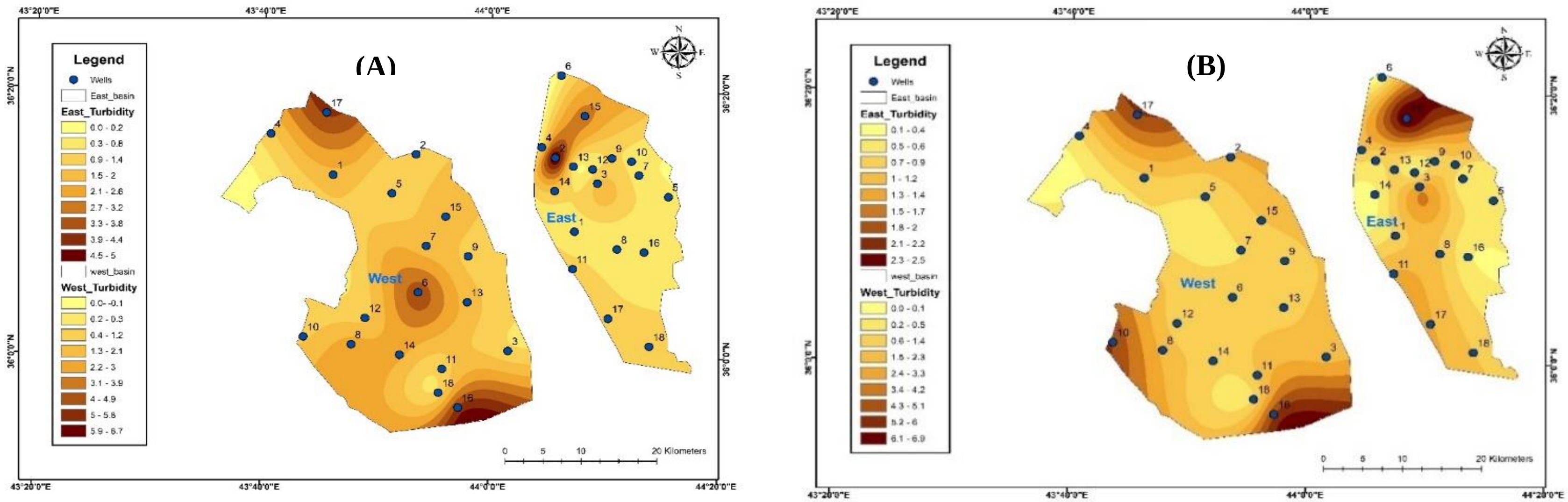

Fig. 6. Distribution of TU in the study area for: (A) dry season and (B) wet season

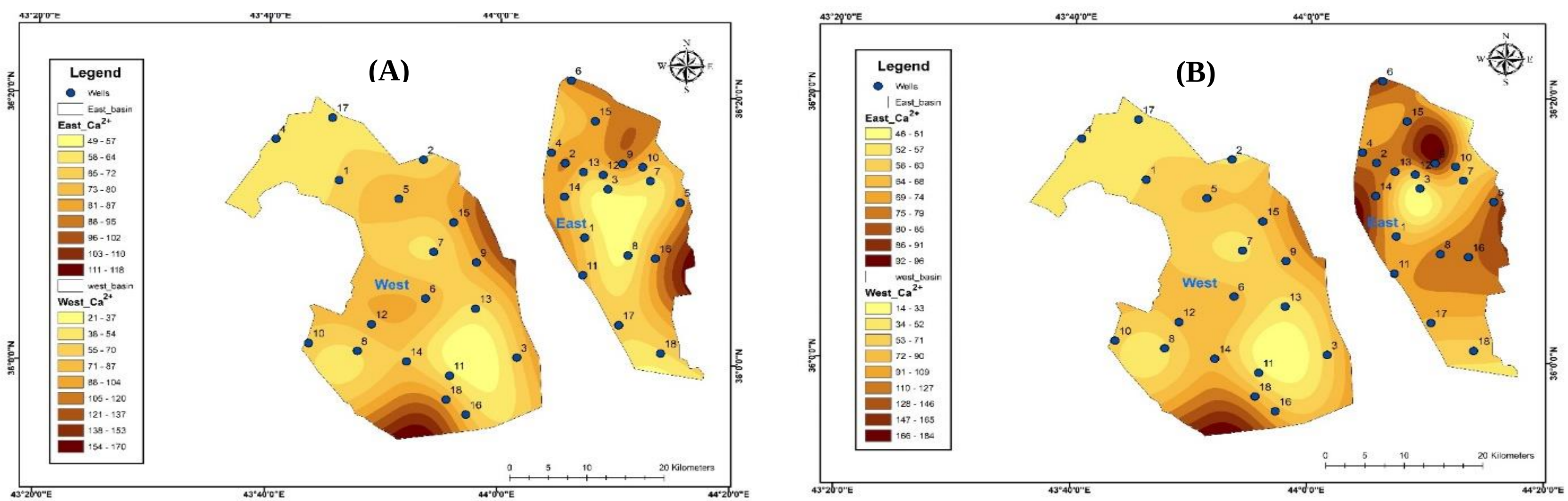

Fig. 7. Distribution of Ca^{2+} in the study area for: (A) dry season, (B) wet season

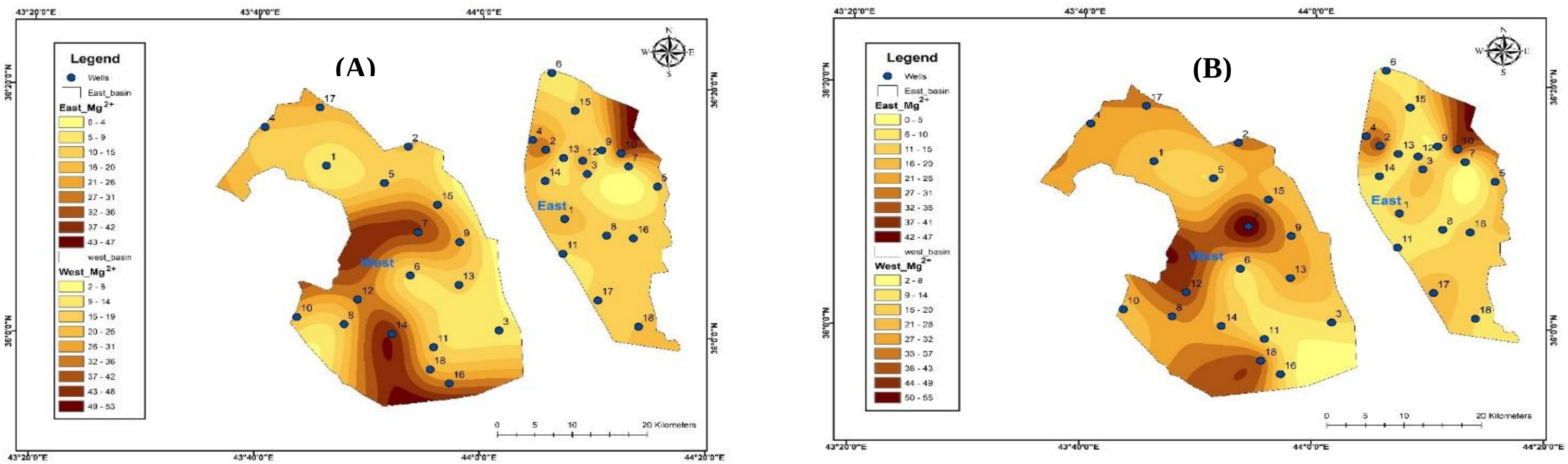

Fig. 8. Distribution of Mg^{2+} in the study area for: (A) dry season and (B) wet season

