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Evaluation of Groundwater Using The Water Quality Index (WQI) In Hawija Area, Kirkuk, Northern Iraq

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ABSTRACT

The water quality index (WQI) is used to comprehend the Hawija region's groundwater quality for drinking purposes, where some people solely utilize the groundwater for drinking purposes. Forty groundwater samples are collected from Hawija region's wells. The groundwater is somewhat hard and slightly alkaline. The collectrd water samples are sent to (Acme Lab.Canada) for analysis. The results then are compred with the Iraqi standards, the World Health Organisation (WHO) standdards and with the Environmental Protection Agency (EPA) classification of water quality in order to decide the water suitability for various uses. This paper also examines the physical properties such as pH, electrical conductivity, temperature, dissolved salts, and chemical properties, including estimating the water content of major ions. In the low-flow season, the WQI values vary from 29.96 to 112.5, whereas in the high-flow season, they range from 25.61 to 142.32. Out of 40 groundwater samples, 12 (30%) are deemed to have excellent water quality, 17 (42.5%) are deemed to have bad water quality, 10 (25%) are deemed to have extremely poor water quality, and 1 (2.5%) are deemed unfit for drinking during the low flow season. Groundwater samples taken during the high flow season had a water quality rating of 16 (40%) good, 14 (35%) bad, 7 (17.5%) extremely poor, and 3 (7.5%) unfit for drinking. This suggests that much of the research area's groundwater samples are unsuitable for human consumption.

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تقييم المياه الجوفية باستخدام مؤشر جودة المياه (WQI) في منطقة الحويجة ، كركوك، شمالي العراق

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الملخص

تم استخدام مؤشر جودة المياه (WQI) لفهم نوعية المياه الجوفية في منطقة الحويجة لأغراض الشرب. حيث يستخدم بعض السكان المحليين المياه الجوفية فقط لأغراض الشرب. تم جمع 40 عينة مياه جوفية من الآبار الجوفية بمنطقة الحويجة. كانت المياه الجوفية عسرة إلى حد ما، وقليلة القلوية. تم ارسال العينات إلى مختبر (Acme Lab) في كندا لتحليلها. بالإضافة إلى مقارنة نتائج الدراسة الحالية بالمتطلبات العراقية وتصنيف منظمة الصحة العالمية ووكالة حماية البيئة لجودة المياه ومدى ملاءمتها للاستخدامات المختلفة ، تتناول هذه الدراسة أيضًا الخصائص الفيزيائية مثل الأس الهيدروجيني والتوصيلية الكهربائية ودرجة الحرارة واجمالي الأملاح الذائبة والخصائص الكيميائية ، بما في ذلك تقدير المحتوى المائي للأيونات الرئيسية. في موسم التدفق المنخفض ، تفاوتت قيم WQI من 29.96 إلى 112.5 ، بينما تراوحت في موسم التدفق العالي من 25.61 إلى 142.32. من بين 40 عينة من المياه الجوفية، تم اعتبار 12 عينات (30٪) ذات جودة مياه ممتازة، و 17 (42.5٪) ذات نوعية مياه رديئة، و 10 (25٪) ذات نوعية مياه رديئة للغاية، و 1 (2.5 ٪) غير صالحة للشرب خلال موسم الجريان المنخفض. عينات المياه الجوفية المأخوذة خلال موسم الجريان المرتفع كان تصنيف جودة المياه فيها 16 (40٪) جيد ، 14 (35٪) رديئة ، 7 (17.5٪) فقير للغاية ، و 3 (7.5٪) غير صالحة للشرب. يشير هذا إلى أن الكثير من عينات المياه الجوفية في منطقة البحث غير مناسبة للاستهلاك البشري.

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Introduction

Water is as important as oxygen for humans beings, as it is a basic demand to life and the basis of existence for all aspects of survival of living things. An important matter in determining water suitability is by focusing on some physical and chemical properties of surface and groundwater to understand causes and problems of the water pollution, and then to treat polluted water simply and inexpensively (Han et al., 2022; Hasan and Muhammad, 2020). Groundwater is not pure when it contains colloidal, soluble, and suspended materials in different concentrations. Thus, it is necessary to determines its quality and for various uses because its components differ from surface water (Deutsch, 2020) The hydrological cycle has a vital effect in the chemical and physical properties and content of ions and heavy elements in water. More than 1.5 billion people depend on the groundwater for drinking, according to Shen et al., (2008). In the last two decades, the demand for groundwater resources has skyrocketed not only in the semi-arid region but also globally, particularly for drinking and irrigation (Kundzewicz and Doell, 2009; Alfarrah and Walraevens, 2018; Priyan, 2021). In addition, the groundwater contamination has rapidly increased in numerous geological terrains that have experienced a rapid increase in industrialization and urbanization, huge population growth, significant development in agriculture, excessive use of fertilizers, vast evaporation, and low rainfall (Sarker et al., 2021). Additionally, it is estimated that more than 60% of the irrigated farmland and 85% of drinking water supplies are derived from groundwater, making it an essential resource for rural populations in the Hawija region. This paper includes the study of physical properties such as pH, electrical conductivity, temperature, dissolved salts, and chemical properties that include estimating the water content of major ions and heavy elements, as well as comparing the results of the current study with the Iraqi specifications with the World Health Organization (WHO) standards and with the Environmental Protection Agency (EPA) classification of water quality and its suitability for various uses. The WQI findings show that out of 40 samples, 30 percent are classified as having excellent water quality, 42.5% as having bad quality, 25% as having extremely poor quality, and 2.5% were not fit for human consumption during the low flow season. In the high flow season, the water quality of groundwater samples range from fair (40%) to bad (35%) to extremely poor (17.5%), and 3 samples (7.5%) are unfit for drinking. This shows that further groundwater samples from the research region are unsafe for human consumption.

Materials and Methods

Study area

Hawija is a city in the north of Iraq and the largest of the main districts in Kirkuk Governorate, referring to the south. Its population is estimated at 215,000 people (UN Migration, 2020). The second-largest agricultural district is a source of vegetables in Iraq and includes more than two hundred villages and several administrative districts affiliated with it, namely, Al-Riyadh, Al-Abbasi, Al-Zab, and Al-Rashad (Fig 1). Therefore, it is important to study the health effects and environmental pollution with heavy metals in the soil and drinking water as a result of industrial, agricultural activities and military waste that were present as a result of liberation operations from terrorist gangs. Therefore, the study of this region will give a complete picture of the environmental and health situation and its effects on the population of the region. Hawija is located in the Kirkuk Governorate in the north of Iraq, between the two longitudes (34º 55ˈ 59.99″ - 35º 27ˈ 39.26″ N)(44º 07ˈ 58.55″ - 43º 15ˈ 37.58″), Its height is about 193 above sea level, and it is 65 km away from the centre of Kirkuk Governorate towards the southwest.

Samplinges and Analysis

The sampling of the groundwater was carried out during May 2022 and October 2021. A total of 40 groundwater samples were obtained from bore wells in the Hawija area and held on-site at 4 °C until analysis in high-quality polyethylene bottles that had been extensively prewashed. After fifteen to twenty minutes of purging each hand pump/bore well until flowing groundwater displayed steady hydrogen ion concentration and electrical conductivity values, groundwater samples were obtained. The groundwater sample locations in the research area are shown in (Fig. 1). A portable pH/EC/TDS meter (HI 99300 EC Meter) was used to test the pH, electrical conductivity (EC), and total dissolved solids (TDS) values in the field during the groundwater sample. After that, these samples were sent to (Acme Lab) in Canada for chemical analysis. Bicarbonate (HCO_3^{-1}), chloride (Cl^{-1}), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{-2}), nitrate (NO_3), sodium (Na^{+1}), and potassium (K^{+}) are all measured in the laboratory.

