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Evaluation of groundwater quality and the hydrogeochemical processes of shallow Dibdibba aquifer in Basra Governorate, southern Iraq

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Abstract

Thirty seven groundwater samples were taken from groundwater wells to evaluate the groundwater quality of shallow Dibdibba aquifer at Safwan-Zubair area in Basrah governorate.

The physiochemical parameters were analyzed including pH, total dissolved solids (TDS), electrical conductivity (EC), the cations and anion elements. The results show that 81% and 19% of the studied samples are within (CaCl and NaCl) water type respectively. The results show that the middle and southern parts of the study area have the largest concentration of the most chemical and physical characteristics indicating increasing in it is agricultural and domestic activities.

The geochemical evaluated of the groundwater samples results show that 83.7% represented by probable mixing water affected by dissolution depended on Durov diagrame. All the studied samples were considered unsuitable for drinking purposes because of high total dissolved solids ranged between (2704 to 10322 mg/l). The groundwater samples were considered as unsuitable for irrigation because of higher concentration of Sodium adsorption ratio (SAR), Sodium percentage (Na%), Permeability index (PI), Magnesium ratio MR and Residual sodium bicarbonate (RSBC).

Keywords: Groundwater quality, GIS, Spatial analyses, Hydrogeochemical processes, Dibdibba formation, Iraq.

Introduction

Groundwater considered as one of the most important sources in arid and semi-arid regions. Evaluating and monitoring their sources are urgent for hydrogeologist to detect the factors that caused negative anomalies in groundwater quality, in addition to implementing of any management plan [1].

Groundwater of Dibdibba formation considers the main source for many peoples who lived at southwestern parts of Basrah governorate. They depended on groundwater wells for domestic and agriculture life requirements. At the last twenty years, the extreme intensive pumping operations, in addition to, drill many groundwater wells without any management plan by private companies with different depths and numbers causes deterioration the quality of groundwater, beside increased the salinity of groundwater at the most groundwater wells. These factors are important problems in arid and semi-arid regions due to urbanization and agricultural activities [3].

Detected the spatial distribution of the main factors that caused this problem and try to control the main sources of pollutants is important in giving clear vision about the hydrogeological evaluation of groundwater and to giving the main factors that affect the groundwater characteristic and assess the validity of groundwater for different purposes.

The interaction soil/rock-water process during recharge, groundwater flow, dissolution of minerals species, ..etc are considered the main processes that responsible for the variation of groundwater and vice versa [2].

Geological and hydrological sitting of the study area

The study area is located in the southern part of Iraq in Basra governorate within Zubair-Safwan area between longitudes (47˚55’0’’-47˚30’0’’) Easting and latitudes (30˚27’0’’-30˚03’0’’) Northing, with an average area of 2,874.2 km^2 (Figure 1).

The study area contains shallow valleys, which are drainage systems in the region; these valleys form parallel to each other and are usually located in the south and south-west of the study area. The valleys are filled with water during the rainy season; considered as a recharge system for groundwater in the region [4].