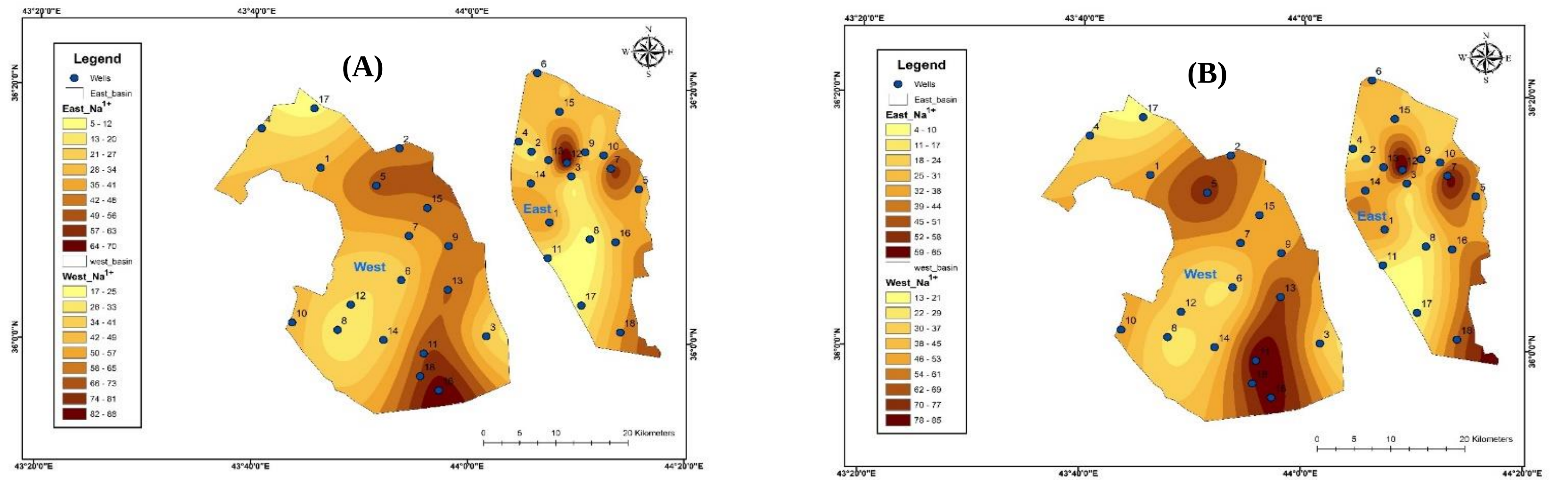

Fig. 9. Distribution of Na^{+} in the study area for: (A) dry season and (B) wet season

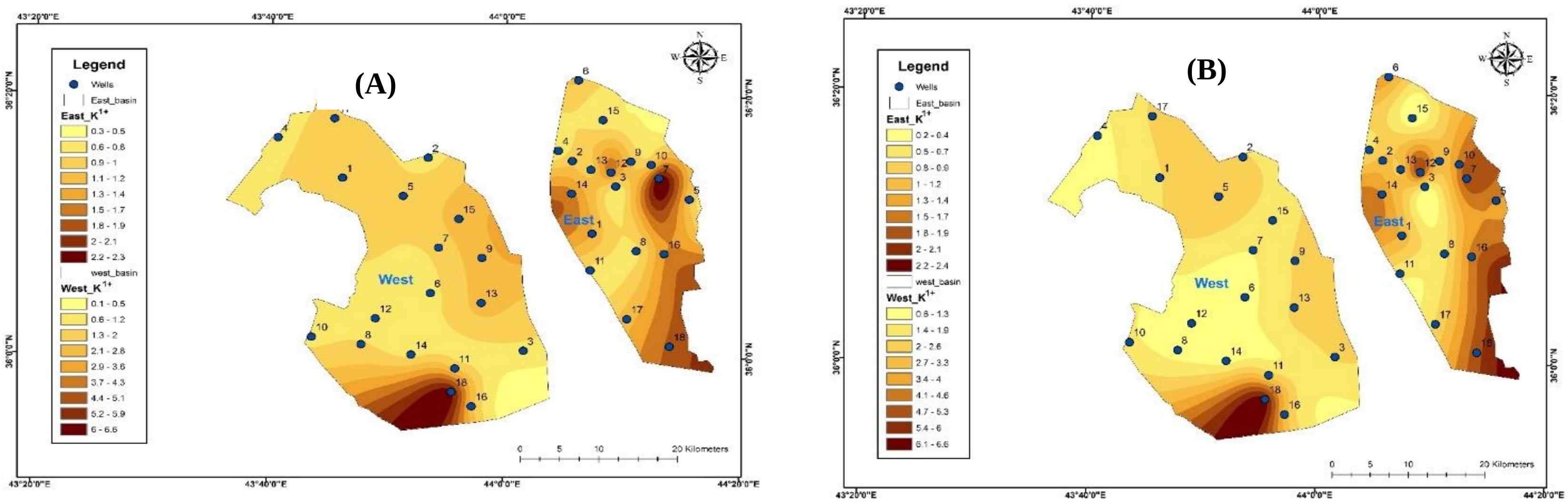

Fig. 10. Distribution of K^{+} in the study area for: (A) dry season and (B) wet season