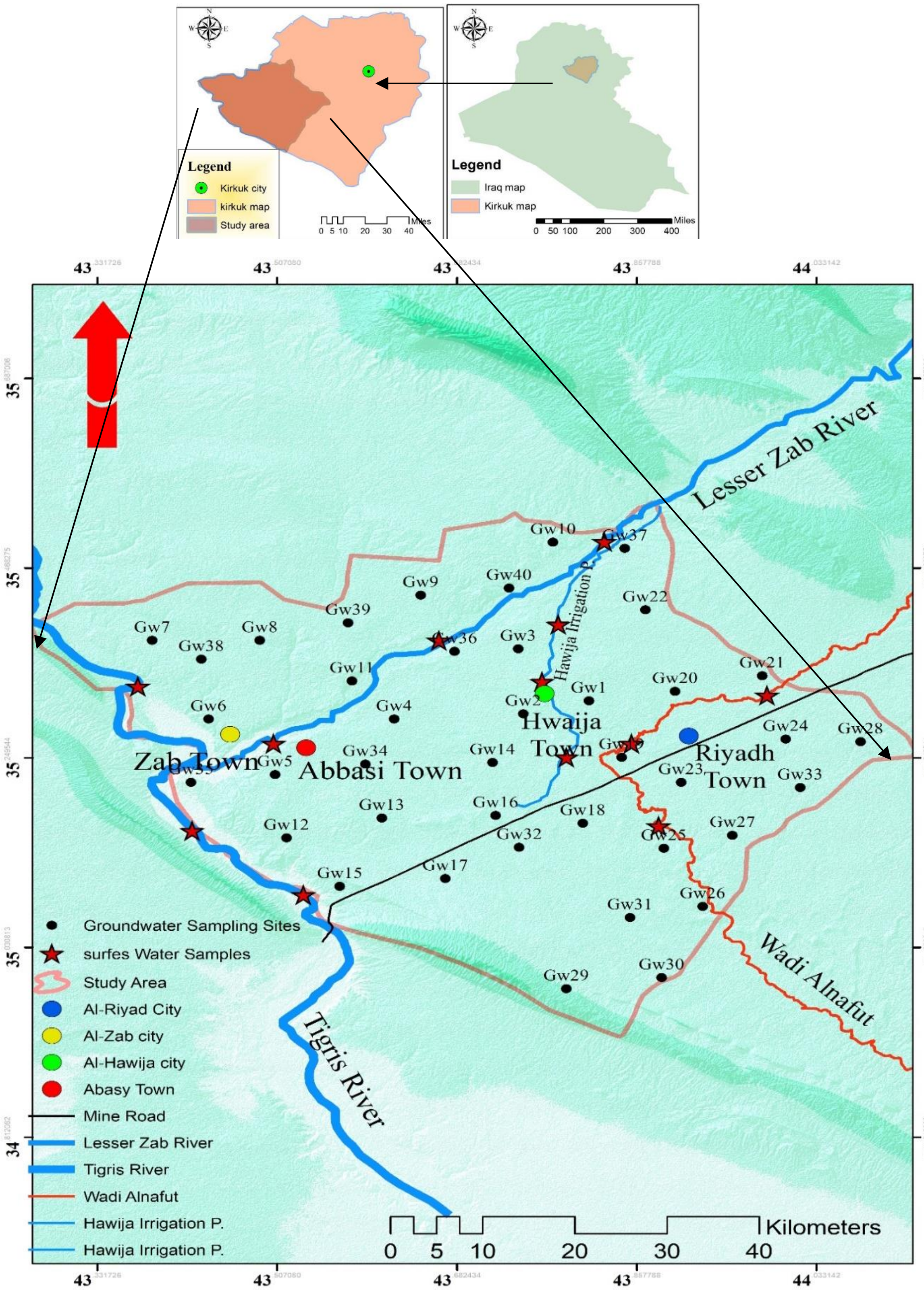

Fig. 1. Water Sampling Sites at the Study Area.

Methods

Water quality index (WQI)

Due to the effects of the oil industry, agricultural, and other industrial activities in the research region, water resources identifying the hazards and threats upon then trying to find support for their management (Štambuk-Giljanović, 1999; Pak et al., 2021). Therefore, urgent need for water quality assessment following Brown (Brown et al., 1972) for water quality assessment as:

$$Wi = K / Si \quad \ldots\ldots\ldots\ldots(1)$$

$$K = 1 / \sum^{n}_{i=1}(1/Si) \quad \ldots\ldots\ldots\ldots(2)$$

$$Qi = [(V-Vi)/(Si-Vi)] * 100 \ldots\ldots\ldots\ldots(3)$$

$$WQI = ((\sum^{n}_{i=1} Wi * Qi)/(\sum^{n}_{i=1} Wi)) \ldots(4)$$

Whereas, W*i* = relative weight of the physicochemical standards of water K, = constant, Si = maximum permissible for standards, Qi = sub-coefficient of I standards, V = monitored value (analyzed value), and Vi = ideal values (equal to zero for each Physiochemical criteria, except pH equal to 7, the sign (-) denotes the numerical difference between two values. For determining water quality, when the values of Water Quality Index (WQI) <25 means Excellent quality, 26-50 Good, 51-75 Poor, 76-100 Very Poor, and >100 Unsuitable for drinking Purposes (Brown et al., 1972).

Results and Discussion

Physicochemical characteristics

Temperature

Warm water encourages microorganisms to proliferate, which may affect taste, color, and odor of the water (Cavelan et al., 2022). Water quality depends on physical elements like temperature (WHO, 2017). Rising surface water temperatures affect mineral melting, sedimentation, degradation, and chemical, biological, and geochemical processes (WHO, 2006) (Table 1), shows extensive groundwater temperature observations. The mean annual groundwater temperature in the wet and dry seasons was (21.43 and 25.13 °C) respectively.

Total Dissolved Solids (TDS)

The geology of a basin significantly influences the concentration and makeup of dissolved solids in a basin. Inorganic salts like calcium, magnesium, potassium, sodium, bicarbonate, chlorides, and sulfates are examples of total dissolved solids (TDS) (Kuchelar et al., 2022). The chemical makeup of the water supplying the aquifer, the rate at which groundwater moves and the chemical and mineral makeup of the rocks that form the aquifer are some variables that affect the concentration of dissolved salts in groundwater (Taniguchi, 2011). The measured values of TDS in the groundwater range from (234 to 16248) ppm with a mean of (4357.62 ppm); for low flow season, they range from (200 to16201 ppm), with a mean of (4154.37 ppm) for high flow season (Table 1). Hillel Classifications of water (Hillel, 2000) is according to TDS. Category according to TDS (Freshwater <500, Slightly Brackish 500-1000, Brackish 1000-2000, Moderately saline 2000-5000, Saline 5000-10000, High saline 10000-35000, and Brine >35000). The water type classification depending on TDS considered all the groundwater samples as freshwater to moderately saline except for the GW15 and GW18 (Table 1) for both seasons, which are classified as high saline, the variety in geological formations may be to blame for the variance in TDS readings of well samples. The TDS in well samples increases in the low flow season and decreases in high flow season. The mean TDS concentration of groundwater sample is higher than that of (WHO and IQS) in low flow season, while the mean TDS concentration of groundwater samples in high flow season is higher than that of (WHO and IQS) (Table 1).

Table 1: Minimum, Maximum, and Mean Physicochemical Characteristics of Groundwater Samples in the Study Area.

	Low Flow Season				High Flow Season			
Sites Name	Tem. Co	TDS ppm	PH	EC ()	Tem. Cº	TDS ppm	PH	EC
Gw1	24.9	4398	7.88	3876	18.2	4343	7.8	3421
Gw2	26	3460	7.67	3845	19	3448	7.55	2897
Gw3	29.7	3012	8.05	3287	21.2	2987	8	2654
Gw4	25.7	2843	7.56	3159	21.3	2840	7.88	3100
Gw5	25	2954	7.2	2210	20.5	2784	7.71	2213
Gw6	28	5000	7.86	5633	23.5	5001	7.63	5629
Gw7	26	2856	7.2	2310	21.8	2356	7.88	2010
Gw8	25	2479	7.91	2739	23	2411	7.9	2767
Gw9	25	3491	7.7	3879	20.3	3489	7.71	3854
Gw10	23.3	4116	7.73	2108	22.7	4030	7.68	1928
Gw11	30	1440	7.94	1600	23.1	1408	7.97	1588
Gw12	28	8764	7.88	6397	21.5	6999	7.57	5892
Gw13	26.3	1234	7.88	532	18.5	1000	7.75	511
Gw14	26	2668	7.1	2955	22.1	2543	7	2717
Gw15	26	16248	7.66	18053	19.2	16201	7.59	17004
Gw16	23	6861	8	7624	22.3	6901	7.97	7643
Gw17	25	234	8.58	390	22	200	7.9	385
Gw18	25	13458	7.65	14953	19.3	13364	7.62	14893
Gw19	29	2318	7.78	928	23.2	2318	7.87	987
Gw20	25.8	4555	7.84	3287	19.8	4522	7.67	3210
Gw21	25	9675	6.62	6481	20.8	9670	6.78	6290
Gw22	27.1	3217	7.74	3574	22	3203	7.66	3575
Gw23	25.8	6401	7	6864	20.3	6377	7	6832
Gw24	27.3	6008	7.16	3251	27	5321	7.08	2991
Gw25	25	6484	7.5	6432	18.1	5643	7.4	4899
Gw26	25.3	3145	7.97	3494	19	2643	7.98	1976
Gw27	25.8	3946	7.8	4384	22	2966	7.93	1922
Gw28	25.9	1232	7.68	480	23.3	1254	7.86	488
Gw29	26.2	6879	7.94	7644	25	6821	7.99	7619
Gw30	24.8	5943	7.64	6603	20	5843	7.5	6573
Gw31	24.2	834	7.53	1043	22	850	7.87	1014
Gw32	26.4	1189	7.6	978	18.5	900	8	923
Gw33	25	1532	7.64	1003	23.1	1236	7.49	949
Gw34	26.1	1897	7.52	1320	25.2	1567	8.01	1076
Gw35	21.6	3235	7.12	3595	23	2643	7.73	3056
Gw36	29	984	7.13	1230	23	1054	7.93	1162
Gw37	24	9521	7.99	10579	22.9	9467	7.81	8723
Gw38	25	1494	7.42	1662	20.2	1355	7.2	1600
Gw39	26	4840	7.3	5377	19.8	4801	7.88	5309
Gw40	25.4	3460	7.82	4848	19.7	3416	7.54	4832
Min.	21.6	234	6.62	390	18.1	200	6.78	385
Max.	30	16248	8.58	18053	27	16201	8.01	17004
Mean	25.84	4357.62	7.62	4265.17	21.43	4154.37	7.68	3927.8
(IQS,2009)	-	1000	6.5-8.5	2000	-	1000	6.5-8.5	2000
(WHO,2021)	25	1000	6.5-8.5	2500	25	1000	6.5-8.5	2500
U.S. EPA,2017	-	500	-	-	-	500	-	-

pH

The neutral limit of the acidity function is 7. If its value is less than 7, it indicates the acidic property. Still, if it is higher than 7, it means the basic property; as pH value drops, it impacts how water interacts with water-bearing rocks and sediments. (WHO, 2021). The pH of groundwater range from (6.62 to 8.58) and has a mean of (7.62) in the low flow season, while the rainy season has a mean of (7.68) (Table 1). Therefore, the pH values of the studied samples are within the permissible limits according to (WHO, 2021) and the Iraqi specifications (IQS, 2009). According to WHO, a pH less than 6.5 or greater than 9.2 would markedly impair the portability of drinking water. The pH values for the two seasons are within the acceptable range, indicating that the groundwater and surface water are considered acceptable for pH. The study area's water had a weak alkaline character according to the World Health Organization classification (WHO, 2004), which may be due to the presence of $CaCO_3$ in rocks of some geological formations in the regions of northern Iraq (Toma, 2006).

Electrical Conductivity (EC)

The quantity and quality of ions in water determine their conductivity to electric current. Water conductivity increases by 2% every degree Celsius. The greater the EC value, the bigger the water contamination owing to increased solubility (Ram et al., 2021). The values of EC of groundwater range between (390 and 18053 µs/cm) with a mean of (4265 µs/cm) in the low flow seasons, but in the high flow seasons, the EC mean was (3927.8 µs/cm) (Table 1). Then the water is within the permissible limits according to the Iraqi specifications (ISO,2009) at a rate of (2000 µs/cm).