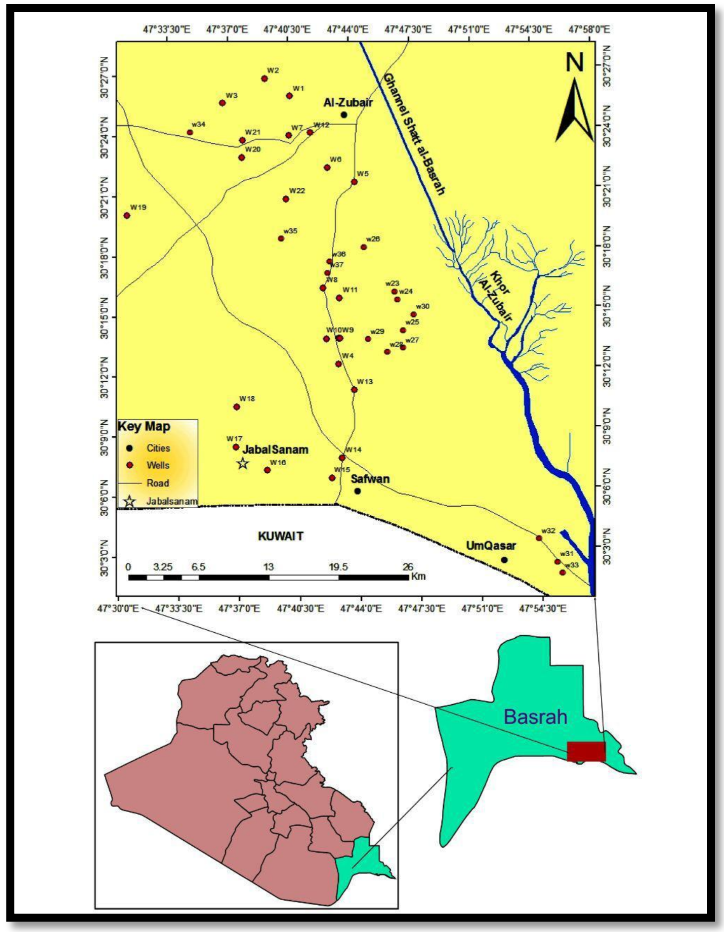


Figure 1: Location map of the Study area with selected wells

Geologically the area mainly covered with Dibdibba formation which contains sandy gravel soil. Many geomorphological features can be seen in Dibdibba plain such as Jabal Sanam hill, sand dunes and shallow wadies [5][6] [4], (Figure 2). The elevation of the study area referenced to the sea level is ranged from (5-158m), figure (3), the land surface is generally flat with a slow gradient from the highest surface level at Jabal Sanam at south-west to the north-east of the study area.