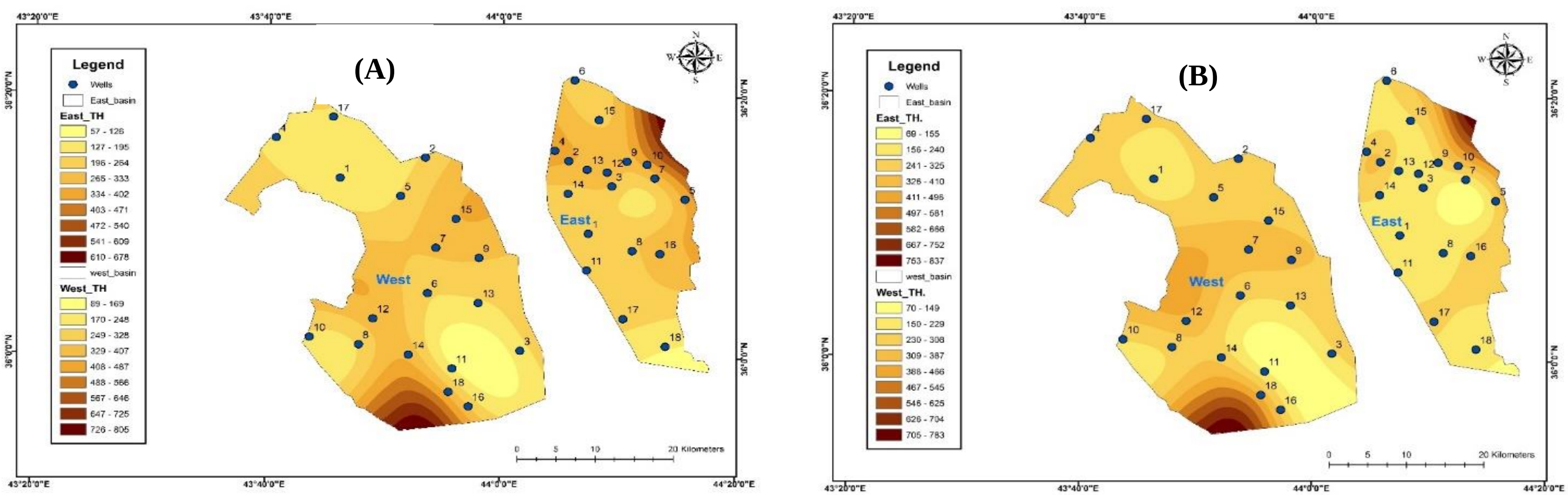

Fig. 11. Distribution of TH in the study area for: (A) dry season and (B) wet season

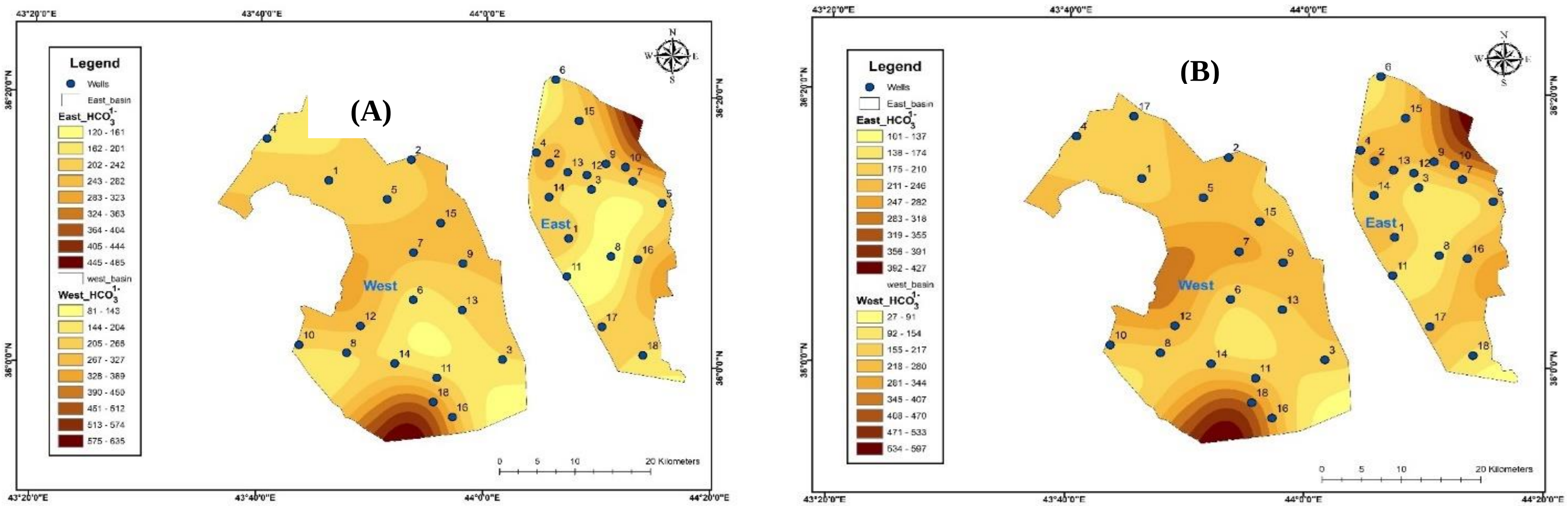

Fig. 12. Distribution of HCO_3^- in the study area for: (A) dry season and (B) wet season

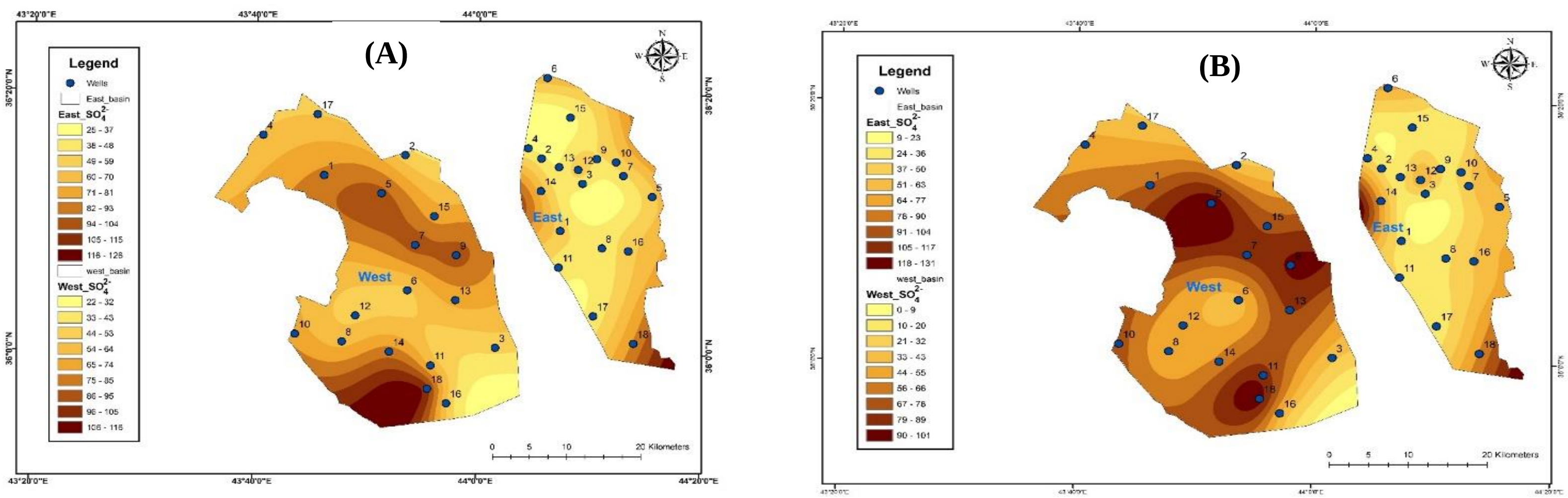

Fig. 13. Distribution of SO_4^{2-} in the study area for: (A) dry season, (B) wet season

