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Temporal Geochemical Changes and Evaluation the Suitability of Groundwater in Badra District in Eastern Wasit Governorate, Iraq

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ABSTRACT

Groundwater is essential for its different uses, especially when surface water is scarce or absent. The scarcity of surface water in various locations in eastern Iraq is a significant concern for life and the future. The temporal chemical changes of 20 groundwater samples collected from groundwater wells in Badra District, eastern Iraq are evaluated. The results reveal the mean values of cations; Ca2+ (215 ppm), Mg2+ (100.7 ppm), Na+ (256.5 ppm), and K+ (3.5 ppm), and anions such as SO42- (956.7 ppm), Cl- (342 ppm), and HCO3- (48.13 ppm), PO43- (3 ppm) and NO3- (21.5 ppm). The total dissolved solids (2128 ppm), electrical conductivity (3084µs\cm), pH (7.43), and temperature (20.18 °C) of the samples are obtained. The results are compared with other studies conducted in the two years (2005 and 2009). Despite a relative increase in the sulfate, TDS, chlorides, and sodium contents, the water quality has remained the same during the last ten years. In the recent study (2020), the same type of water quality characterized the water chemistry. At the same time, the increasing of SO42-, Cl-, NO3-, Mg2+, Ca2+, and K+ during ten years ago were due to climatic changes toward the aridity. The observed temporal chemical changes of groundwater are consoled with the climatic factors' alteration. The groundwater of the studied wells is unsuitable for human and livestock drinking and for irrigation with a risk of total dissolved solids and sulfates.

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التغيرات الجيوكيميائية الزمنية وتقييم مدى ملاءمة المياه الجوفية في قضاء بدرة شرق محافظة واسط، العراق

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الملخص

المياه الجوفية ضرورية لاستخداماتها المختلفة، خاصة عندما تكون المياه السطحية شحيحة أو غائبة. تعتبر ندرة المياه السطحية في مواقع مختلفة في شرق العراق مصدر قلق كبير للحياة والمستقبل. تم تقييم التغيرات الكيميائية الزمنية لعشرين عينة من المياه الجوفية جمعت من آبار المياه الجوفية في قضاء بدرة شرق العراق. أظهرت النتائج ان معدل تراكيز للكاتيونات Ca^{2+} (215 جزء في المليون)، Mg^{2+} (100.7 جزء في المليون)، Na^{+} (256.5 جزء في المليون)، و K^{+} (3.5 جزء في المليون)، والأنيونات مثل SO_4^{2-} (956.7 جزء في المليون)، Cl^{-} (342 جزء في المليون)، و HCO_3^{-} (48.13 جزء في المليون) ، PO_4^{3-} (3 جزء في المليون) و NO_3^{-} (21.5 جزء في المليون). تم الحصول على مجموع المواد الصلبة الذائبة، والتوصيل الكهربائي والأس الهيدروجيني، ودرجة حرارة العينات. تمت مقارنة النتائج مع دراسات أخرى أجريت في عامي 2005 و2009. على الرغم من الزيادة النسبية في محتويات الكبريتات والمواد الصلبة الذائبة والكلوريدات ومحتويات الصوديوم، فقد استمرت جودة المياه كما هي خلال السنوات العشر الماضية. في الدراسة الأخيرة (2020)، تميزت كيمياء المياه بنفس النوعية. في نفس الوقت؛ كانت هناك زيادة SO_4^{2-} وCl^{-} و NO_3^{-} و Mg^{2+} و Ca^{2+} و K^{+} منذ عشر سنوات بسبب التغيرات المناخية تجاه الجفاف. تُعزى التغيرات الكيميائية الزمنية المرصودة للمياه الجوفية إلى تغير العوامل المناخية. المياه الجوفية للآبار المدروسة غير مناسبة للشرب البشري. وهي مناسبة لشرب الماشية والري مع مخاطر المواد الصلبة الذائبة الكلية والكبريتات.

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Introduction

Climate change and its resulting impact on global warming have had significant detrimental effects on Iraq, making it one of the hardest-hit nations worldwide. Precipitation has become scarce and irregular, leading to a shortage of surface water resources (Tzanakakis et al., 2020). Additionally, Iran's construction of dams along river courses has disrupted the traditional irrigation of eastern Iraqi lands. Consequently, the reliance on groundwater wells, such as those in the Badra area, has become essential for survival. Thus, it is crucial to establish ongoing monitoring systems for these wells to manage production levels and maintain water quality suitable for various uses (Al-Jubory, 2005).

The principal aquifer in the eastern and northeastern regions of Iraq comprises Late Miocene - Pliocene deposits, specifically the Mukdadiya and Bi Hassan formations, with Quaternary deposits. These formations extend longitudinally, covering areas adjacent to the Iraqi-Iranian border (Jassim and Goff, 2006). Wells excavated to a depth of 20 meters yield valuable insights into the characteristics and distribution of the aquifer within the Quaternary deposits, particularly in the upper sections (Aqrawi et al., 2010). Deeper wells, reaching depths of up to 60 meters, provide a more comprehensive understanding of the nature, distribution, and extent of these reservoirs within the alluvial plain deposits (Ministry of Sciences and Technology, Saleh et al., 2020).

The primary factors that influenced the geochemistry of groundwater are the geological formations including the water-rock interaction and relative mobility of ions (Youssef et al., 2009). The presence of major ions percent and their ratios are significant in inferring the impact of rock chemistry on the composition of groundwater.

It has been reported that the main trend of groundwater movement happens according to the regional topography (Al-Abadi et al., 2016; Saleh et al., 2020). Groundwater movement from higher pressure to lower pressure region is slower than surface water movement. It is possible to determine the suitable sites for future drilling of the wells in the locations of the water aquifer with abundance by drawing the flow net that represents the direction of groundwater movement (Merkel et al., 2008).