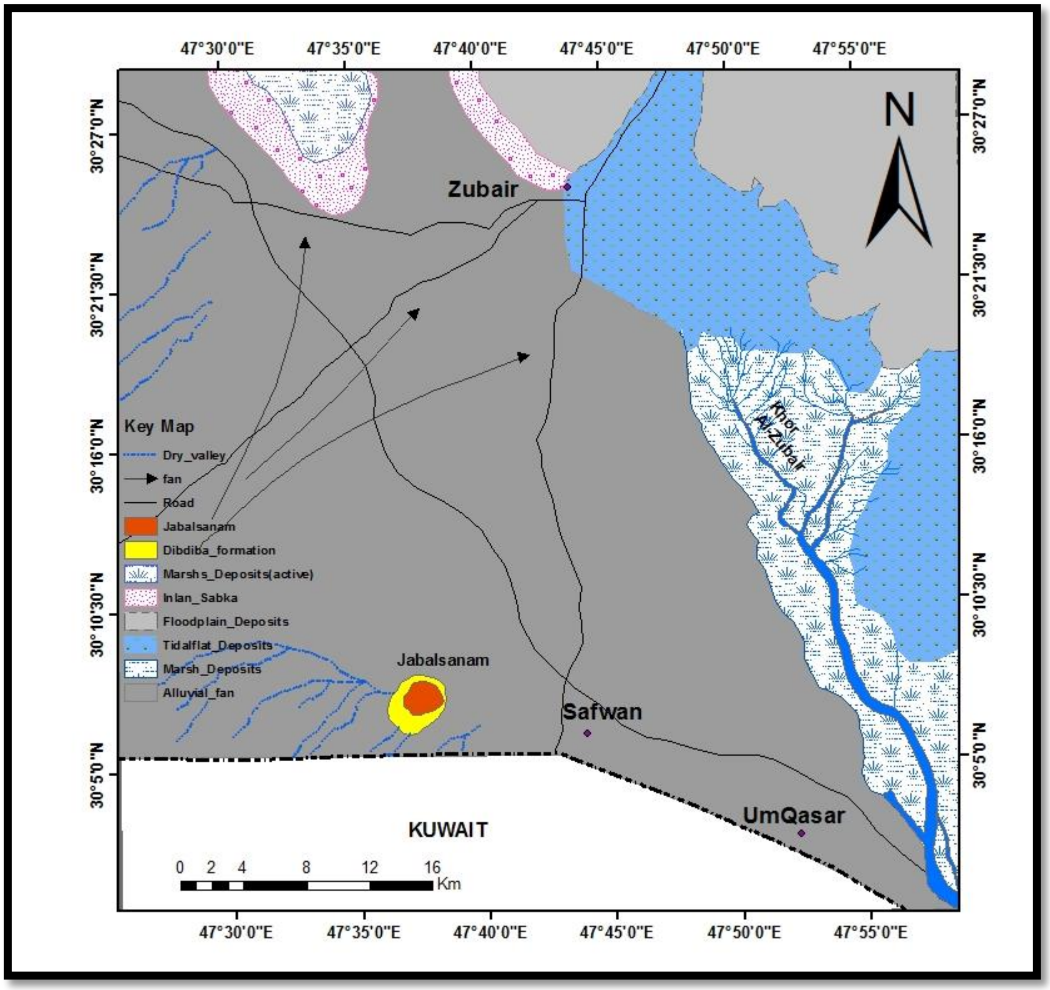


Figure 2: Geological map of the study area (modified from GEOSURV, 2011)

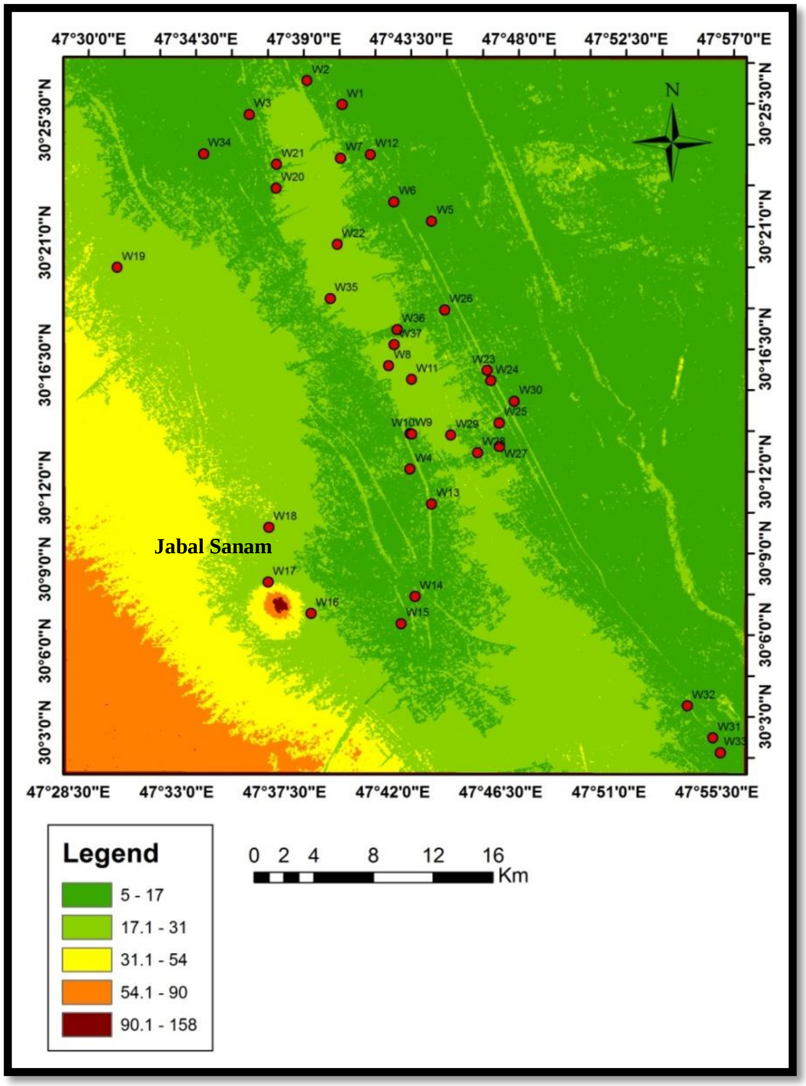


Figure 3: The Digital Elevation Model (DIM) of the study area

Dibdibba formation considered the most important aquifer of the study area, where the upper part of aquifer is unconfined separating from the deeper part of aquifer, which is semi-confined to confined aquifer, by hard clay layer of 2 to 4 m thickness [6]. The flow system in the area, based on the correct static water levels is characterized by groundwater direction from the west and southwest to the east and north-east towards the drainage region in Khor al-Zubair and the Shatt al-Basrah Channel, (Figure 4). The structural and geological sitting controls the flow of groundwater movement in this direction.