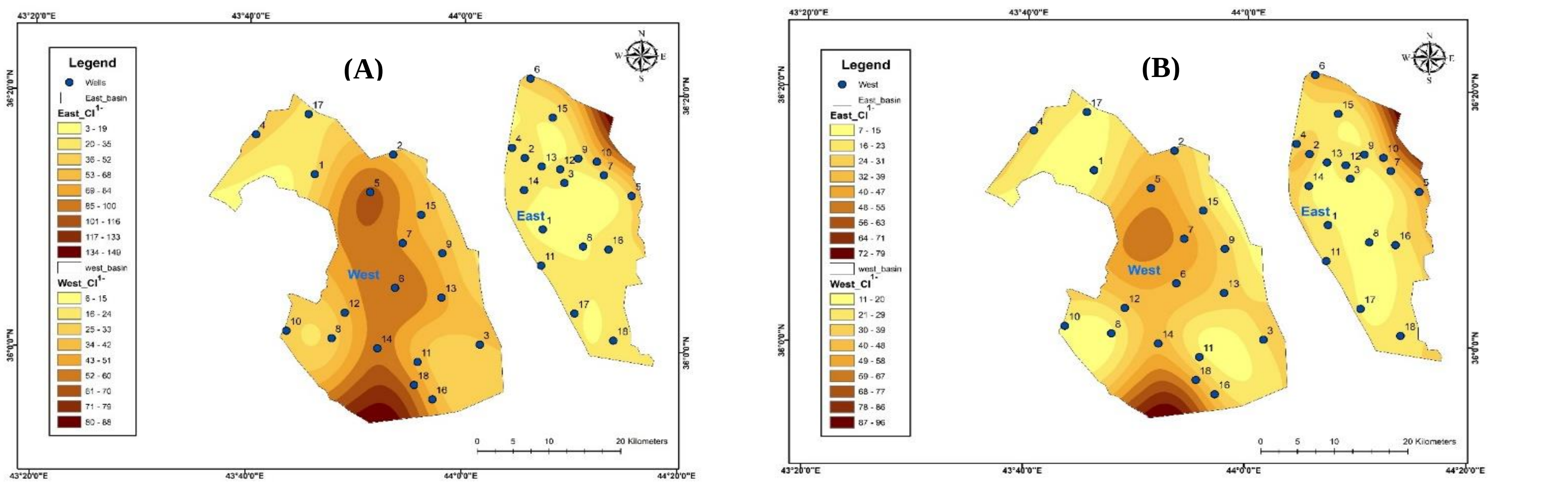

Fig. 14. Distribution of Cl^- in the study area for: (A) dry season, (B) wet season

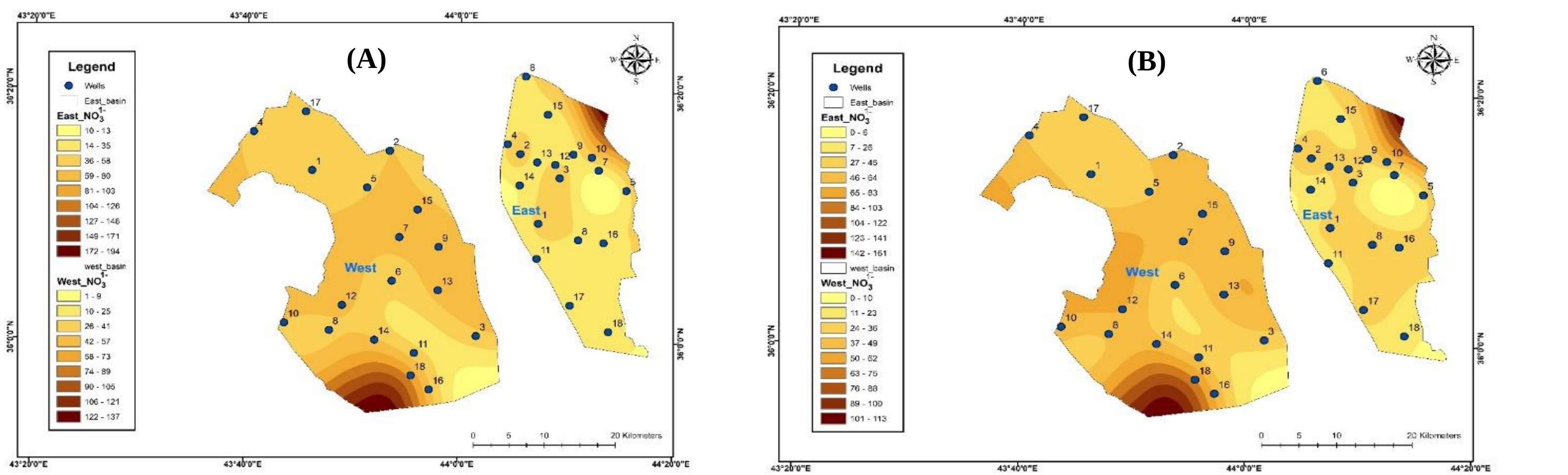

Fig. 15. Distribution of NO_3^- in the study area: (A) dry season and (B) wet season

Mechanisms Controlling Groundwater chemistry

Gibbs's diagrams, which depict the ratios of Na^{+}: (Na^{1+}+ Ca^{2+}) and Cl^{-}: (Cl^{-} + HCO_3^{-}) as a function of TDS, are frequently used to determine the valuable sources of dissolved chemical constituents (Gibbs, 1970; Langmuir, 1997). The chemical data of groundwater sample points in the area for both periods are plotted in Gibbs's diagrams (Figs. 16 and 17).

The distribution of sample points as a cluster suggests that the chemical weathering of rock-forming minerals has influenced the groundwater quality showing that the interaction between the aquifer and rocks is the main source for the concentration of chemical ions. As the study area enjoys arid to semi-arid climatic conditions, the weathering process and interactions enhance and release more dissoluble elements (Kumar et al., 2009).