Biological Characteristics

Dissolved Oxygen (DO)

Water has dissolved oxygen (DO). Aquatic creatures need oxygen levels. (Rasouli, 2021). Aquatic plants and algae photosynthesis provide most of the dissolved oxygen in natural aquatic environments (Cavelan et al., 2022). Atmospheric oxygen diffuses into the water. Temperature, salinity, air pressure, water flow, pollutants, and organic matter affect DO levels (WHO, 2021). Fish and other aquatic organisms require oxygen. Low DO may also promote water pollution by anaerobic microorganisms. Even hardy fish may suffocate at 3-4 ppm dissolved oxygen (Cavelan et al., 2022). Thus, DO monitoring is essential for water quality management in drinking water, recreational, and commercial water bodies.

The concentration of dissolved oxygen in the groundwater samples during the low flow seasons ranges between (6 and 13.3 ppm) with a mean value of (7.83 ppm) and in the high flow season DO range is between (6.7 to 13.4 ppm) with a mean value of (9.1ppm). DO levels during the low flow season are lower than that of high flow seasons (Table 2) due to the difference in water temperature, where the dissolved oxygen content is higher in cold water than in warm water(Hanjaniamin et al., 2023). All groundwater samples taken during the high flow season are categorized as good water according to Weiner's Classification of Water (Weiner, 2008) according to (DO ppm). When DO >8 Good, 6.5 – 8 Slightly polluted, 4.5 – 6.5 Moderately polluted, 4 – 4.5 Heavily polluted, and <4 Severely polluted). In contrast, samples taken during the low flow season, their DO values range from good water to slightly polluted, except for the site (GW20-GW21) having (6.1 – 6) respectively, which are moderately polluted (Table 2).

Table 2: Minimum, Maximum, and Mean Biochemical Characteristics of Groundwater Samples (ppm) of the Study Area.

	Low Flow Season			High Flow Season		
Sites N.	**DO**	**BOD_5**	**COD**	**DO**	**BOD_5**	**COD**
Gw1	7.1	2.8	17	9.6	2.2	3
Gw2	7.1	3	Lo	9.1	3.22	Lo
Gw3	6.8	2.7	Lo	8.8	2.9	Lo
Gw4	7.3	3.3	5	7.9	3.9	Lo
Gw5	7	3.8	Lo	8	3.9	Lo
Gw6	8.1	3.1	Lo	9.4	4.1	Lo
Gw7	7	3.7	Lo	7.7	3.9	Lo
Gw8	6.9	1.9	Lo	8.1	3.5	Lo
Gw9	7.9	1.4	Lo	9.6	3.9	Lo
Gw10	9.4	2	Lo	9.9	3.1	Lo
Gw11	10.2	1.39	Lo	10.2	5.2	Lo
Gw12	10.1	2.27	1	10.5	3.9	Lo
Gw13	13.3	2.4	1	12.3	5.4	Lo
Gw14	9.65	3.55	Lo	10.6	4.4	Lo
Gw15	6.9	2.6	165	8.5	1.6	165
Gw16	7	2.7	Lo	10.1	1.9	Lo
Gw17	7.4	3.39	Lo	8.1	2.3	Lo
Gw18	8.9	1.1	150	9.1	-	137
Gw19	6.72	4.9	153	8.5	4.4	97
Gw20	6.1	3.9	62	7.5	4	31
Gw21	6	5.9	143	6.7	5.1	76
Gw22	8.2	2	Lo	7.5	1.3	Lo
Gw23	7	3	5	7.9	0.9	Lo
Gw24	6.99	1.29	Lo	7.5	1.9	Lo
Gw25	6.84	2.74	15	8.4	2.1	14
Gw26	7	2	12	8.2	0.9	18
Gw27	7.21	2.01	11	8.7	1.7	19
Gw28	7.3	2.1	Lo	9.6	1.3	Lo
Gw29	9.2	2.3	Lo	11.4	1.2	Lo
Gw30	7.32	2.32	4	9.3	3.2	4
Gw31	6.98	2.68	Lo	8.5	3.3	Lo
Gw32	8.9	3.9	Lo	10.1	3.2	Lo
Gw33	10.1	2.31	Lo	13.4	3.2	Lo
Gw34	7.51	2.51	Lo	8.3	2.1	Lo
Gw35	6.7	2.7	Lo	9.7	-	Lo
Gw36	8.8	4.8	Lo	10.4	1.4	Lo
Gw37	9.3	3.8	Lo	9.9	2.3	Lo
Gw38	6.9	2.3	Lo	7.9	0.9	Lo
Gw39	7	2.9	Lo	8.7	3.4	Lo
Gw40	7.3	1.2	Lo	8.4	4.2	Lo
Min.	6	1.1	1	6.7	0.9	3
Max.	13.3	5.9	165	13.4	5.4	165
Mean	7.83	2.82	44.91	9.1	2.97	57.12
(IQS,2001)	-	-	-	-	-	-
(WHO,2021)	6	-	-	6	-	-
U.S. EPA, 2017	-	-	-	-	-	-

Biochemical Oxygen Demand:

The quantity of oxygen for microorganisms need is that when they break down organic materials in the ground or surface water. It measured as biochemical oxygen demand (BOD) (Jouanneau et al., 2014). BOD gauges the quantity of oxygen consumed in water-based chemical processes. These organisms undergo a test to determine how much oxygen they use during a certain time duration (often five days at 20°C)(Yang et al., 1996). Many factors, including pH, temperature, certain species of microbes, and the organic and inorganic material in the water, impact the oxygen consumption rate in (ground or surface water).It is measured and expressed after five days of sampling at 20°C (Kim et al., 2003), where:

BOD_5 ppm = $DO_1 - DO_5$ ……..(5)

DO_1 = dissolved oxygen content (ppm) after 15 minutes.

DO_5 = dissolved oxygen content after 5 days.

Table (2) data reveales that groundwater sample BOD levels varied from (1.1 to 5.9) ppm, with a mean value of (2.82) ppm in the low flow season, and (0.9 - 5.4) ppm, with a mean value of 2.97 ppm in the high flow season. According to (Gupta, 2016), classification for water relies on BOD value, except for sample (GW21) (5.9)ppm (Table 2), which is critical. The water type is clean and maybe clean in the low flow season. GW11, GW13, and GW21 (5.2, 5.4, and 5.1) ppm are classified as Critical pollution water in the high flow season, but the samples of well water were certified as clean water and maybe clean in the low flow season according to (Gupta, 2016).

Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is a direct indication of the possible effects of oxygen consumption and an excellent predictor of the effects of industrial waste on water. (Lu et al., 2006). When COD is high, it means a high pollutant load (Prambudy et al., 2019; Wei et al., 2019). COD of groundwater ranges from 1 ppm to 165 ppm with a mean value of 44.91 ppm in the low flow season, and from 3 ppm to 165 ppm with a mean value of 57.12 ppm in the high flow season (Table 2).

Chemical Properties:

Total Hardness (TH)

Total hardness (TH) measures water's calcium and magnesium ions. Many water sources include these ions, which may impact how soap affects water flavour, appearance, and behaviour. Divalent ions (calcium, magnesium) from mineral ions in ground and surface water generate total hardness. It has temporary and carbonate hardness (Veríssimo et al., 2007). Calcium and magnesium ions with water bicarbonate cause temporary hardness. Boiling water precipitates calcium and magnesium, removing hardness. The second is permanent hardness. Calcium and magnesium ions react with sulphates, chlorates, and nitrates to create hardness. Heating cannot destroy it (Boyd, 2019). Aquifer composition affects hardness (Mosavi et al., 2020). Water samples are hardened using the following equation (6) (Todd and Mays, 2005):

$$T.H\ (ppm) = 2.497(Ca^{++}) + 4.115(Mg^{++}) \quad \text{……………..(6)}$$

Total hardness TH is classified according to each (Altoviski, 1962; Todd and Mays, 2005; Boyd, 2019)(Table 3). The groundwater for the two periods in the studied area is classified as very hard water (Table 4). This may be due to the natural source of the rock type studied represented by gypsum and anhydrite scattered in the region, such as the formations of Fatha and Injana. Table (4) shows that the TH values of groundwater are lower than the acceptable limits for drinking water adopted by (WHO, 2021) in the two seasons. The concentration of (TH) ranges between (255.5 and 4402.1 ppm) with a mean of (1369.5)ppm in the low flow season and in the high flow season, the mean total hardness concentration is (1071.1) ppm and it ranged between (208.7 and 4214.16) ppm.

Table 3: Classification of Water According to TH value (Todd, Boyd, and Altoviski).

Waty type	***TH*** ppm		
	(Altoviski, 1962)	(Todd and Mays, 2005)	(Boyd, 2019)
Soft	0 -75	0 - 75	0 -50
Moderate Hard	75 – 175	75 – 150	50 – 150
Hard	175 – 300	150 – 300	150 – 300
Very Hard	< 300	< 300	<300

Table 4: Total hardness of Groundwater in the study area.