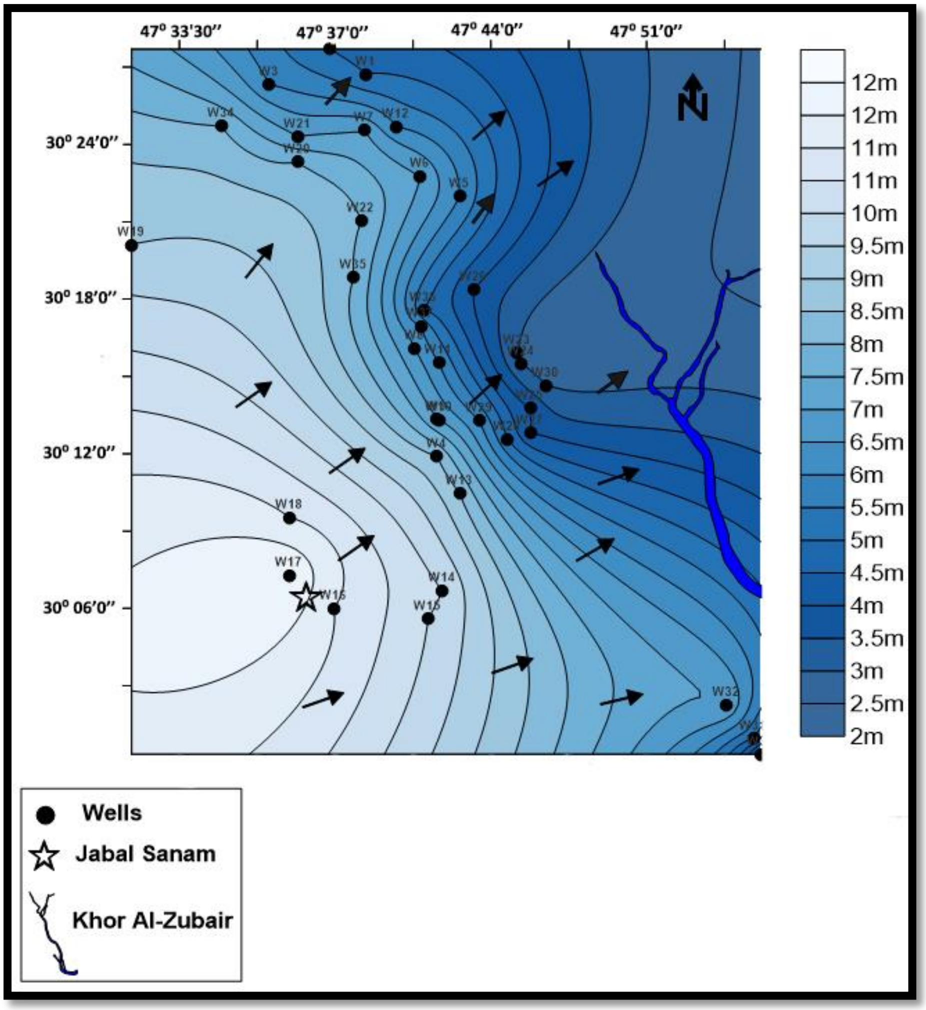


Figure 4: The flow direction of groundwater in the study area

Tectonically the area situated within the unstable shelf within Zubair subzone which is part of the Mesopotamian zone [7], According to Fouad (2010) the study area is located in the Mesopotamia foredeep within the outer platform of The Arabian platform [8]. Al-Zubair fold, Rumaila fold and Al-Luhais fold are the main subsurface structures within the area which are usually long narrow and forming subsurface anticlines folds separated by synform folds towards NW-SE [9], (Figure 5).