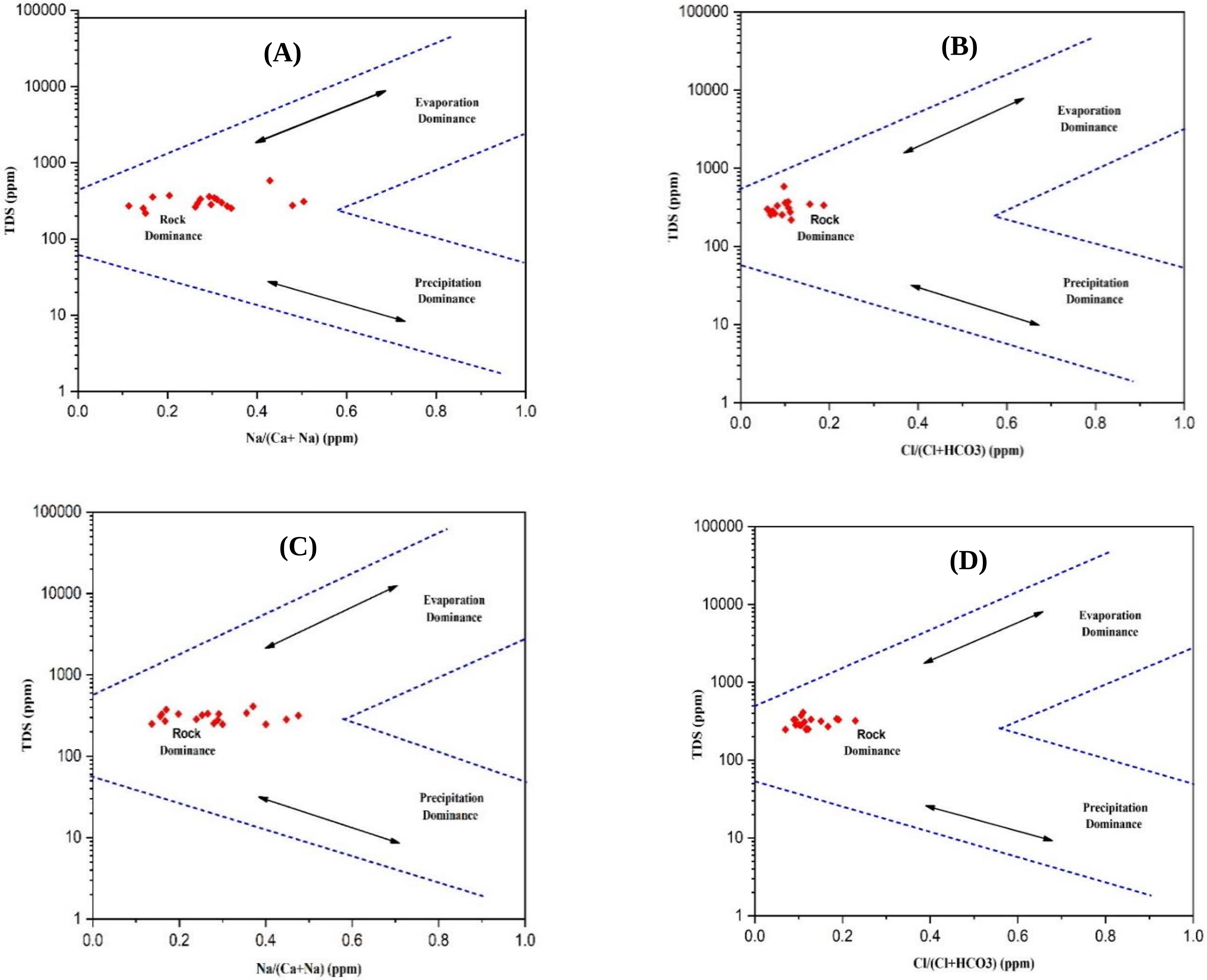

Fig.16. Mechanisms controlling groundwater quality (After Gibbs 1970) from the eastern part: (A, B) dry season (C, D) wet season

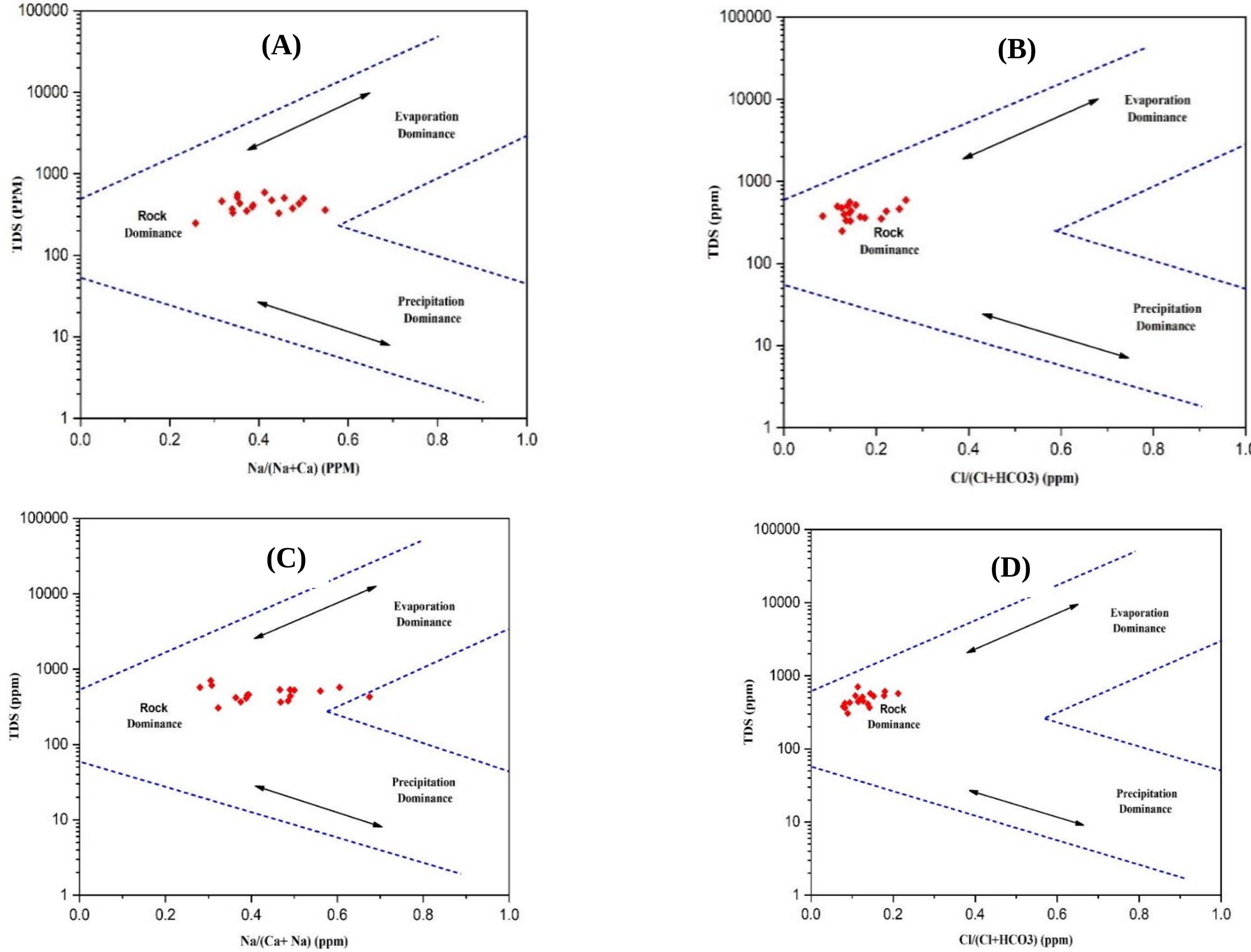

Fig.17. Mechanisms controlling groundwater quality (After Gibbs 1970) from the western part: (A, B) dry season (C, D) wet seas

Groundwater Classification

Piper (1944) diagram is used in order to classify the water samples under study. Chemical data of representative samples from the study area (east and west) are presented by plotting them on a Piper-tri-linear diagram for dry and wet seasons (Figs. 18 and 19). All water samples in the eastern and western parts during the first (dry) and second (wet) periods are of calcium bicarbonate water type. Also, Schoeller (1972) diagram is used to classify water samples according to the major cations and anions by plotting the concentration (in epm units) of these ions on a semi-logarithmic paper (Fig. 20). This type of diagram allows a visual comparison of the composition of different waters in descending order (Fetter, 1994). All water samples in the eastern and western parts during the first (dry) and second (wet) periods are of calcium bicarbonate water type.