Sites N.	*TH* (ppm)		Sites N.	*TH* (ppm)	
	Low flow Season	High flow season		Low flow Season	High flow season
Gw1	579.485	487.633	Gw21	4402.16	1776.47
Gw2	928.4	694.399	Gw22	1077.72	924.528
Gw3	733.438	665.455	Gw23	1227.29	702.29
Gw4	2149.48	1858.64	Gw24	749.566	624.92
Gw5	454.211	309.066	Gw25	777.032	526.52
Gw6	1421.56	651.785	Gw26	1218.39	1428.53
Gw7	1076	889.552	Gw27	837.463	767.41
Gw8	2046.06	2909.71	Gw28	739.996	577.086
Gw9	2039.84	1737.9	Gw29	845.404	690.638
Gw10	1056.65	846.408	Gw30	1154.77	1055.39
Gw11	927.644	557.987	Gw31	704.646	998.985
Gw12	1757.35	1521.12	Gw32	875.097	736.303
Gw13	974.106	673.464	Gw33	255.513	208.702
Gw14	666.18	625.374	Gw34	690.32	730.123
Gw15	1237.52	806.345	Gw35	1656.9	496.283
Gw16	1003.61	897.164	Gw36	978.789	615.347
Gw17	1006.18	518.55	Gw37	1179.51	678.818
Gw18	3850.82	4214.42	Gw38	1560.3	969.029
Gw19	2540.05	1794.81	Gw39	1540.25	1119.2
Gw20	3487.5	2697.58	Gw40	2376.27	1861.21
Min.				255.513	208.702
Max.				4402.16	4214.42
Mean				1369.59	1071.13
(WHO,2021)				**1000**	
(IQS,2009)				**500**	

Major and Minor ions

Calcium Ca^{+2} : is a common alkaline earth metal. The chemical weathering of rocks and minerals produces the most significant dissolved ion, calcium. Calcite, dolomite, gypsum, and anhydrides are calcium bearing sedimentary rocks. (Al-Jumaily and Alhamdany, 2018) have found these rock units in the local formation. The Iraqi fertilizer facility manufactures triphosphate, which is rich in calcium (Al-Nuzal, 2017). In low flow season, groundwater samples had a mean calcium ion content of 276.6 ppm, ranging from (50.74 to 276.6ppm), while in high flow season, it is 229.22 ppm, ranging from (53 to 963.85ppm) (Table 5 and Fig. 2).

Table 5: Minimum, Maximum, and Mean Concentration Major and Minor Elements in Groundwater in (ppm)

Elements	low flow Seasons			high flow Seasons			IOS 2009	WHO 2021	EPA 2018
	Min.	Max.	Mean	Min.	Max.	Mean			
Ca^{+2}	50.74	657.6	276.6	53	963.85	229.21	50	150	-
Na^{+1}	8.5	261.12	91.39	4.28	418	63.05	200	200	-
Mg^{+2}	10.09	898.3	164.98	9.57	992	121.2	50	70	-
K^{+}	0.09	4.16	1.67	0.89	4.21	1.85	-	12	-
HCO_3^{-1}	162.7	5800.7	765.15	39.2	5143	555.35	-	-	-
SO_4^{-2}	22.1	1881.6	621.85	3.3	2091.3	521.79	250	250	-
Cl^{-1}	10.4	527.6	110.37	2	426	76.35	350	250	250
PO_4^{-3}	0.007	1.02	0.25	0.003	0.9	0.12	-	0.4	-
NO_3^{-1}	4.34	376	96.72	0.06	476	104.1	50	50	10

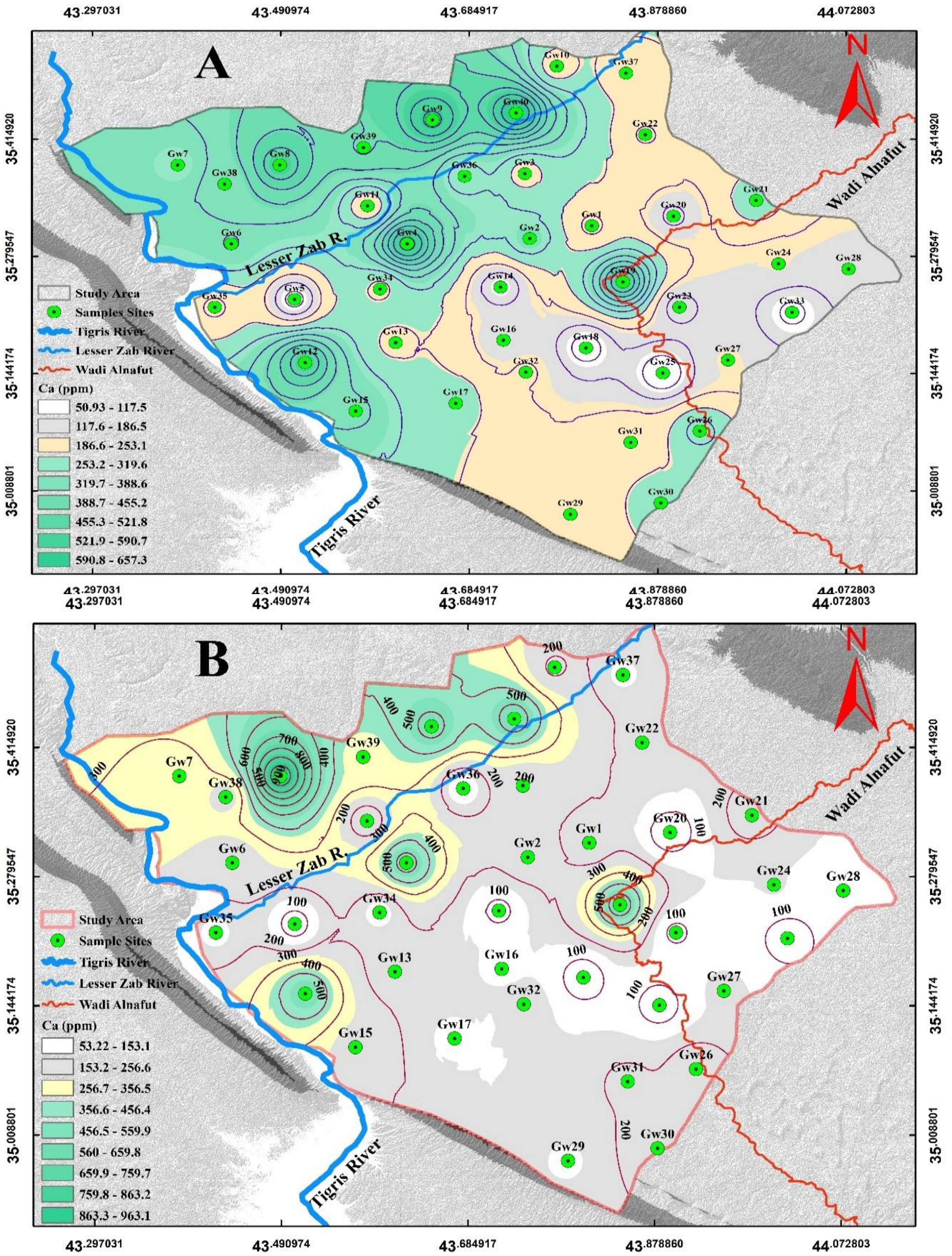

Fig. 2. Spatial Distribution of Ca in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Calcium ion concentration in groundwater has exceeded the permissible limits according to the specifications of the World Health Organization (WHO, 2021) and the Iraqi specifications (IQS, 2009). The highest concentration of calcium ion is found in wells (GW4, GW9, and GW40) (623.6, 615.7, and 657.6 ppm), respectively in low flow season, while in high flow season, the highest concentrations are found in wells (GW4, GW8, GW9, GW12, GW19, and GW40) (Fig. 2).

Sodium Na^{+1}: The main source of sodium ions in aquatic systems is the weathering of alkaline feldspar rocks, which dissolve easily in water (Hem, 1985), as well as some clay minerals, industrial wastes rich in sodium, and wastewater irrigation (Appelo and Postma, 2004). Table (5) and Figure (3) show that in low flow season, thegroundwater samples haved 8.5 to 261.12 ppm sodium ions, and in high flow season, 4.28 to 418. According to WHO (WHO, 2021) and Iraqi standards (IQS,2009), the mean groundwater content of Na^{+1} ion in the study location is within the permissible limits (200 ppm) for both seasons (Table 5).