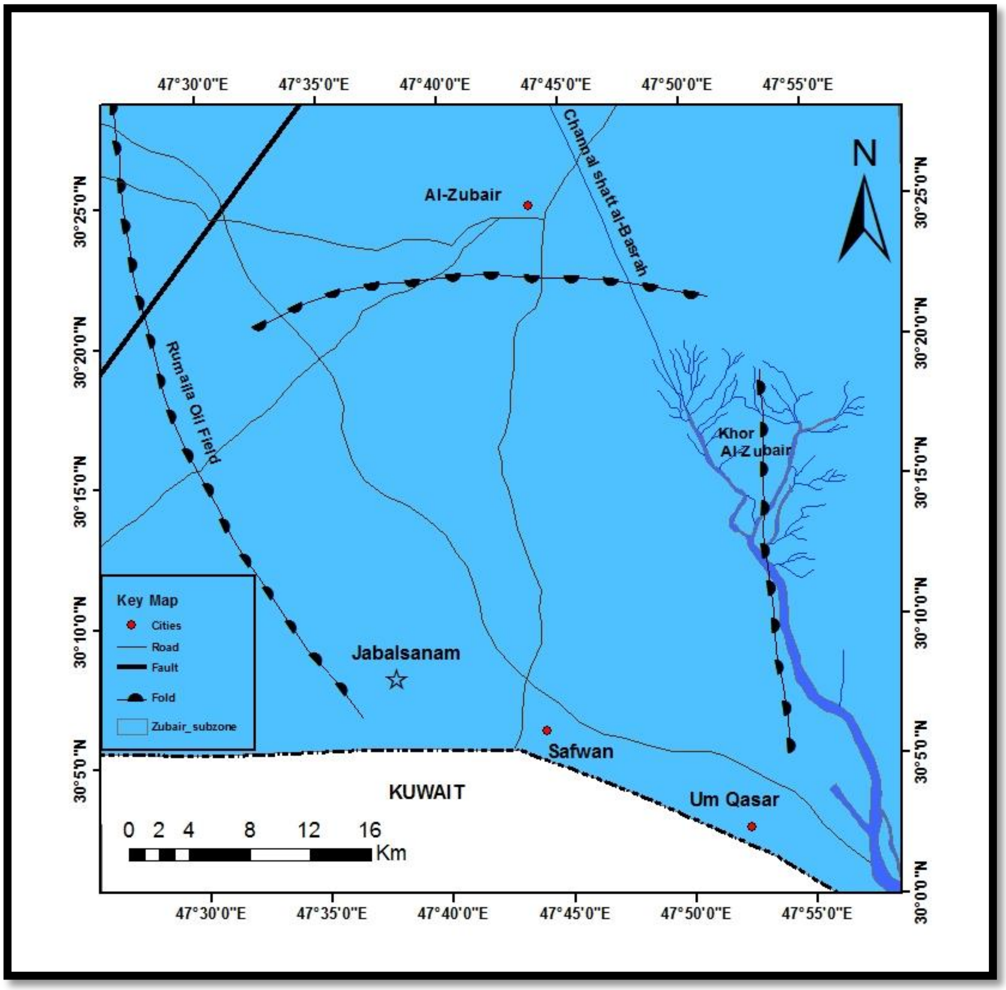


Figure 5: Structural map of the study area (GEOSURV, 2008 and 2012)

Materials and methods

Thirty-seven groundwater samples were collected from the wells distributed at the area between Zubair and Safwan at September 2017. The samples were analyzed for thirty physiochemical parameters: total dissolved solids (TDS), electrical conductivity (EC), pH and temperature (T) were measured in the field. Major and minor elements analyzed in the laboratory of Basrah Environmental Agency, Ministry of Environment. All the physical and chemical parameters were analyzed by using the routine techniques described by APHA, 2005 [10], (Table 1). The spatial distribution of the groundwater quality in the study area was represented by using ArcGIS 10.4.1 (Geographic Information System) software, the Aquachem v.2014 software was used for plotting Piper and Durov diagrams. Besides to calculate sodium adsorption ratio (SAR), sodium percentage (Na%), Magnesium hazard (MR), permeability index (PI) and residual sodium bicarbonate (RSBC).