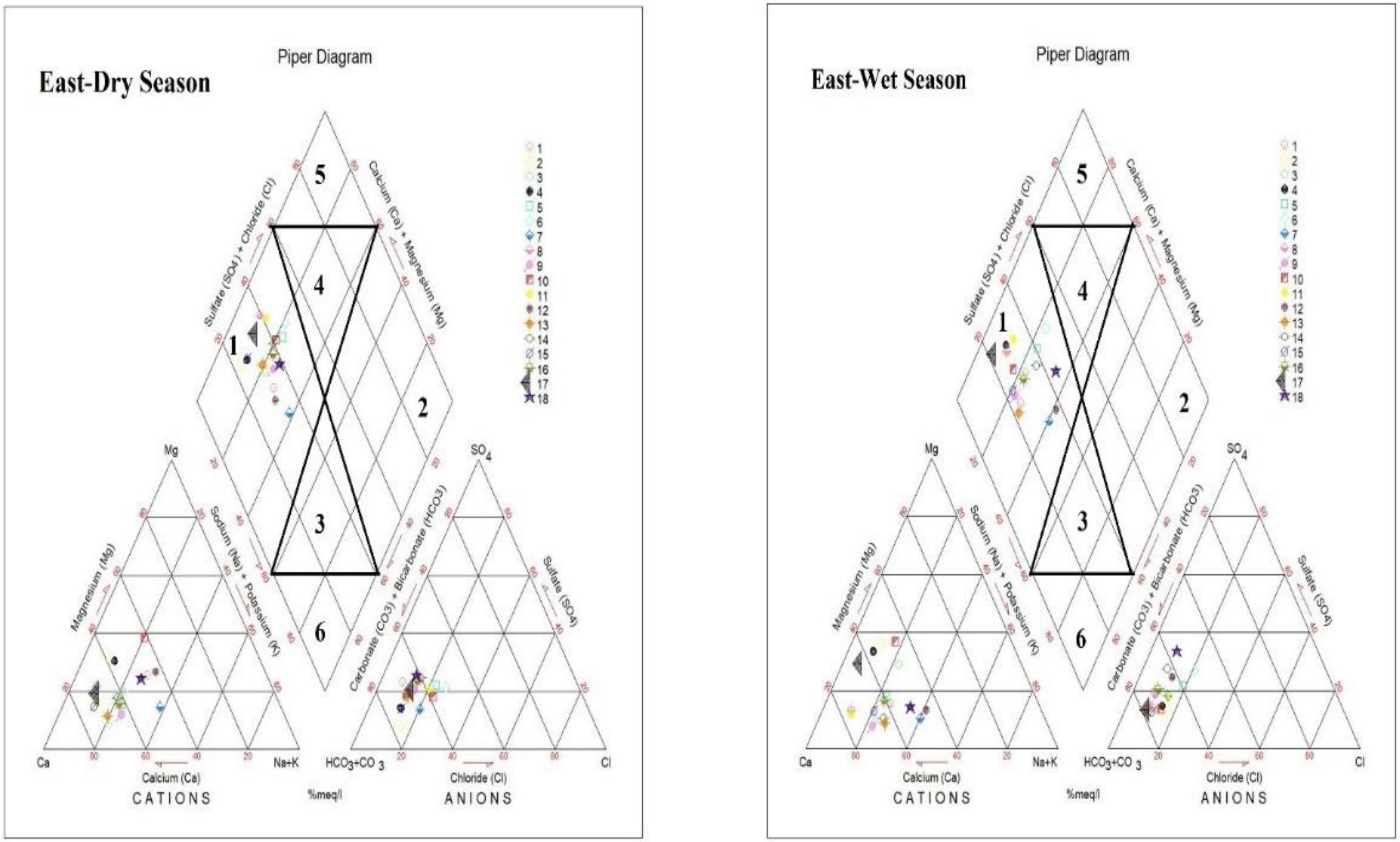

Fig. 18. Piper diagram depicting hydrochemical facies in dry and wet seasons from the eastern part of Erbil Basin