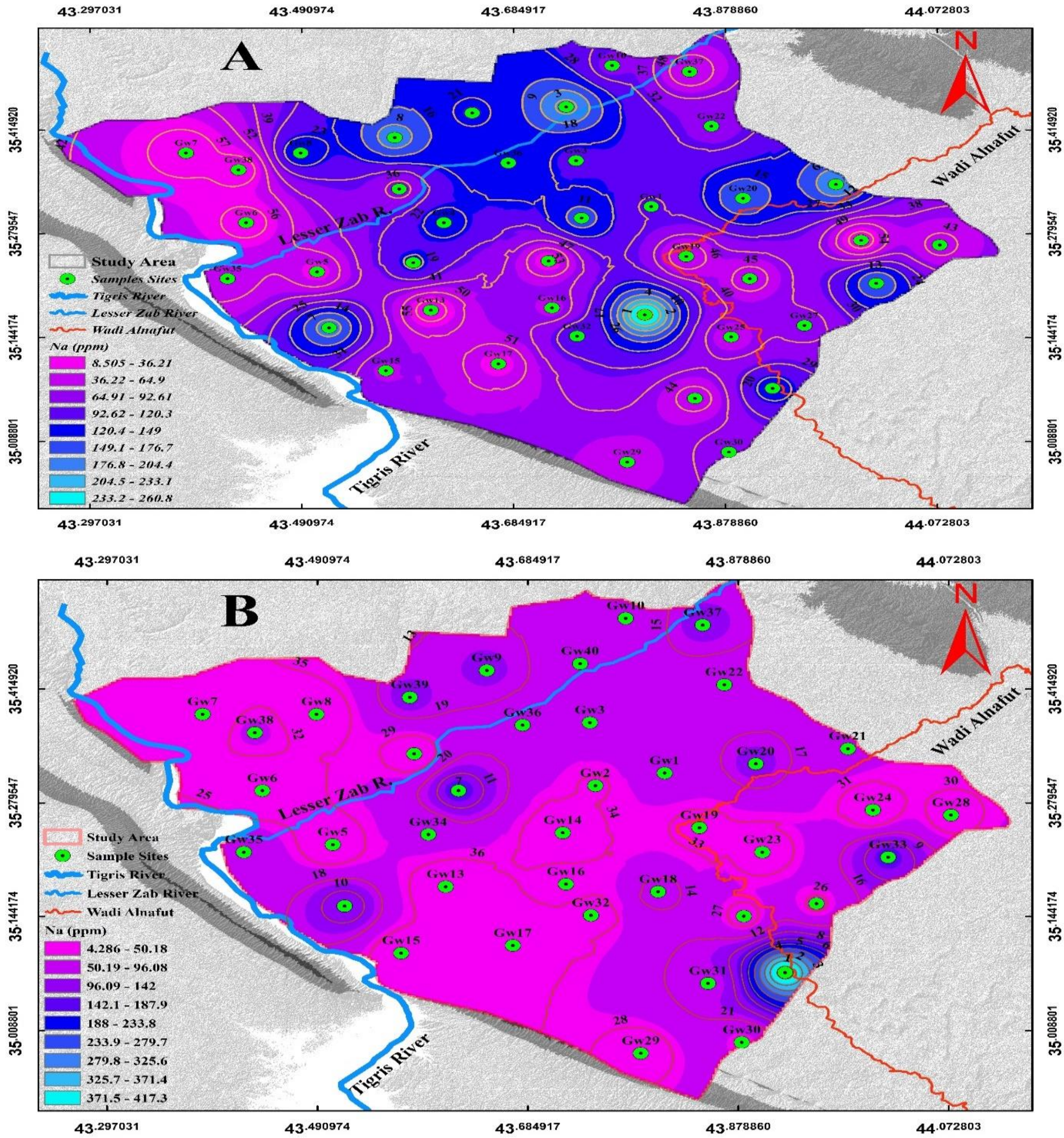

Fig. 3. Spatial Distribution of Na in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Magnesium Mg^{+2}: The magnesium ion occupies the second rank among the most abundant positive ions in water (Allnér et al., 2012). Magnesium is one of the alkaline earth elements and is characterized by one valence state (Mg^{+2}). It is derived mainly from the weathering of sedimentary rocks such as carbonate and dolomite rocks (Helstrup et al., 2007). Mud minerals are also a source of magnesium ions in water (Collins, 1975). Since it is smaller than calcium and sodium ions and can fit with the crystal structure of water molecules, the magnesium ion behaves differently from those ions. The mean concentration of magnesium ions in groundwater during the low flow season is (164.98 ppm) with a range of (10.09 - 898.3ppm) (Table 5), and during high flow season, it is (992 - 9.57 ppm) with a mean of (121.21 ppm)(Table 5 and Fig. 4). The results for both seasons are higher than that of IQS (IQS, 2009) and WHO (WHO, 2021).

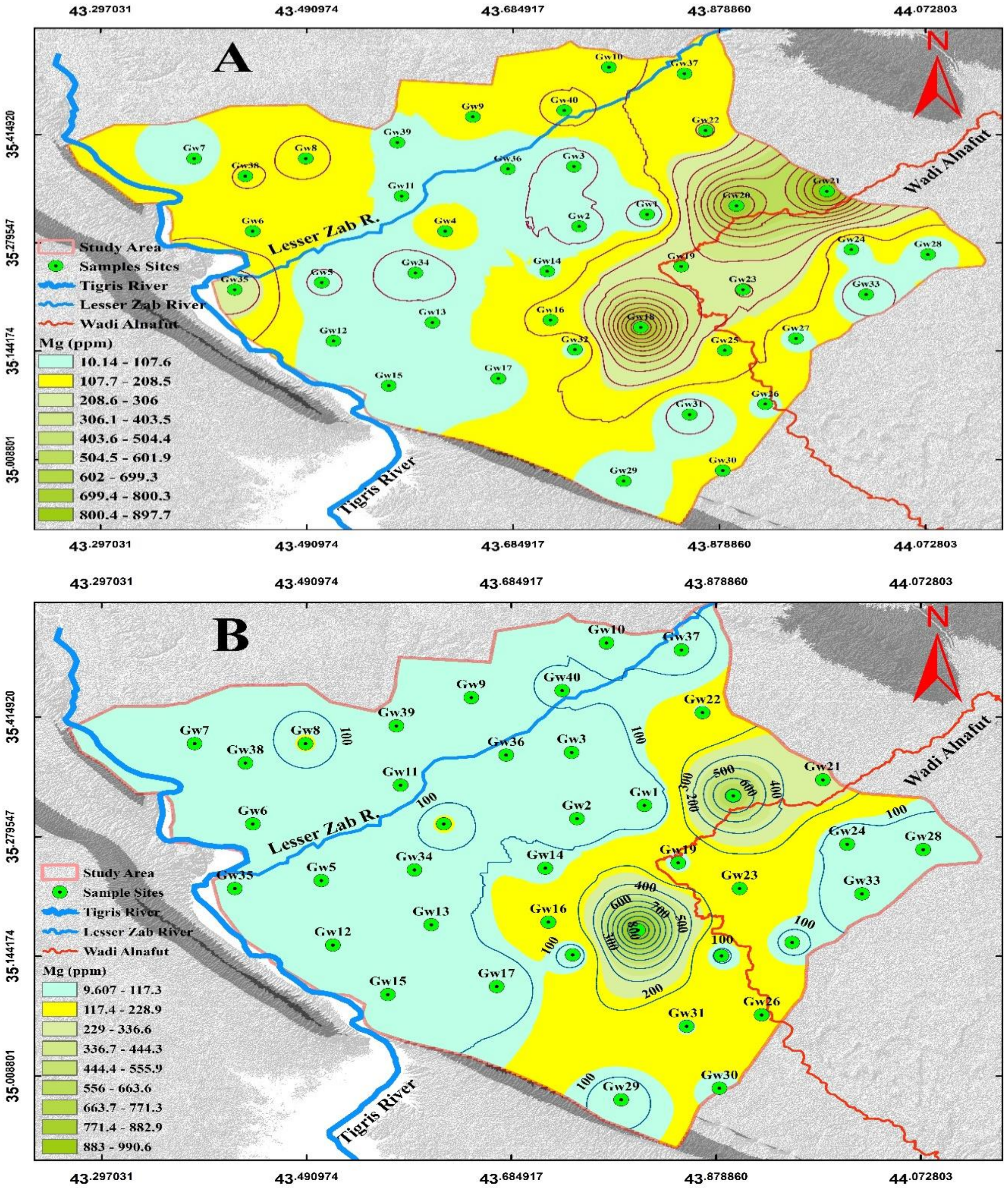

Fig. 4. Spatial Distribution of Mg in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Potassium K^{+1}: The concentration of potassium ions in water is silicate rocks, so its concentration in water is low compared to other positive ions, because silica minerals that contain potassium are more resistant to chemical weathering (Singh et al., 2008). In groundwater samples, potassium ion concentrations vary from (0.09 to 4.16 ppm), with a mean of 1.67 ppm during low flow season. Its mean concentration is 1.85 ppm and a range (0.89-4.21

ppm) during the high flow season (Table 5 and Fig. 5). The means concentration of K^{+1} value of groundwater for both seasons are below the standards WHO (WHO, 2021).

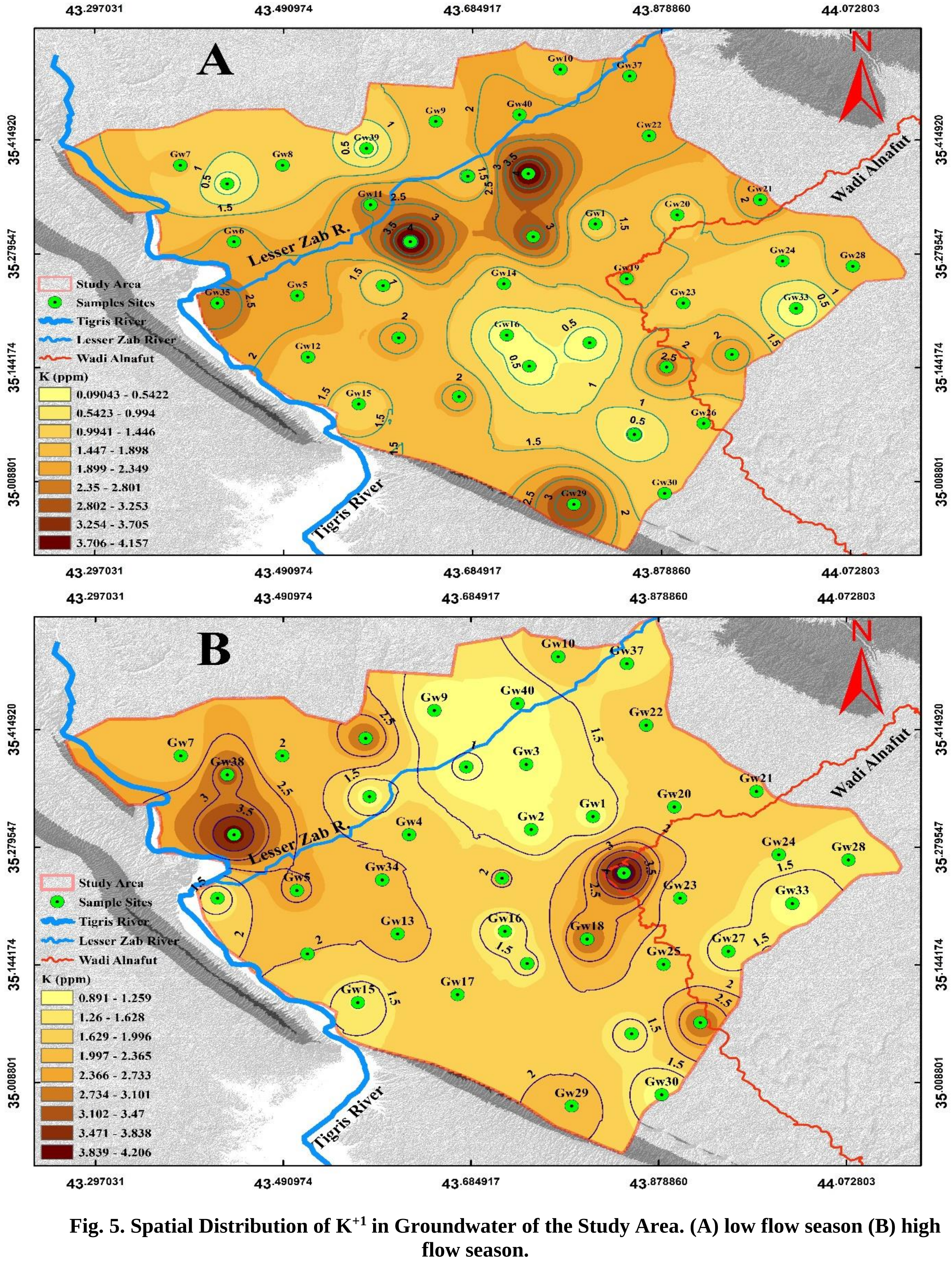

Fig. 5. Spatial Distribution of K^{+1} in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Anion Major Ions