Additionally, the geochemistry of groundwater is strongly influenced by the geological formations, water-rock interaction, and relative mobility of ions (Youssef et al., 2009). Major ions and their ratios are significant geological and hydrological factors such as porosity and permeability of rocks, presence of faults, the velocity of water movement, solubility, oxidation -reduction processes, and ion exchange can be useful to regulate and identifying the dissolved elements in the water.

To assess the geochemical changes that occurred over time, the samples are compared to the international standards and validated their appropriateness for different purposes. It became evident that the composition of groundwater is significantly influenced by the chemistry of the surrounding rocks. Additionally, the quality of the water is found to depend on the physical and chemical properties of the rocks through which it flows. The difference in water quality results from the diversity in the rock type in the geological formation and the geochemical features variation from place to place (Hiscock and Bense, 2021).

In this study, the selected area is the Wasit Governorate in Iraq within the tectonically Unstable Shelf (Fig. 1). The northeastern part is characterized by the high Mountain at the Iranian-Iraqi boundary, within the low folded zone, and other parts of the Wasit Governorate are in the Mesopotamian zone. Briefly, the study area lies within two zones, called the Mesopotamian Zone (Tigris Subzone) and the Foothill Zone (Himreen-Makhul Subzone) along the border of Iraq and Iran (Faisal and Mahdi, 2020).

Quaternary deposits mostly cover the Mesopotamian plain, including the study area. The upper part of the Mukdadiya Formation is very well exposed, about 20 km southeast of Badra town along the west side of the Foothill zone (Al-Shammary, 2009).

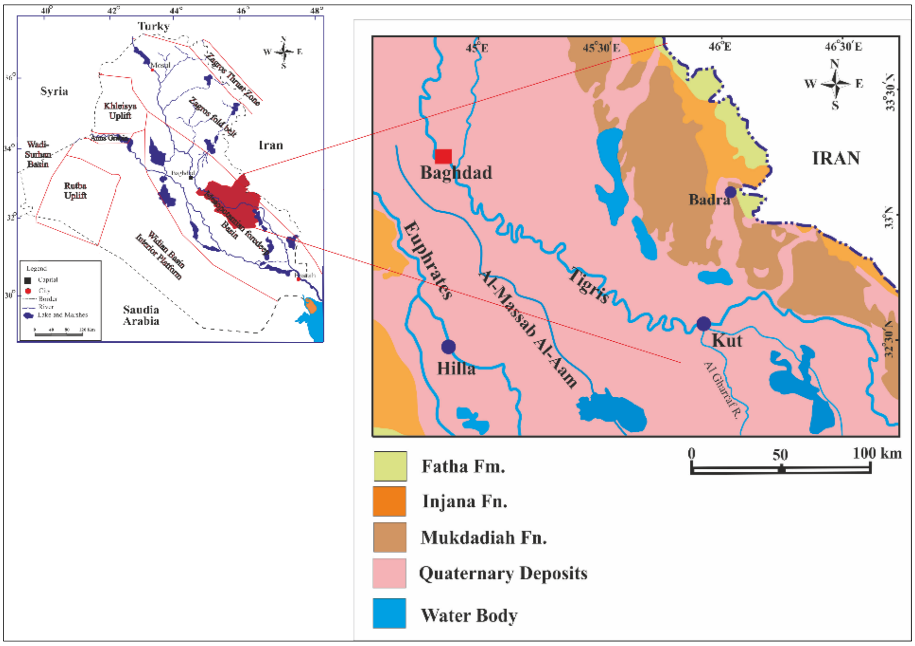

Fig. 1. Geological map of the study area

In the study area, the Pliocene age represents Mukdadiya and Bai Hassan formations (Fig. 1). In addition, Jeribe and Fatha formations represent some geological outcrops. The studied region is a part of the alluvial fan, and hydraulically is a part of the independent systems of the Mandali-Badra-Teeb aquifer (Jassim and Goff, 2006; Saleh et al., 2020).

The topographic elevation of the area is illustrated in Figure 2 wherein the Jeribe Formation is mainly composed of massive dolomitic limestone while the Fatha Formation is comprised of limestone and gypsum with layers of calcareous claystone.

This research aims to study the temporal chemical changes and groundwater assessments in the northeastern part of the Wasit Governorate for 15 years. Determining the suitability of groundwater for different uses.