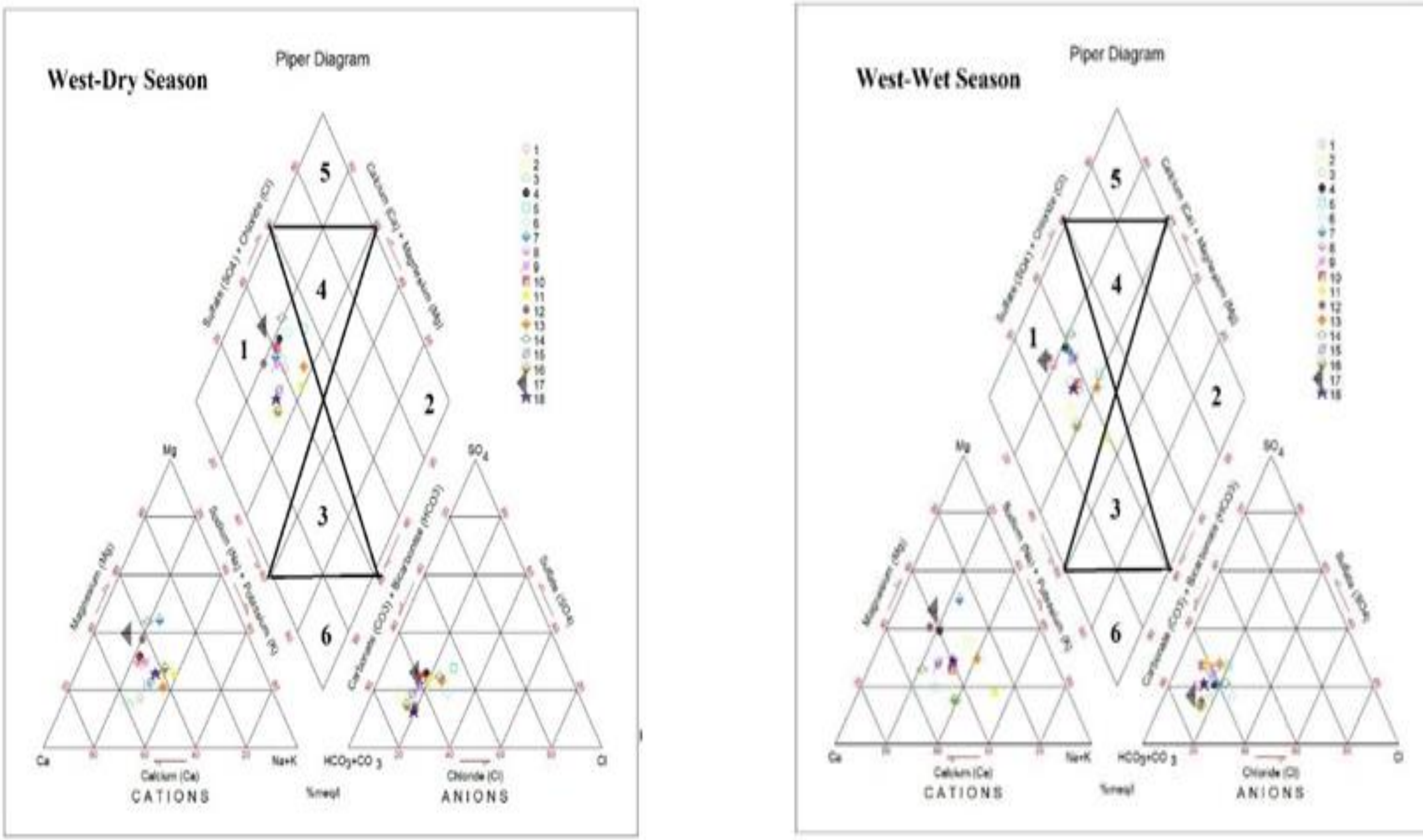

Fig. 19. Piper diagram depicting hydrochemical facies in dry and wet seasons from the western part of Erbil Basin

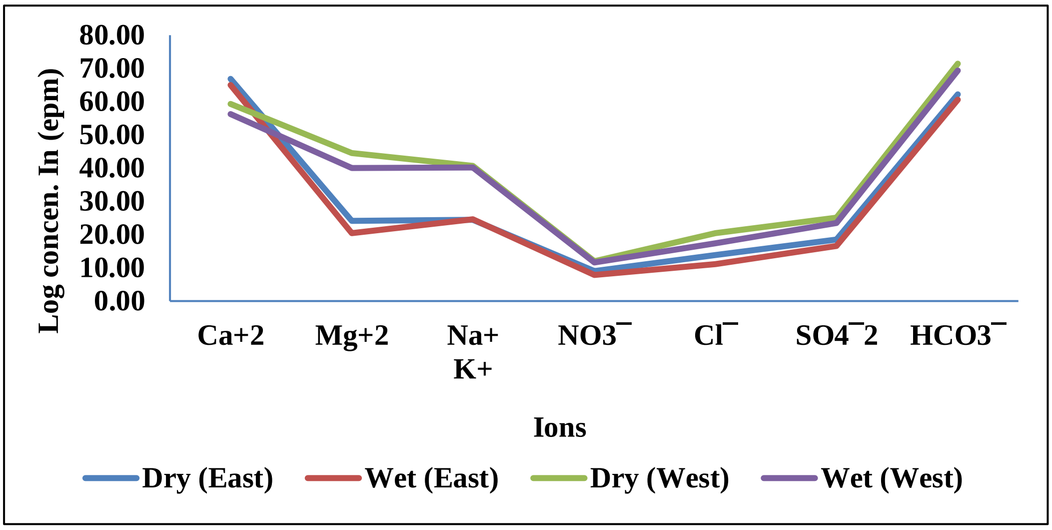

Fig. 20. Scholler classification of water samples in the eastern and western parts of Erbil Basin

Groundwater Uses

Groundwater Uses for Drinking Water Purposes

When drinking water does not result in any health issues or illnesses, it is said to be sanitarily non-defective water (Hassan, 1998). Groundwater's suitability as drinking water is based on several factors including its main and minor inorganic compounds, organic chemicals, biological content, and radioactive features (Al-Manmi, 2008).

According to Davis and DeWiest (1966), the two basic factors for determining drinking water standards are:

1. the existence of offensive flavors, smells, or colors.
2. a substance's presence that has harmful physiological (health) consequences.

Several standards, like WHO and Iraqi standards, can be used to determine if groundwater is safe to drink. Using the Sawyer and McCarthy (1967) hardness classification, the water samples are analyzed and put into groups based on their hardness (Table 8);

According to the Iraqi Drinking Water Standards (IDWS, 1996), the maximum amount of hardness that should be in the water is 500 mg/l. The TDS (ppm) amount is also safe based on the recommended limit of 1000 ppm allowed in all groundwater samples during both seasons. According to WHO (2006) generally water samples of both seasons are suitable for drinking with respect to cations and anions (Table 9).

Table 9: Comparison of studied water samples with (WHO, 2006 and IDWS, 1996) standard for drinking water from the Eastern and Western parts of Erbil Basin.

Variables	WHO (2006) ppm	IS (1996) Ppm	Eastern Part		Western Part	
			Dry Season Samples	Wet season Samples	Dry Season Samples	Wet season Samples
a^{2+}	75 - 200	50	57 - 90	50 - 88	46 - 90	40 - 87
Mg^{2+}	50 - 100	50	7 - 33	6 - 34	13 - 59	14 - 55
Na^{1+}	200 - 250	200	9 - 68	9 - 63	22 - 86	20 - 83
K^{1+}	10 - 12	-	0.6 - 2.2	0.2 - 1.8	0.9 - 6	1 - 6.1
Cl^{1-}	250	250	18 - 49	12 - 38	22 - 62	17 - 54
SO_4^{2-}	250	250	34 - 83	28 - 78	46 - 99	35 - 97
No_3^{1-}	50	50	18 - 48	14 - 43	30 - 67	25 - 62
T.H.	-	500	135 - 364	190 - 330	180 - 402	160 - 370
TDS	1000	1000	250 - 586	218 - 582	309 - 715	307 - 704
PH	6.5 - 8.5	6.5 - 8.5	7.5 - 8.2	7 - 8.1	7.3 - 8.5	7.4 - 8.1
Turbidity	5 NTU	-	0.3 - 5	0.3 - 2.5	0.5 - 5	- 5

Water Quality Index (WQI)

The composition of the recharge water, as well as interactions between the water and soil, soil gas, and rocks it comes into touch with in the saturated zone, all affect the quality of groundwater (Toma, 2013). According to the WHO organization, clean water is essential for many functions in order to live a healthy life; roughly 80% of all human illnesses are related to water (Toma, 2013).

The Water Quality Index is one of the fundamental methods for alerting consumers and decision-makers about water quality (WQI). It thus becomes a significant element in the assessment and management of groundwater in a specific region. The term "WQI" refers to a rating that takes into consideration the overall effect of numerous water quality factors (Ramakrishnaiah et al., 2009).

Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, NO_3^{-}, Cl^{-}, turbidity, pH, EC, TDS, alkalinity, total hardness, are analyzed using standard analytical methods (APHA, 1998).

Overall WQI= Σqiwi/ Σwi…………………. (7)

Water Quality Index (WQI) = Σqiwi……. (8)

Where, qi (Water Quality Rating) = 100 X (Va-Vi) / (Vs-Vi), When, Va = actual value present in the water sample; Vi = ideal value (0 for all parameters except pH and DO which are 7.0 and 14.6

(mg l^{-1} respectively); Vs = standard value.

If quality rating qi = 0 means the complete absence of pollutants, while 0 < qi < 100 implies that, the pollutants are within the prescribed standard.