Bicarbonate HCO_3^{-1}: The bicarbonate ion is one of the most common negative ions in water (Deutsch, 2020). The primary sources include weathering of carbonate minerals, industrial and agricultural operations, and atmospheric carbon dioxide, which is dissolved in water and is one of the most significant sources of carbonates and bicarbonates. The activity of HCO_3^{-1} increases with a rise in pH, impacting the bicarbonate ion concentration(Zeebe and Wolf-Gladrow, 2001). For every unit of pH rise, the concentration of the carbon dioxide ion doubles. Bicarbonates (HCO_3^{-1}) prevailed from pH > 6.3 to pH 10.3, and CO_3^{-2} is dominant at pH > 10.3 (Mather, 2020). The mean concentrations of bicarbonate ions in groundwater samples are (765.15 ppm) in low flow season with a range of (162.7 - 5800.7 ppm). In high flow season, it is (555.35ppm) and ranges (from 39.2-5143ppm) (Table 5 and Fig. 6). The highest concentration of HCO_3^{-1} ion is found in wells (GW18, GW19, GW20, and GW21), in both seasons (Fig. 6). The reason for the increase in these wells may be their proximity to the Wadi Alnaft because the oil pollutants are rich in carbon(Nor et al., 2013).

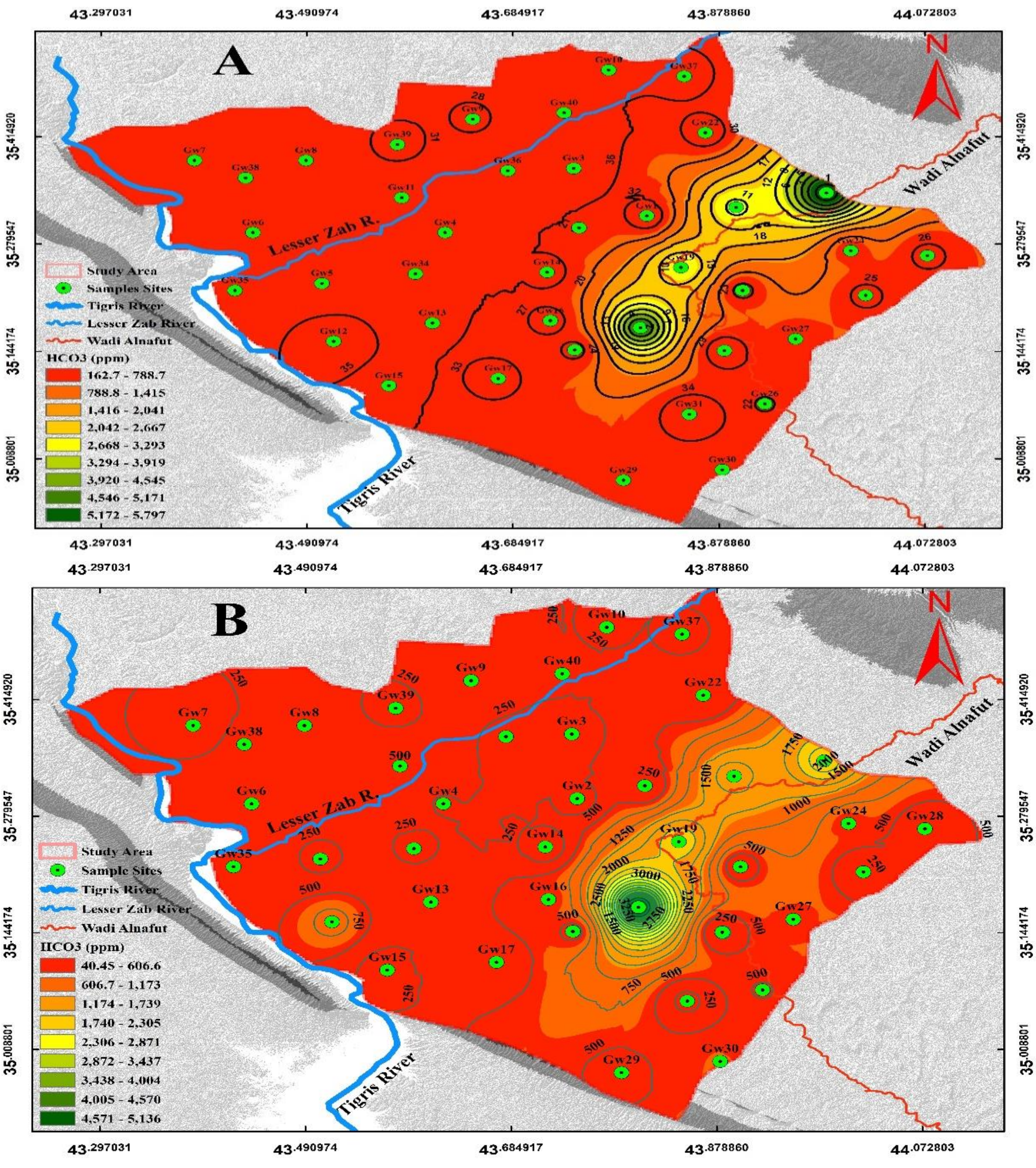

Fig. 6. Spatial Distribution of HCO_3^{-1} in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Sulphat SO_4^{-2}: One of the major ions in water is sulfate, and the weathering and dissolving of sulfate-bearing rocks like gypsum and anhydrite are its principal sources. (Osselin et al., 2019)(Osselin et al., 2019). The oxidation of sulfur ores, as well as the atmosphere, are an important source of sulfate resulting from industrial processes, volcanic natural emissions, liquid waste and chemical fertilizers (Kalisz et al., 2022). During the low flow season the mean concentration of sulfate ions is (621.85 ppm), and it varies groundwater samples between (22.1

and 1881.6 ppm) (Table 5 and Fig. 7). Throughout the high flow season, it has a range of (3.3-2091.3 ppm) with a mean of (521.79 ppm), as shown in Table (5). The mean concentration of SO_4^{-2} for both seasons is higher than the standard WHO (WHO, 2021) and IQS (IOS, 2009). According to the aforementioned standards, it is within the permitted range for WHO (WHO, 2021), IQS (IQS, 2009), and EPA (EPA,2018).

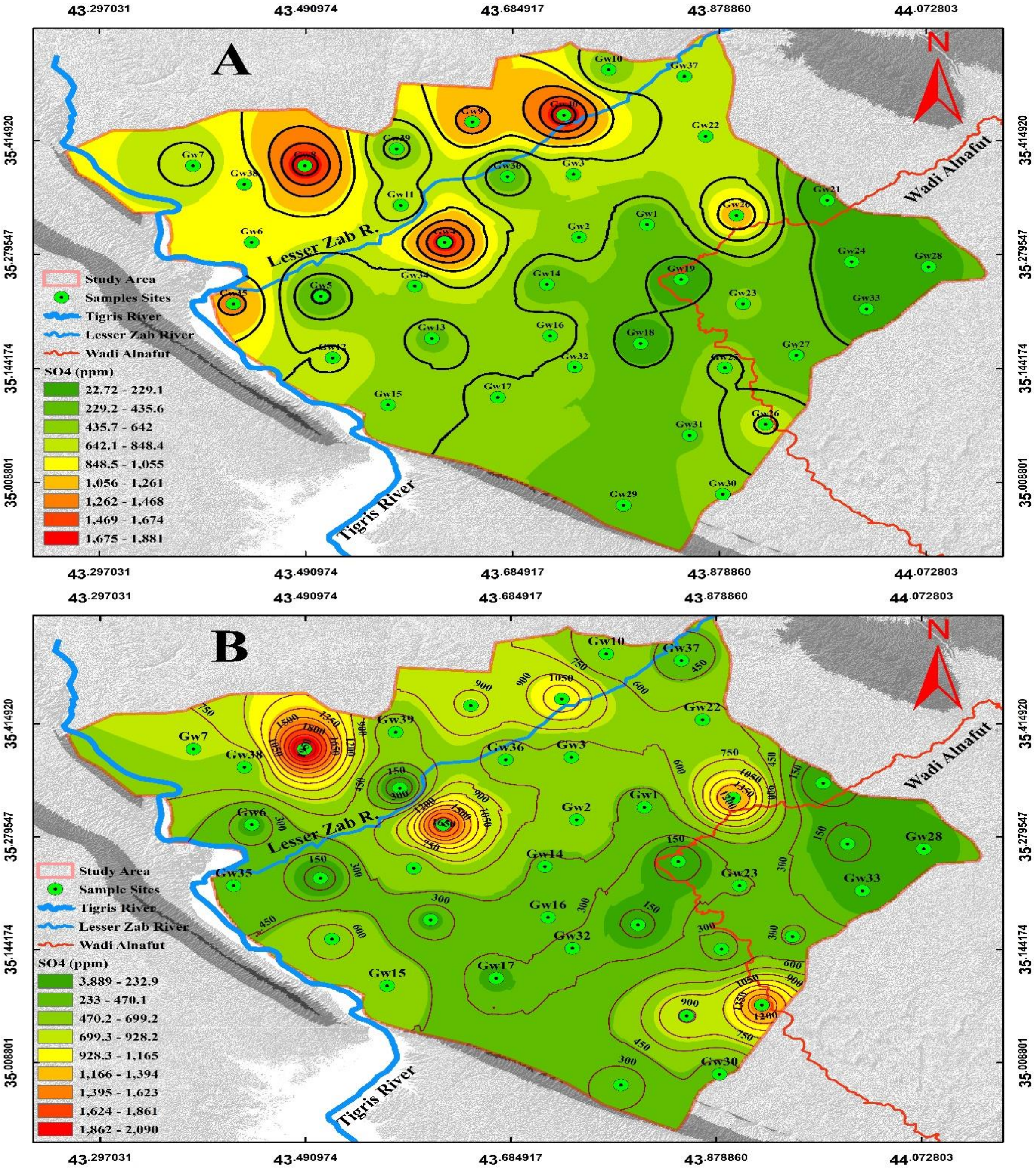

Fig. 7. Spatial Distribution of SO_4^{-2} in Groundwater of the Study Area. (A) Dry season (B) Wet season.