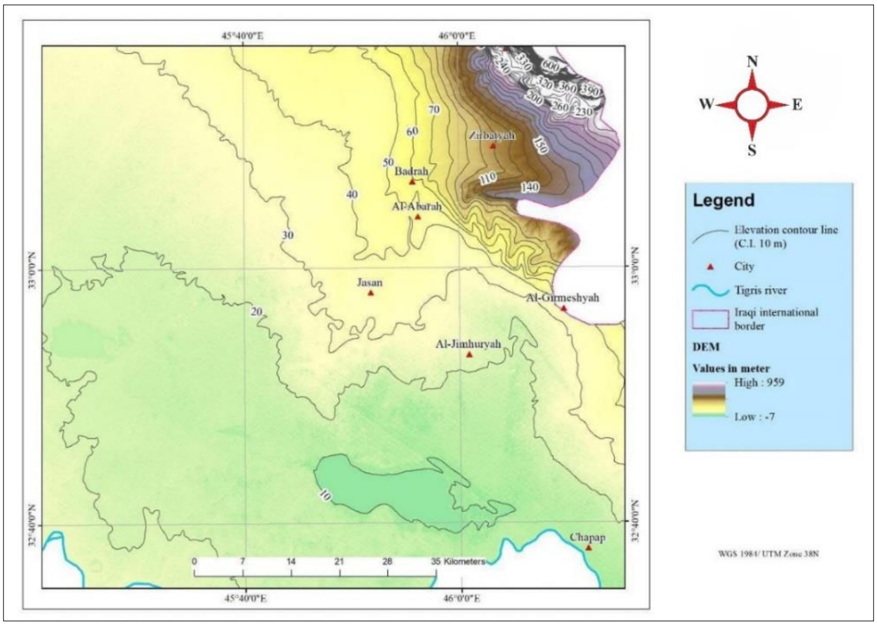

Fig. 2. The elevation map of the studied area

Methodology

Groundwater samples is located at various stations in the Badra district in the Wasit Governorate of Iraq. 20 groundwater samples are gathered from various wells located in the northeastern region of Wasit Governorate. They are collected from various wells located in this region for further evaluation of the temporal chemical alterations. The obtained groundwater samples are collected in April 2020 and stored in polyethylene bottles; each is one liter for further physiochemical analyses (Table 1; Fig. 3).

Table 1: Location and coordination of the collected groundwater samples in the studied area

No.	Sample Name	Station	N	E
1	1GW	Badra	33º 07′ 27″	46º 02′ 54″
2	2GW	Badra	33º 06′ 28″	45º 56′ 54″
3	3GW	Badra	33º 07′ 21″	46º 01′ 25″
4	4GW	Badra	33º 06′ 20″	45º 57′ 45″
5	5GW	Badra	33º 03′ 28″	45º 54′ 39″
6	6GW	Badra	33º 03′ 36″	45º 54′ 41″
7	7GW	Jassan	32º 53′ 38″	45º 54′ 41″
8	8GW	Jassan	33º 01′ 08″	45º 53′ 55″
9	9GW	Mazilia Village	33º 00′ 52″	45º 55′ 59″
10	10GW	Jassan	33º 06′ 5.7″	45º 58′19.5″
11	11GW	Qilmat	33º 07′ 14″	45º 58′ 53″
12	12GW	Quarry	32º 55′ 50″	46º 2′ 41″
13	13GW	Quarry	32º 55′ 56″	46º 2′ 34″
14	14GW	Quarry	32º 55′ 26″	46º 2′ 09″
15	15GW	Quarry	32º 56′ 08″	46º 2′ 29″
16	16GW	Quarry	32º 55′ 56″	46º 4′ 58″
17	17GW	Badra	33º 06′ 57″	45º 56′ 31″
18	18GW	Said Sifr Village	33º 03′ 47″	45º 57′ 12″
19	19GW	Gazprom Company	33º 03′ 47″	45º 59′ 11″
20	20GW	Jal Al-Hamra	33º 06′ 06″	45º 57′ 23″

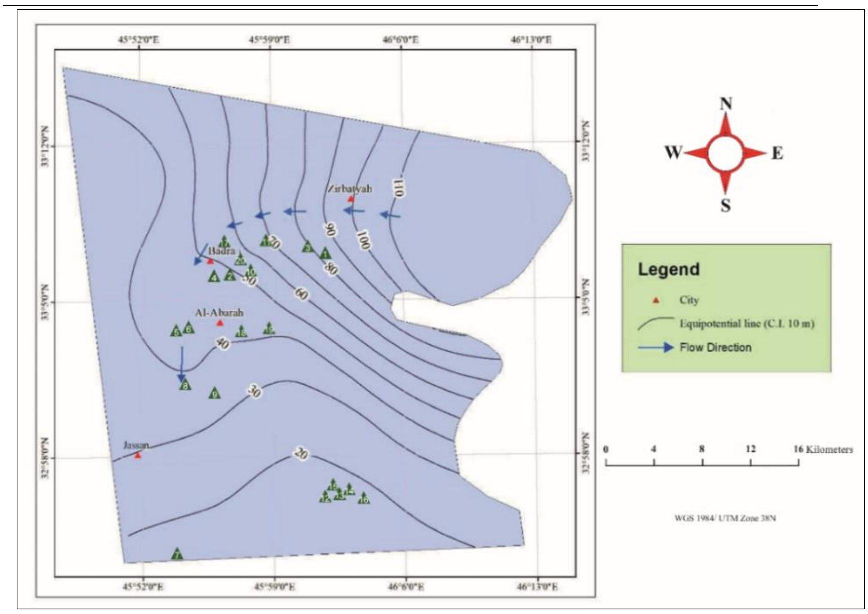

Fig. 3. Well location and groundwater movements in the studied (G.C.G.W., 2020)

The physical and chemical properties of the collected groundwater samples are measured using diverse techniques (TDS-EC-pH meter, Elico-Flame Photometer, titration device, and UV-Visible spectrophotometer). All equipments are cleaned using deionized water (DIW) to ensure the complete absence of any detectable contaminants (Faure, 1998). pH -EC is measured directly in the field by a TDS-EC- pH meter (Hanna HI 9813-6N, Italy made and conduct Janeway).

Vaporization is used at 105 °C (hotplate) to measure the TDS (Boyed, 2020). K^+ and Na^+ ions are analyzed by the Elico-Flame Photometer method (Flame photometer 410 device type Corning, India Made).

Titration with the EDTA method is used to measure the Mg^{2+} and Ca^{2+} contents in the samples. The concentration of calcium ion (Ca^{2+}) in the groundwater is determined by titration with EDTA (0.01N) wherein NaOH of 1 N is added to the unknown sample. Finally, SO_4^{2-}, PO_4^{3-}, and NO_3^- in the samples were analyzed using a UV-Visible spectrophotometer (Metertech Dr3000, HACH Company, USA Made). In addition, HCO_3^- and CO_3^- in the samples are analyzed by titration with HCl and the Bromo Cresol Green+ methyl red indicator method (Kenkel, 2013).