Table 1: Standard methods for chemical and physical analysis [10]

Parameters	Methods and equipment
pH and EC	pH meter, EC meter
TDS	Gravimetric Method
Ca^{2+}, Mg^{2+}	EDTA titrimetric method
Na^{+}, K^{+}	Flame photometer method
Cl^{-}	Argentometric method
SO_4^{2-}	Turbidimetric and colorimetric methods
HCO_3^{-}	Titration method by indicator titrated with HCL
NO_3^{-}	Ultraviolet spectrophotometer screening method
PO_4^{3-}	Ascorbic acid method using the spectrophotometer

Results and discussion

The chemistry of groundwater is important to understand the factors that affect the suitability of groundwater for drinking, agriculture, domestic and industrial purposes [11][12]. Table (2) shows the summary analysis results of the present groundwater samples which include the minimum, maximum and average for physical and chemical characterizes.

The results of chemical analyses of groundwater show different variation, where pH values of groundwater samples ranged between 7 to 8.1 with an average 7.3, the nature of water in the region was slightly alkaline**,** where all the samples consider normal according to IQS (2009) and WHO (2011) standers.

The total dissolved solids ranged between 2704 – 10322 mg/l with an average 6198.1 mg/l, (Table 2). The concentration of TDS in groundwater is dependent on the type of rock and the variation of mineral solubility [13]. The concentrations of total dissolved solids are increased at the recharge areas in Safwan and Jabal Sanam, whereas it decreases towards groundwater flow in the region to the discharge areas towards Khor al-Zubair, figure (6-A). According to [14] and [15], table (3), most groundwater samples are fall within slightly-brackish water class except the samples W32 which is considered as brackish water, table (3).

The EC values at 25 C° ranged between 4160 to 15880 µs/cm with an average 9535.6 µs/cm, (Table 2). The high variation in conductivity is due to various geochemical processes such as ionic-exchange, reverse ionic-exchange, rock-water interaction, evaporation, silicate weathering, oxidation and sulphate reduction processes [16]. Figure (6-B) shows the spatial distribution of the EC in the study area, the concentration value very high in south and middle parts of the region. According to [17] the groundwater samples in the study area are classified as excessively mineralized water, (Table 4).