The mean concentration of sulfate in groundwater is higher than that of surface water due to the rock types of the aquifer which is mainly composed of gypsum and anhydrite, besides oil operation and the types of fertilizer used in the area. All or most of the above factors contribute in rising of sulfate in groundwater (Shokri and Fard, 2022). The highest concentration of SO_4^{-2} ion is found in wells (GW4, GW8, GW35, and GW40), in both seasons, (Fig. 7).

Chloride Cl^{-1}: Water contains a lot of chloride ions, and because chloride salts are soluble, they built up in solutions (Sami, 1992). Evaporite rocks like halite and sulfate provide chloride ions to water(Kateb and Al-Youzbakey, 2022). Groundwater chloride ions come from reservoir rock dissolution, industrial waste, and home sewage(Vengosh and Pankratov, 1998). Industrial activities and fertilizer contribute to the research region's chloride ions, although the aquifer rocks are the main source. In groundwater samples, the chloride concentration mean is (110.37 ppm) with a range of (10.4-527.6 ppm) in the low flow season, whereas the mean concentration value of chloride ion is (76.35 ppm) with a range of (2-426 ppm) in the high flow season (Table 5 and Fig.8). The rate of chloride ion concentration is within the permissible limits according to the specifications of the World Health Organization (WHO, 2021) and the Iraqi standard (IQS, 2009) and EPA (2018) for both seasons.

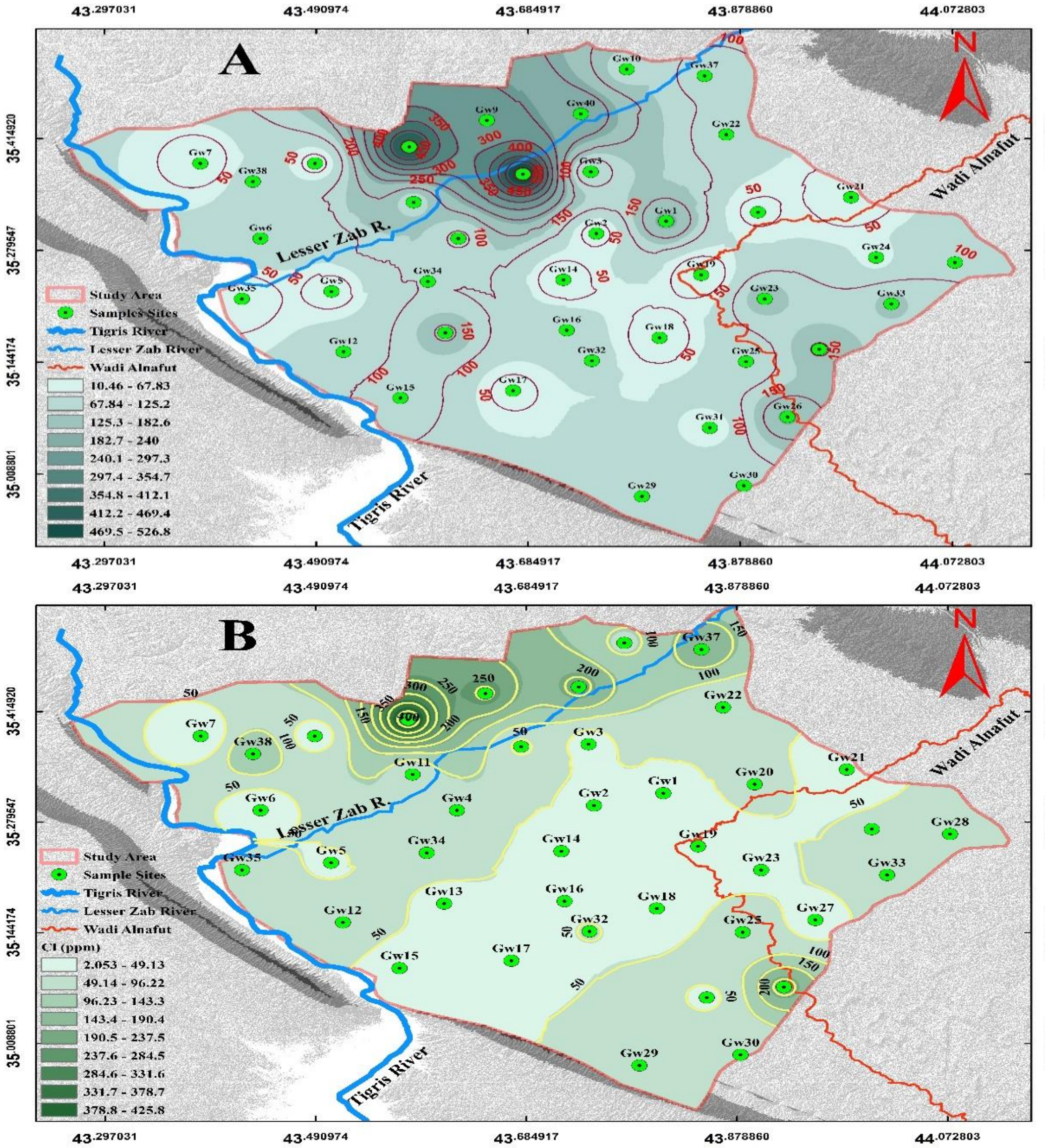

Fig. 8. Spatial Distribution of Cl^{-1} in groundwater of the study area (A) low flow season (B) high flow season.

Secondary ions

Phosphate PO_4^{-3}

Phosphates are phosphorus-bearing rocks as chemical compounds (Na, 2020). As water runs over and through rocks, it carries small amounts of elements such as calcium and phosphate (Balaram et al., 2022). The mineral apatite clusters are the main source containing phosphorus in the earth's crust at 0.12%. The sediments contain more phosphate than surface and groundwater (Dill, 2001). During the current study, the phosphate ion concentration in groundwater samples during the low flow season ranged from (0.007 to 1.02ppm) with a mean of (0.25 ppm), while during the high flow season, it ranges between (0.003 to 0.9ppm) with a mean of (0.12ppm) (Table 5 and Fig. 9). The above results show that PO_4^{-3} concentration in groundwater is below the standard (0.4 ppm) of WHO (WHO, 2021).

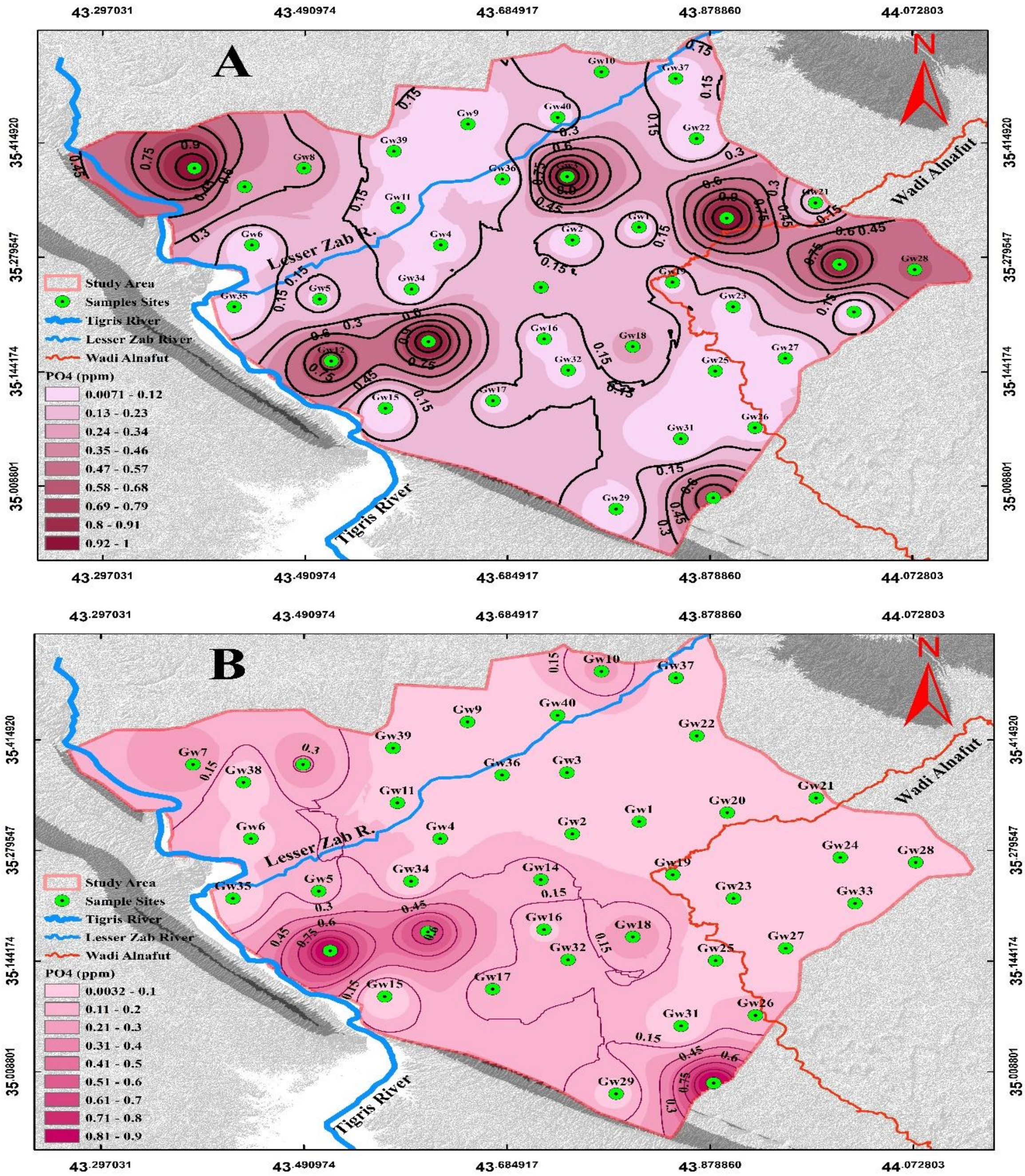

Fig. 9. Spatial Distribution of PO_4^{-3} in Groundwater of the Study Area. (A) low flow season (B) high flow season.