To estimate various physiochemical parameters of the groundwater samples, the researchers used different equations for index measurement. The presence of Na% is calculated (Todd, 2007) via:

$$Na\% = [Na + K] \times 100/\ [Ca + Mg + Na + K] \qquad (1)$$

The Magnesium Adsorption Ratio (MAR) is considered one of the significant qualitative principles in determining the quality of water used for irrigation. The value of the MAR in the studied groundwater samples is estimated via (Raghunath, 1987):

$$MAR = Mg^{2+}/\ (Ca^{2+} + Mg^{2+}) * 100 \qquad (2)$$

The sodium hazard of groundwater can be inferred to estimating the value of the Sodium Adsorption Ratio (SAR). The value of SAR in terms of the elemental concentration in meq/l is calculated using the relation (Richard, 1954):

$$SAR = [Na]\ /\ \sqrt{}(([Ca] + [Mg])/2) \qquad (3)$$

Results and discussion

The degree of the hydraulic connection varies from place to place according to the nature of these depositions as well as the presence of hydraulic connection among the reservoirs of the Quaternary deposits. The older deposits are represented by Bai Hassan and Al-Mukdadiya formations wherein the piezometric water level is considered to be continuous. In addition, the hydraulic connection between the groundwater and surface water is observed where the rivers and main canals are the important sources of groundwater in the region (Brunner et al., 2009).

The results are compared with the set international standard and validated to determine the suitability of such groundwater for different uses. The impact of rock chemistry on the groundwater composition. Water quality depends on the physical and chemical properties of the rocks that water passes through. The dissolved salt concentrations in water and their types depend on the aquifer nature, rock quality, water movement, water resources the contact surface among the rocks and water contained in the unit size, and contact time (Merkel et al., 2008).

The groundwater samples in the studied area are discerned to be odorless and colorless with a salty taste because of their high TDS concentration (Al-Shammary, 2009). In the unconfined aquifer of Quaternary sediments throughout eastern Wasit Governorate, the physical parameters (TDS, EC, pH, and total hardness (TH)) and chemical compositions of groundwater in terms of cations (Ca^{2+}, Mg^{2+}, Na^- and K^-) and anions ($PO_4^=$, HCO_3^-, $SO_4^=$, Cl^-, and NO_3^-), in addition to Na%, MAR, and SAR have revealed the groundwater specifications

(Table 2). Hydrochemical properties of the groundwater samples taken from the area are characterized by high TDS (2128 ppm) and EC (3084 μs/ cm) (Table 2). In this study, it is found that the hydrochemical changes present in the groundwater are due to increased salinity, and TDS. The majority of geological formations in the region are composed of evaporated deposits. In order to gain a comprehensive understanding of the temporal chemical changes of groundwater in this region, the results are compared with earlier studies. The samples are unsuitable for drinking, but acceptable for irrigation based on Na%, TDS, EC, and SAR values compared to available standards.

Thus, by drawing the flow net, it is possible to represent the direction of groundwater movement (high to low pressure region), providing the location of the suitable sites for future well drilling and areas of water aquifer abundance.

Table 2: The physical-chemical parameters of groundwater sample

Studies	Sam.	pH	Temp.	EC	TDS	$SO_4^=$	Cl^-	HCO_3	$PO_4^=$	NO_3^-	Mg^{2+}	Ca^{2+}	K^-	Na^-	TH
			°C	μs/ cm	ppm										
present study (2020)	1W	7.08	49	3081	2126	839	334	44	1.86	8.4	51	186	3.2	295	674.1
	2W	7.07	9.8	3068	2117	762	326	42	1.48	38.4	46	122	3.3	215	493.6
	3W	7.5	9.4	3057	2109	1097	203	30	1.06	24.8	102	174	3.9	237	853.2
	4W	7.6	9.6	3070	2118	984	297	36	1.12	22.8	112	191	3.4	232	936.7
	5W	7.4	18.4	3081	2126	982	367	61	5.44	41.2	118	198	3.7	256	978.8
	6W	7.4	18.6	3088	2131	1002	381	58	6.42	36.4	123	199	3.4	262	1001.8
	7W	7.4	18.6	3062	2113	978	264.6	57	2.66	36.8	109	192	3.8	232	926.9
	8W	7.43	18.2	3020	2084	944	225	64	2.41	30.3	105	176	3.5	212	870.5
	9W	7.7	19	2087	1440	582	276	45	1.48	23	43	152	3.8	210	556.3
	10W	7.2	28.5	3058	2110	968	252	36	0.64	12	87	182	3.6	228	811.7
	11W	7.6	28.5	3143	2169	1124	328	47	0.86	16.6	94	194	3.8	329	870.4
	12W	7.5	29.2	3094	2135	967	294	48	2.71	15.3	104	266	3.7	206	1091.4
	13W	7.47	28	3097	2137	896	333	58	1.88	14.9	94	248	3.6	214	1005.4
	14W	7.46	25.6	3280	2263	985	524	38	2.23	15.6	124	238	3.8	290	1103.4
	15W	7.51	25.5	3054	2107	928	305	44	2.06	14.4	98	216	4	196	941.8
	16W	7.44	25.3	3074	2121	960	320	54	1.94	15.1	96.4	210	3.3	261	920.24
	17W	7.5	20.5	3761	2595	1164	494	57	6.24	16.8	118	380	3.7	295	1433.8
	18W	7.2	20.8	3216	2219	1092	396	34	3.85	13.4	106	132	3.6	410	764.6
	19W	7.4	20.2	3162	2182	980	392	65	5.42	11.8	150	246	2.9	230	1230
	20W	7.8	20.5	3445	2377	1068	480	46	6.8	15.6	142	328	2.8	228	1402.2
	Min	7.07	9.4	2087	1440	582	203	30	0.64	8.4	43	122	2.8	196	493.6
	Max	7.8	49	3761	2595	1164	524	65	6.8	41.2	150	380	4	410	1434
	Mean	7.43	22.8	3084	2128	956.7	342	48.13	3	21.5	100.7	215	3.5	256.5	945
Al-Jubory, 2005	Min	7.1		980	800	500	22	37		8	30	150		200	
	Max	7.9		9104	7152	2971	1534	295		60	249	899		1380	
	Mean	7.58		4183	3255	1942	712	112		22.16	100	572		578	
Al-Sham-mary, 2008	Min	7.5	22	3250	2227	697.4	190	89.6	----	6.4	56	184	1.18	228	814.5
	Max	8.1	25	6220	4292	2307	884.5	649.35	----	30	191.3	700	20.85	539	2548.5
	Mean	7.7	23.6	4285	3057	1132.6	502.5	280.6	----	16.38	79.58	360	6.43	375	1286.2