Table 10: Water quality classification based on WQI value

Water Quality Index Level	Water Quality Status
WQI< 50	Excellent
50.1-100	Good
100.1-200	Poor
200.1-300	very Poor
> 300	unsuitable

The Water Quality Index (WQI) results illustrate that the studied groundwater is within a good level for all water samples from the eastern part in both periods; only the Baghmra Shahab well is within an excellent level in the first period (dry), and all water samples from the western part in both seasons are within a good level (Table 11).

Table 11: WQI of water samples from the eastern and western parts of Erbil Basin.

Name of wells (East)	WQI		Water Quality Status	Name of wells (West)	WQI		Water Quality Status
	Dry	Wet			Dry	Wet	
Bnaslawa	61.268687	50.299495	Good	Kawraban	69.842424	67.063434	Good
Shawes	75.166667	52.820000	Good	Sebiran	82.095960	80.432323	Good
Kasnazan	69.437374	54.536667	Good	Qushtapa	69.581818	64.370707	Good
Pirzin	66.425253	50.276364	Good	Xabat	60.043434	58.446667	Good
Braghi Gawra	68.564646	64.577879	Good	Kani Qrzhalla	75.175758	74.824848	Good
Qallamurtk	71.577778	66.136869	Good	Dalldaghan	95.129293	68.791919	Good
Mam Choghan	65.817172	57.042525	Good	Arab Kand	95.367677	91.090505	Good
Pungina	58.513131	60.331313	Good	Alyawa	77.003030	79.114646	Good
Shaomer	68.667677	63.984848	Good	Qatawy	88.722222	73.845253	Good
Sharaboti Gawra	88.112121	76.188990	Good	Shekh Sherwan	76.686869	69.404444	Good
Baghmra Shahab	60.006061	48.879293	Excellent	Trpaspian	75.951515	69.300000	Good
Pirash	73.326263	62.638586	Good	Mastawa	88.483838	96.043535	Good
Kani Gani	62.820202	54.029697	Good	Sherawa	83.845455	82.409394	Good
Sebardan	55.778788	56.495253	Good	Doghan	92.968687	82.321212	Good
Mala Omer	63.520202	57.989394	Good	Turaq	72.038384	68.391717	Good
Grdishi Xwaru	64.347475	58.215354	Good	Dukalla	89.830303	76.491919	Good
Lajan	56.340404	57.048485	Good	Topzawa	73.775758	71.767071	Good
Mirakani Shekh	68.963636	63.382020	Good	Baqrta	94.651515	85.354949	Good

Groundwater Uses for Livestock

According to Altoviski (1962), all water samples (Table 12) are great for cattle and poultry.

Table 12. Water quality guide for livestock and poultry uses (Altoviski, 1962) water from the eastern and western parts of Erbil Basin.

Elements ppm	Very Good	Good	Permissible Used	Can Used	Upper Limit	Water samples (Eastern Part)		Water samples (Western Part)	
						Dry Season	Wet Season	Dry Season	Wet Season
Na^{1+}	800	1500	2000	2500	4000	9 - 68	9 - 63	22 - 86	20 - 83
Ca^{2+}	350	700	800	900	1000	57 - 90	50 - 88	46 - 90	40 - 87
Mg^{2+}	150	350	500	600	700	7 - 33	6 - 34	13 - 59	14 - 55
Cl^{-}	900	2000	3000	4000	6000	18 - 49	12 - 38	22 - 62	17 - 54
SO_4^{2-}	1000	2500	3000	4000	6000	34 - 83	28 - 78	46 - 99	35 - 97
T.D. S	3000	5000	7000	10000	15000	250 - 586	218 - 582	309 - 715	307 - 704
T.H	1500	3200	4000	4700	54000	135 - 364	190 - 330	180 - 402	160 - 370

Groundwater Uses for Building Purposes

Altoviski (1962) classification is used in this study to figure out if the water could be used for building. Table (13) represents the comparison between Altoviski (1962) specificatios with water samples in the study area, demonstrating that this water is suitable for building purposes.

Table 13. Water quality using for building purposes according to Altoviski (1962) compared with studied water samples from the eastern and western parts of Erbil Basin.

Ion	Permissible limit (Altoviski,1962)	Permissible limit of studied water (Eastern Part)		Permissible limit of studied water (Western Part)	
		Dry Season	Wet Season	Dry Season	Wet Season
Na^{+}	1160	9 - 68	9 - 63	22 - 86	20 - 83
Ca^{+2}	437	57 - 90	50 - 88	46 - 90	40 - 87
Mg^{+2}	271	7 - 33	6 - 34	13 - 59	14 - 55
Cl^{-}	2187	18 - 49	12 - 38	22 - 62	17 - 54
SO_4^{2-}	1460	34 - 83	28 - 78	46 - 99	35 - 97
HCO_3^{-}	350	130 - 270	164 - 269	180 - 386	174 - 380

Groundwater Uses for Agricultural Purposes

Electrical conductivity and total dissolved solids both affect vegetation resistance (Todd, 1980). All water samples under study are appropriate for all sorts of agricultural crops at both parts and both seasons according to a comparison of water well samples with Todd's categorization criteria for agricultural crops (Table 14).

Table 14: Todd (1980) Classification for agricultural crops in comparison with water samples from the eastern and western parts of Erbil Basin.

Crop divisions	Low TDSendurance	Medium TDS endurance	High TDSendurance	Water samples (Eastern Part)		Water samples (Western Part)	
				Dry season	Wet season	Dry season	Wet season
fruit	3.0 dms/cm Avocado, lemon, Orange, apple Strawberry, picot Prune, plum	3.0-4.0 dms/cmOlive, date, fig Cantaloupe, pomegranate	4.0-10.0 dms/cmpalm	0.250 - 0.586 dms/cm	0.218 - 0.582 dms/cm	0.309 - 0.715 dms/cm	0.307 - 0.704 dms/cm
vegetable	3.0-4.0 dms/cm green bean,celery Radish,	4.0-10.0 dms /cm Cucumber, onion,peas Carrot, potato,cauliflower Lettuce,squash	10.0-120.0 dms/cm Spinach, kale Asparagus,				
Fieldcrops	4.0-6.0 dms/cmField bean,	6.0-10.0 dms/cm Sunflower, corn, riceFlax, castor bean,corn wheat	10.0-100.0 dms/cm Cotton, sugar beet, barley				

Conclusion

Generally, the concentration of physiochemical parameters, cations, and anions in the eastern part is lower than that in the western part because the eastern part is a good recharge zone and it depends on the soil formation and depth of wells. According to Gibbs diagram, the mechanism controlling groundwater chemistry from the eastern and western parts is the chemical weathering of rock-forming minerals in dry and wet seasons. According to Piper and Schoeller diagrams, the dominant types of groundwater from both parts is calcium bicarbonate in the dry and wet seasons. According to WHO (2006), all samples from both seasons are suitable for drinking with respect to cations and anions. The Water Quality Index (WQI) results illustrate that the studied groundwater is within a good level for all water samples from the eastern part in both periods; only the Baghmra Shahab well is within an excellent level in the first period (dry), and all water samples from the western part in both seasons are within a good level.

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