Nitrate NO_3^{-1}: A naturally occurring or microbially digested nitrate ion comes from nitrogen-bearing waste such as animal dung or nitrogen-based fertilizers(Reinik et al., 2008). River water has low nitrate concentrations (Abdulredha et al., 20). Nitrate levels may kill aquatic life. It damages human and animal health. The US EPA set the nitrate level in drinking water at 10 ppm. The mean nitrate ion concentration in groundwater samples is (96.72 ppm) and ranges from (4.34 to 376 ppm) during the dry season and from (0.06 to 476 ppm) during the wet season (104.1 ppm) (Table 5 and Fig. 10).

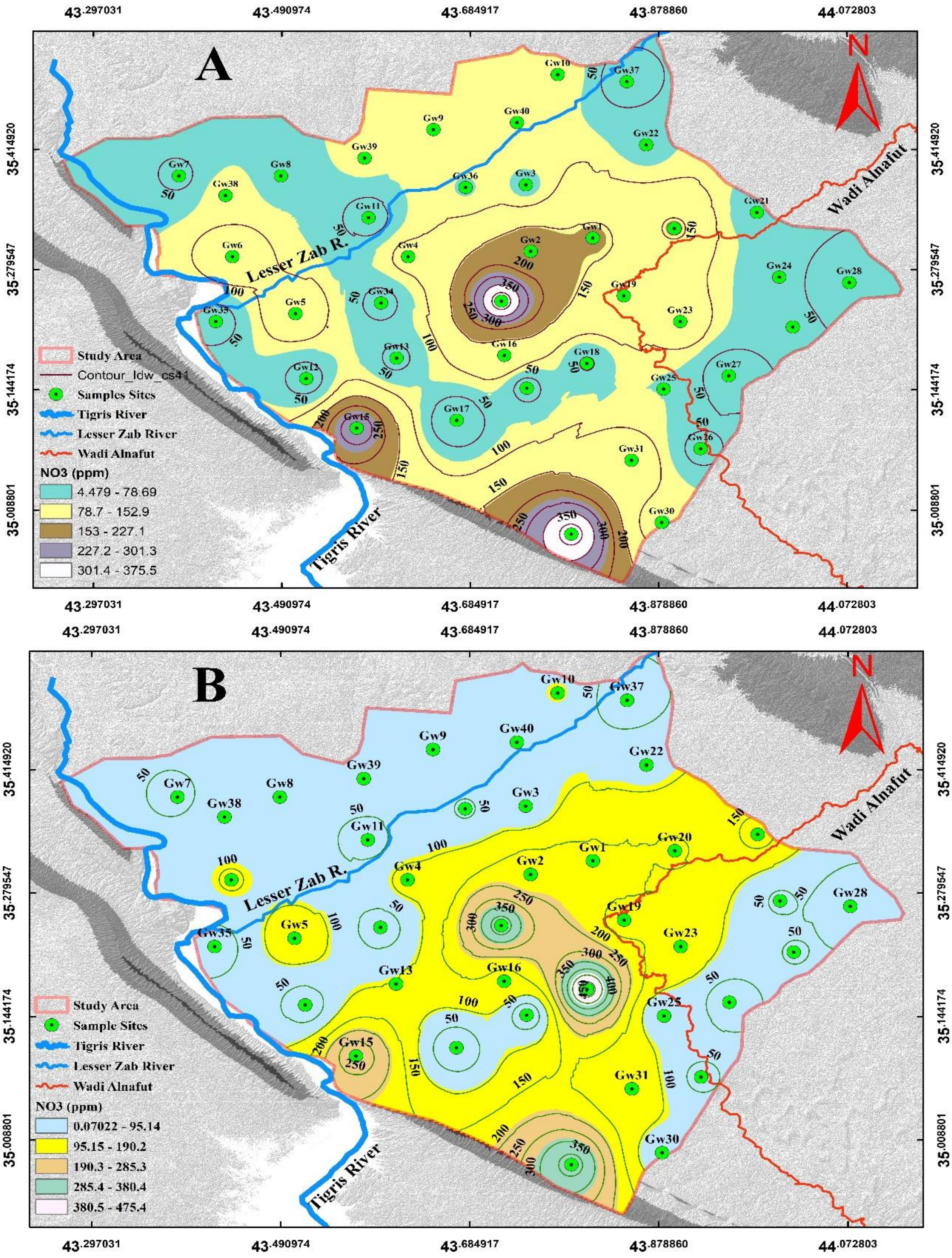

Fig. 10. Spatial Distribution of NO_3^- in Groundwater of the Study Area. (A) Dry season (B) Wet season.

The mean nitrate ion concentration value for both seasons is higher than all standards of IQS (IQS, 2009), WHO (WHO, 2021) and EPA (EPA,2018). The increased concentration of NO in groundwater above all standards may be interpreted as the heavy use of NPK fertilizers besides using a septic system in the region's lack of sewage, besides spreading of poultry raising chickens all the above factors contribute to raising NO_3^{-1} in groundwater By this high concentration of NO_3^{-1} in groundwater will threaten human health especially the newborn children. The maximum NO_3^{-1} concentrations are detected in (GW14, GW15, and GW29) for both seasons (Fig. 10). The increase in nitrate ions in agricultural areas can be attributed to several factors: fertilizer use, irrigation practices, and animal manure.

Hydrochemical evaluation of water in the study area

The water quality index values of groundwater samples for both low flow season and high flow season are listed in Table (7) according to the classification of Brown et al., (1972) depending on the physiochemical characteristics (Table 6). The values of WQI range from (29.96 to 112.5) in the low flow season; and for the high flow season, they range from (25.61 to 142.32). Out of forty groundwater samples, the water quality values of 12 of them (30%) are categorized as good, 17 samples (42.5%) are categorized as poor, 10 samples (25%) are very poor, and 1 sample (2.5%) is unsuitable for drinking purposes in the low flow season (Table 8). In high flow season, , the water quality values of 16 samples of groundwater (40%) are good, 14 samples (35%) are poor, 7 samples (17.5%) are very poor, and 3 samples (7.5%) are unsuitable for drinking purposes. This indicates that a greater number of groundwater samples in the study area are unfit for human consumption.

Table 6: Physicochemical parameters' Standard Values (WHO, 2021) and Unit Weights for WQI Calculation

Parameter	Si*	1/Si	K=(1/ sum1/si)	Wi
pH	8.5	0.117647	3.92187	0.461396
TDS	1000	0.001		0.003922
TH	500	0.002		0.007844
Ca^{+2}	100	0.01		0.039219
Mg^{+2}	70	0.008		0.031375
Na^{+1}	200	0.005		0.019609
K^{+1}	12	0.083333		0.326823
SO_4^{-2}	250	0.004		0.015687
Cl^{-1}	250	0.004		0.015687
NO_3^{-1}	50	0.02		0.078437
Total		0.25498		1
Si= Standard Values (WHO, 2021)				

Table 7: Water Quality Index (*WQI*) of Groundwater Samples of the Study Area.

Site N.	dry season	Wet season	Site Name	dry season	Wet season
Gw1	69.76	64.56	Gw21	51.12	48.15
Gw2	79.18	64.23	Gw22	58.66	57.17
Gw3	71.42	58.99	Gw23	44.42	37.01
Gw4	91.76	91.3	Gw24	29.96	25.61
Gw5	43.99	56.7	Gw25	48.62	36.05
Gw6	82.79	59.66	Gw26	64.34	76.83
Gw7	37.75	57.06	Gw27	48.88	47.76
Gw8	84.25	102.24	Gw28	40.9	42.45
Gw9	82.86	74.59	Gw29	112.5	107.84
Gw10	61.92	58.33	Gw30	57.02	48.17
Gw11	57.58	45.75	Gw31	52.18	68.61
Gw12	73.68	59.6	Gw32	40.65	48.99
Gw13	56.09	42.92	Gw33	36.06	32.01
Gw14	76.23	75.3	Gw34	40.83	53.63
Gw15	97.48	88.1	Gw35	43.28	41.32
Gw16	71.97	71.08	Gw36	40.44	49.49
Gw17	73.09	42.39	Gw37	62.52	45.91
Gw18	67.36	142.32	Gw38	55.83	48.08
Gw19	84.23	87.18	Gw39	55.99	72.97
Gw20	95.16	83.57	Gw40	95.35	70

*Excellent * Good *poor * Very poor * Unsuitable for drinking purpose

Conclusion

The assessment of groundwater quality for drinking purposes utilizing water quality index studies has been discussed in this research. Forty groundwater wells distributed in the study area having WQI values that reflect the water quality in the groundwater aquifer. They are characterized by heterogeneity of water chemistry because of the region's geology, which contains the formations (Fatha, Injana, and recent deposits) in addition to the spread of oil and agricultural activities in the region. Overall evidences suggest that the research region's groundwater is moderately hard and somewhat alkaline. The average ionic dominance pattern is bicarbonate > Sulphate > calcium > magnesium > chloride > nitrate > sodium > potassium > phosphate in the low flow season, and bicarbonate > Sulphate > calcium > magnesium > nitrate > chloride > sodium> potassium> phosphate for cations and anions respectively, in the high flow season. Studies found that 70% of the groundwater in the research region was of poor quality for drinking, according to the water quality index (WQI). As a result, there is a larger demand among the population of the research area for risk education on the nitrate contamination of groundwater, which might aid the locals in taking the appropriate precautions to prevent using such polluted water for drinking.

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