The groundwater samples indicate their slight alkaline pH which range from 7.07 to 7.8. Water hardness (945 ppm) is influenced by dissolved polyvalent metallic ions, primarily calcium and magnesium cations (WHO, 2018). Total hardness values in the groundwater samples range from 943.6 to 1433.8 ppm, with an average of 945 ppm. Chloride (Cl) concentrations vary between 203 and 524 ppm, with a mean value of 342 ppm. According to the measured electrical conductivity (EC) of various groundwater samples, it can be classified as moderately mineralized water (Detay, 1997). However, the groundwater water samples are found to be hard based on the TH values (Todd, 2007) as in Table (3).

Table 3: Classification of the groundwater based on the measured EC and TH values (Todd, 2007)

EC µs/ cm	Mineralization	Total Hardness	Water class
< 1000	Very weakly mineralized water	< 75	Soft
1000- 2000	Weakly mineralized water	75- 150	Moderately hard
2000- 4000	Slightly mineralized water	150- 300	Hard
4000- 6000	Moderately mineralized water	> 300	Very hard
6000- 10000	Highly mineralized water		
> 10000	Excessively mineralized water		

The results of this study align with Todd's (2007) assertion that slightly brackish water is characterized by abundant dominant ions such as Ca^{2+} and SO_4^{2-}. The evaluated groundwater in the study area met the standards set by the Iraqi Quality Standards (IQS, 2009) and the World Health Organization (WHO, 2018). Major cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+), major anions (SO_4^{2-}, Cl^-, and HCO_3^-), and nutrients (NO_3^- and PO_4^{3-}) are present in all samples, providing valuable insights into the physiochemical parameters for establishing usage standards. The K concentration remains relatively stable, with no significant variations observed across the study area (ranging from 2.8 to 4 ppm) resulting in an average value of 3.5 ppm.

Significant changes and increases in Na concentrations are observed in the groundwater samples ranging from 196 to 410 ppm, likely due to salt dissolution (Cl^-, SO_4^{-2}, and HCO_3^-) and evaporate deposits entering the wells. The average Na concentration is 256 ppm, which is found to be widely distributed in the groundwater samples. Ca concentrations show wide variation from 122 to 380 ppm with an average of 215 ppm. Mg concentrations ranged from 43 to 150 ppm, with an average of 100.7 ppm. The increase in Mg^{2+} content could be attributed to the formation of carbonate minerals in the sediment. The increase in concentrations of the ions Ca and Mg can be explained by the dissolution of carbonate rocks that groundwater through which moves in the study area. Commonly, Ca and Mg contents maintain a state of equilibrium in most waters. Additional Mg in water can be detrimental to crop production and soil alteration towards more saline (Joshi et al., 2009). If MAR is more than 50, then it is considered harmful and unfit for irrigation, however, if MAR is less than 50, then the water is suitable for irrigation (Naseem et al., 2010).

The increase in Cl and Na content may be attributed to their very intensively solubility and motivation that come by surface water from different places. The main source of Cl ion in the studied water is from the exposure of evaporite rocks like gypsum which contain lenses of halite within gypsum layers of the Fatha Formation. Filtration of salt water from oil fields may contribute to increasing the concentration of dissolved sodium chloride content. The main source of sulfate is the exposure of gypsum rocks of Fatha Formation in the high lands at east. Organic shale can generate sulfates, leading to the oxidation of minerals like marcasite and pyrite (Davis and Dewiest, 1966), as well as the evaporation of dissolved rocks containing gypsum, anhydrite, and sodium sulfate. High sulfate concentrations may have a laxative effect on humans (Obiefuna and Sheriff, 2011). The studied groundwater exhibits sulfate concentrations ranging from 582 to 1164 ppm, with an average of 956.7 ppm.

Except for pH and HCO_3^-, the physicochemical parameters of the groundwater samples display wide variations. The cations followed the trend of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$, while the anions follow the trend of $SO_4^{2-} > Cl^- > HCO_3^-$. The predominance of sodium ions can be attributed to the presence of evaporate outcrops in the area, as reported by Al-Shammary (2009). The mean concentrations of cations and anions exceed the upper limits set by Iraq and WHO (2018).

The suitability of the groundwater samples in the studied area is validated using various standards such as Iraqi (IQS, 2009), World Health Organization (WHO, 2018), and Environmental Protection Agency (USEPA, 2018). Table (4) shows the mean concentrations of different ions and values of the physiochemical parameters of the groundwater samples.

Table 4: Mean concentration and values of physiochemical parameters of groundwater

Parameters	Units	Standards			
		Mean	IQS 2009	WHO 2018	USEPA 2018
Temperature	ºC	22.8	-----	-----	-----
pH		7.43	8.5	8.5	8.5
EC	µs\cm	3083.92	1530	-----	-----
TDS	ppm	2128	1000	1000	500
TH		945	500	500	-----
Ca^{2+}		215	150	100	-----
Mg^{2+}		100.7	100	125	-----
Na^{+}		256.5	200	200	-----
K^{+}		3.5	-----	12	-----
Cl^{-}		342	350	250	250
SO_4^{2-}		956.7	400	250	250
HCO_3^{-}		48.13	-----	-----	-----
NO_3^{-}		21.5	50	50	10
PO_4^{3-}		3	------	0.4	-----

Table (5) summarizes the maximum concentrations of various ions in the proposed groundwater samples when compared with the water quality parameters (ppm) guide for the livestock usage referred to Altoviski (1962). The studied groundwater samples are discerned to be a very good class for livestock with little risk of Ca, and SO_4^{2-} (Altoviski, 1962). For irrigation, the class of the studied groundwater samples is assessed to regulate the exact level of the physicochemical parameters with special importance on its irrigation suitability for sustainable crop production.

Table 5: Maximum concentrations of groundwater in the study area compared with water quality parameters (ppm) guide for the livestock usages after Altoviski (1962)

Para-meter	V. good	Good	Permi-ssible	Can be used	Max. limit	Groundwater current study
Na^{+}	800	1500	2000	2500	4000	410
Ca^{2+}	350	700	800	900	1000	380
Mg^{2+}	150	350	500	600	700	150
Cl^{-}	900	2000	3000	4000	6000	524
SO_4^{2-}	1000	2500	3000	4000	6000	1164
TDS	3000	5000	7000	10000	15000	2595
TH	1500	3200	4000	4700	5400	1433.8

Table (6) displays the standard and class evaluation results of the studied groundwater samples in terms of SAR, MAR, pH, EC, TDS, and Na contents that determined the suitability for agricultural and irrigation uses (Don, 1995).

Table 6: Agricultural assessments according to classification of Don (1995) for irrigation waters

Groundwater	EC µs\cm	TDS ppm	SAR	Na%	MAR%	pH	Water Class
Standard	< 250	< 175	<3 3-5	< 20	< 50	<6.5	Excellent
Standard	250−750	175-525		20-40		6.5-6.8	Good
Standard	750−2000	525-1400	5-10	40-60		6.8-7.0	Permissible
Standard	2000−3000	1400-2100	10-15	60-80	> 50	7- 8	Doubtful
Standard	>3000	>2100	>15	80 <		>8	Unsuitable
Current study	3083.92	2128	5.15	45.42	37.9	7.4	

Appropriate water usage is crucial to preserve plant and soil health in agriculture. Researchers have categorized water to evaluate its impact on crop production and sediment quality, considering salinity hazards, sodium hazards, pH, alkalinity, and specific ions like chloride, sulfate, nitrate, and nitrogen. Irrigation water can potentially contain pollutants such as heavy elements and microbial toxins, affecting its suitability for agriculture (Bauder et al., 2004). When irrigation water contains more Na than Ca and Mg in swelling sediment clays, it reduces water infiltration. This hampers the movement of rainwater or irrigation water through the sediment, negatively affecting plant growth (Hamza, 2012). Ultimately, water used in agriculture should meet the requirements of both plants and animals. It's important to consider permissible ranges for parameters like SAR, pH, TDS, EC, Na %, and MAR, as outlined in Table (6), to determine the quality of irrigation water. For instance, like irrigation water Na content (in percent) above 60% may weaken soil structure, infiltration, and aeration (Hakim et al., 2009).

The mean value of MAR% (37.9) calculated using Equation 2 (Table 6) indicates that the studied groundwater samples are suitable for irrigation. In addition, the values of Na% (obtained using Equation 1), SAR (obtained using Equation 3), and pH of the groundwater samples collected from the selected area confirmed their suitability for using in irrigation and building with attention to the high content of HCO^{-}_{3} and SO_4^{2-} in the drainage canal water. Wherein the SAR value provides a strong idea about the adsorption of Na by the soil. It is the proportion of Na to Ca and Mg that affects the usefulness of water to crop production (Singh and Singh, 2008). The degree of the suitability of water agricultural irrigation is used.

Usually, the correlation between EC and sodium hazard (adsorption ratio) can be used to identify the irrigation water type (Dhok et al., 2011). The studied groundwater samples showed a very high salinization hazard (C4) and medium sodium hazard (S2) as shown by all water quality indices (Fig. 4). It is asserted that the studied groundwater can be used with care in soils as long as it has good permeability with proper drainage.

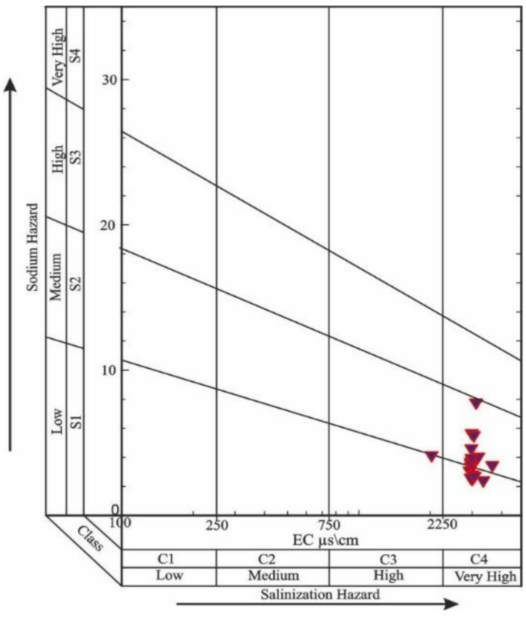

Fig. 4. Irrigation water classification based on the EC and the sodium adsorption ratio

Different industries have specific standards and varying requirements for the quality of water used in their operations (Hem, 1991). For instance, the pharmaceutical and paper industries demand highly purified water is needed similar to distilled water in terms of cleanliness. On the other hand, in industries involving steam boilers operating at higher vapor pressures, distilled water can be purified to meet specific needs. The analyses of various ion concentrations indicate that the groundwater samples in the study area are unsuitable for most industrial purposes due to elevated levels of Ca^{2+}, Mg^{2+}, SO_4^{2-}, and TDS (Table 7). However, for building construction, the groundwater samples are deemed suitable based on the classification by Altoviski (1962).

Table 7: Concentration limits of phytochemical parameters for industrial purposes (Hem, 1991)

No.	Industrial Uses	Ca^{2+}	Mg^{2+}	Cl^-	SO42-	HCO_3^-	TH	TDS	pH
1	Hydraulic Cement Manufacture	----	----	250	250	----	----	600	8.5
2	Leather tanning	----	----	250	250	----	Soft	----	8.0
3	Soft-drinking bottling	100	----	500	500	----	----	----	----
4	Canned, dried, frozen fruits and vegetables	----	----	250	250	----	250	500	8.5
5	Petroleum products	75	30	300	----	----	350	1000	9.0
6	Synthetic rubber	80	36	----	----	----	350	----	8.3
7	Wood chemicals	100	50	500	100	250	900	1000	8.0

The concentration range of cations and anions in the groundwater samples fell within permissible limits, as shown in Table (8). This indicates that the quality of groundwater in the study area is suitable for building purposes.

Table 8: Result of water description for building purposes (Altoviski, 1962) compared with the obtained results of groundwater of the studied area

Ions	Allowable limit	Groundwater	Water Quality
	ppm		
Ca^{2+}	437	215	**proper**
Mg^{2+}	271	100.7	
Cl^-	2187	342	
SO_4^{2-}	1460	956.7	
HCO_3^-	**350**	**48.13**	

It is worth noting that around fifteen years ago, most of the groundwater in the same area was unsuitable for human consumption but acceptable for livestock. Similarly, the majority of groundwater samples from this region are not suitable for agricultural purposes, except in sandy areas with high permeability. Maps illustrating the distribution of total dissolved solids (TDS) in groundwater are derived from the internal report of M.S.T. (2015) and modified in the current study (Fig. 5).

Increasing the concentration of sulfate is reached ions by the processes of dissolving of evaporate rocks, shale, and clay grosses water the property of deep water (Davis and Dewiest, 1966).

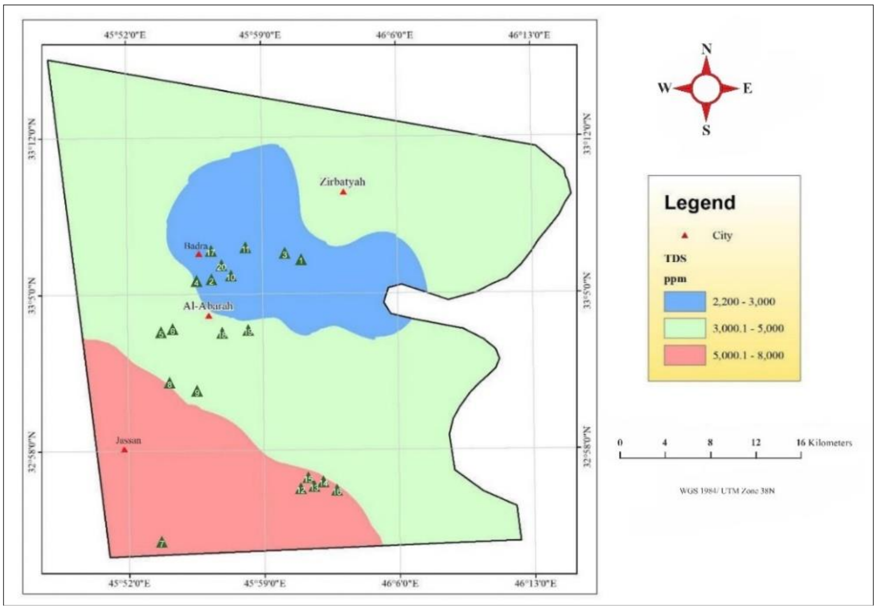

Fig. 5. TDS distribution map in the study area

The groundwater, during its path from feeding zones to drainage areas, is subjected to multiple processes that cause changes in its chemical composition such as evaporation, increasing concentrations of elements, mixing, and dilution. When the sodium ion, concentration is higher than the concentration of chloride ion the water takes the property of continental water (Hiscock and Bense, 2021). The groundwater quality within Wasit Governorate is heterogeneous. It is mostly sulfate in the high northeastern regions, and mostly chloride in the alluvial plain. Bicarbonate water is present in the areas adjacent to river streams and irrigation channels due to direct feeding from these fresh sources.

Using the Piper diagram, it is apparent that the groundwater samples are plotted in Cl-SO_4^{2-} , whose type belongs to the sulphate type (Fig. 6).

About a few years ago, in 2005, 2008, and 2010, most of the groundwater wells in the Waist province showed a high concentration of sulfate (697.4 ppm), chloride (190 ppm), and a slight increase in bicarbonate (89 ppm) respectively (Al-Jubory, 2005; Al-Shammary, 2008). In 2003, the groundwater of the studied area was located in the aquifer of the Quaternary sediments on the right bank of the Tigris River. A sharp increase in the concentration of sulfate (956.7 ppm), chloride (342 ppm), NO_3 (21.5 ppm) and all cations, like Mg^{2+} (100.7 ppm), Ca^{2+} (115 ppm), K^- (3.5 ppm), Na^- (256.5 ppm) are observed, leading to a very TH value of 945 ppm.

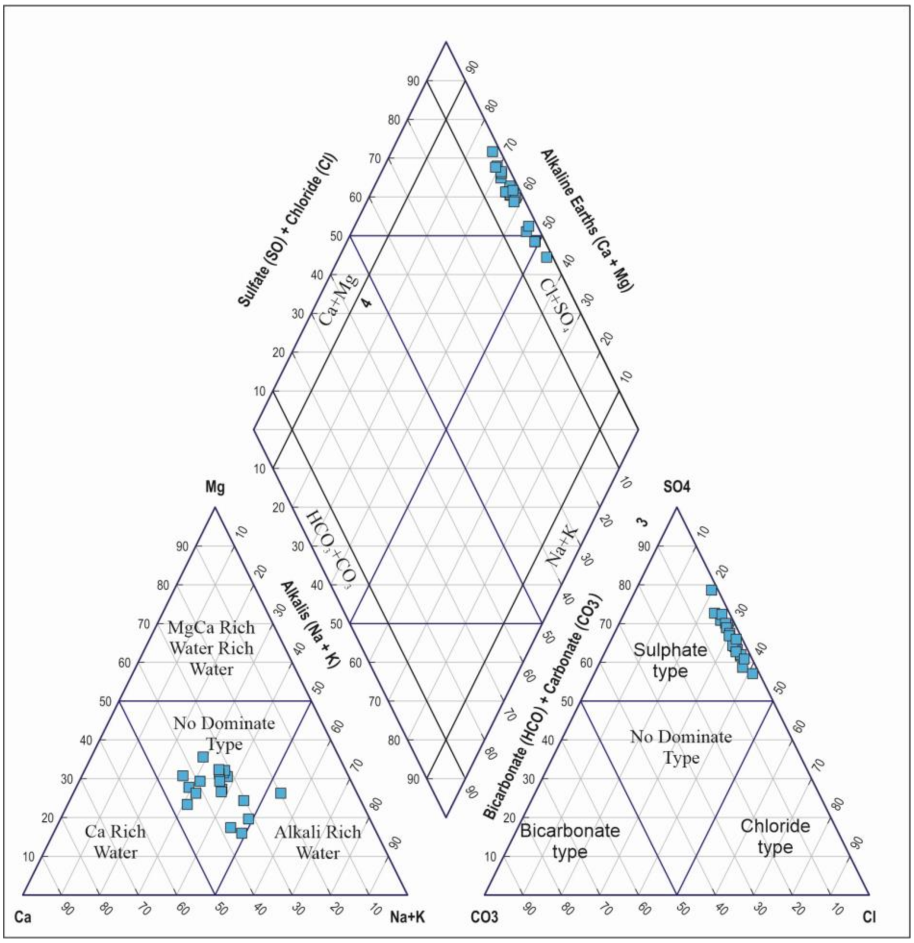

Fig. 6. Piper diagram classification of Badra groundwater.

Conclusions

The hydrogeochemical approach is used to evaluate the groundwater samples' salinity, various ions' concentrations, pH, TDS, MAR, and SAR to ascertain their suitability for drinking, livestock, irrigation, industrial, construction, and agricultural uses. In 2005 and 2008, the groundwater types for the confined aquifer were rich in Na^+, Ca^{2+}, Cl^- and SO_4^{2-}.

In conclusion, the study confirms the prevalence of the dominant ions in slightly brackish water, as suggested by Todd (2007). The evaluated groundwater samples met the set standards and provided insights into their suitability for various uses. However, the concentrations of cations and anions exceeded the standard limits, emphasizing the need for appropriate treatment or management strategies.

After about ten years in 2020 (in the current study), the same type of water quality characterized the water chemistry. This means the convergence and similarity of temporal, chemical, geological, and climatic changes in groundwater over the last thirty years in the region. The concentrations of SO_4^{2-}, Cl^-, NO_3^-, Mg^{2+}, Ca^{2+}, and K^+ ten years ago were due to climatic changes toward the aridity. The increase of SO_4^{2-} and Cl^- precipitation caused the deposition of a large quantity of salts. Based on the results and in-depth analysis, it is shown that the groundwater samples in the studied area are unsuitable for human consumption according to the approved standards of Iraq and WHO. However, it is possible to desalinate the wells to make them suitable for human drinking. Furthermore, the studied groundwater is suitable for livestock drinking and irrigation with a risk factor for TDS and sulfates. Briefly, the water from the wells in Badra is unsuitable for industrial usage but suitable for the building sector.

It is suggested that to use this well water for drinking and human consumption, purification plants must be installed to treat salinity and water sterilization, subjecting the extracted water to total control to ensure that the depletion to the maximum limits as the increasing water demand requires a well-planned move. Necessity clears the frontier areas with Iran of mines in the province because they are relatively promising areas for the investment of groundwater for agricultural purposes (groundwater) in Wasit Governorate.

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Conflict of Interest

The authors declare that there is no conflict of Interest between us as the authors and the institute where the work has been carried out.

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