Table 2: Physiochemical analysis of the groundwater in the study area

Well No.	pH	E.C (µS/cm)	TDS (mg/l)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO4 (mg/l)	HCO3 (mg/l)	NO3 (mg/l)	PO4 (mg/l)
w1	7	4160	2704	430.00	65.00	465.00	15.00	585.00	1150.00	311.1	8.60	0.54
w2	7.11	5300	3445	490.00	85.00	530.00	15.30	675.00	1250.00	305	16.63	0.54
w3	7.05	12700	8255	350.00	200.00	1500.00	30.00	2225.00	1100.00	347.7	25.48	1.3
w4	7.08	5860	3809	500.00	90.00	870.00	33.00	1150.00	1370.00	329.4	25.48	0.56
w5	7.2	12800	8320	430.00	150.00	1400.00	45.00	2100.00	1050.00	268.4	13.95	0.55
w6	7.18	10880	7072	380.00	130.00	440.00	16.50	641.00	1200.00	244	25.49	0.71
w7	7.5	4350	2827.5	450.00	185.00	300.00	35.00	730.00	1075.00	506.3	25.49	0.59
w8	7.33	11400	7410	508.00	144.00	1400.00	20.00	2200.00	850.00	347.7	25.58	0.59
w9	7.1	11700	7605	540.00	210.00	1200.00	40.00	2545.00	530.00	518.5	25.58	0.55
w10	7.22	10600	6890	402.00	121.00	1135.00	35.00	1800.00	530.00	579.5	25.58	0.56
w11	7.3	10500	6825	386.00	107.00	1345.00	32.00	1790.00	975.00	354	25.58	0.54
w12	7.25	6110	3971.5	521.00	300.00	485.00	25.00	1430.00	1024.00	6	6.10	
w13	7.21	13260	8619	912.00	320.00	689.00	45.00	2121.00	1150.00	30	2.50	
w14	7	10160	6604	751.00	205.70	435.90	95.00	1399.60	1060.00	30	11.20	
w15	7.4	11520	7488	695.00	560.00	549.00	32.00	2390.00	1060.00	12	5.10	
w16	7.3	14550	9457.5	390.00	106.20	876.00	28.00	960.00	1401.00	12	2.70	
w17	7.1	12410	8066.5	885.00	410.00	350.00	19.80	2060.00	1009.00	60	1.60	
w18	7.5	12470	8105.5	390.00	490.00	281.00	25.00	995.00	1353.00	280	4.20	
w19	7.2	9670	6285.5	775.00	204.00	230.00	23.00	899.00	1440.00	12	5.40	
w20	7.3	8520	5538	340.00	530.00	112.00	31.30	480.00	2116.00	340	5.30	
w21	7.4	8670	5635.5	721.70	515.00	105.40	35.00	1394.00	1163.00	310	5.20	
w22	7.3	8260	5369	641.00	564.00	100.00	25.00	1095.00	1680.00	90	4.00	
w23	7.4	6610	4296.5	601.50	204.20	200.00	43.00	1178.00	720.00	7.5	2.10	
w24	7.4	10880	7072	525.00	356.00	240.00	24.00	1649.00	550.00	5	2.60	
w25	7.3	8480	5512	901.80	190.80	105.60	33.00	1402.00	783.00	2	1.10	
w26	7.1	8560	5564	620.00	231.00	103.00	32.00	1299.00	650.00	5.5	1.10	
w27	7.2	6780	4407	700.00	255.00	140.00	46.00	1420.00	693.00	5.5	1.40	
w28	7.6	7690	4998.5	989.00	385.00	107.90	27.90	1890.10	885.00	8.5	3.60	
w29	7.2	11120	7228	499.00	218.00	100.00	33.00	1009.00	697.00	5	2.80	
w30	7.5	6400	4160	508.00	225.00	103.00	31.00	1119.00	557.00	10	3.60	
w31	7.2	7660	4979	370.30	430.00	137.00	37.00	1249.00	1020.00	4.5	3.80	
w32	7.4	15880	10322	582.00	420.00	134.00	34.00	1399.00	1049.00	4.5	2.80	
w33	7.3	9020	5863	676.00	315.00	215.00	24.00	1349.00	1154.00	5	3.50	
w34	7.8	6830	4439.5	791.00	700.00	305.00	37.00	2184.00	1465.00	6.7	0.10	
w35	7.7	6830	4439.5	902.00	342.00	209.00	40.00	1488.00	1336.00	12	7.10	
w36	8.1	13950	9067.5	807.00	433.00	350.00	45.00	1399.00	1987.00	12	5.60	
w37	7.8	10280	6682	901.00	150.00	362.00	43.00	1468.00	1150.00	18	8.40	
Minimum	**7**	**4160**	**2704**	**340.00**	**65.00**	**100.00**	**15.00**	**480.00**	**530.00**	**2.00**	**0.10**	**0.54**
Maximum	**8.1**	**15880**	**10322**	**989.00**	**700.00**	**1500.00**	**95.00**	**2545.00**	**2116.00**	**579.50**	**25.58**	**1.30**
Average	**7.32**	**9535.6**	**6198.18**	**601.66**	**285.05**	**475.94**	**33.26**	**1436.94**	**1087.35**	**146.09**	**9.36**	**0.64**

Table 3: Classification of samples based on TDS (mg/l)[14 and 15]

	TDS	Water type	Number of samples	Percentage of samples
According to freeze and cherry 1979	<1000	Fresh water type	-	-
	1000–10,000	Brackish water type	36	97.29
	10,000–100,000	Saline water type	1	2.702
	>100,000	Brine water type	-	-
	Total		37	100
According to Todd (2009)	10 - 1000	Fresh water	-	-
	1000 – 10,000	Slightly-Brackish water	36	97.29
	10,000 – 100,000	Brackish water	1	2.702
	>100,000	Brine water	-	-
	Total		37	100

Table (4) classification of groundwater samples depended on EC.[17]

EC (µS/cm)	Mineralization	Number of samples	Percentage of samples
<1000	Very weakly mineralized water	-	-
1000 – 2000	Weakly mineralized water	-	-
2000 – 4000	Slightly mineralized water	-	-
4000 – 6000	Moderately mineralized water	4	10.81
6000 – 10,000	Highly mineralized water	15	40.54
>10,000	Excessively mineralized water	18	48.64

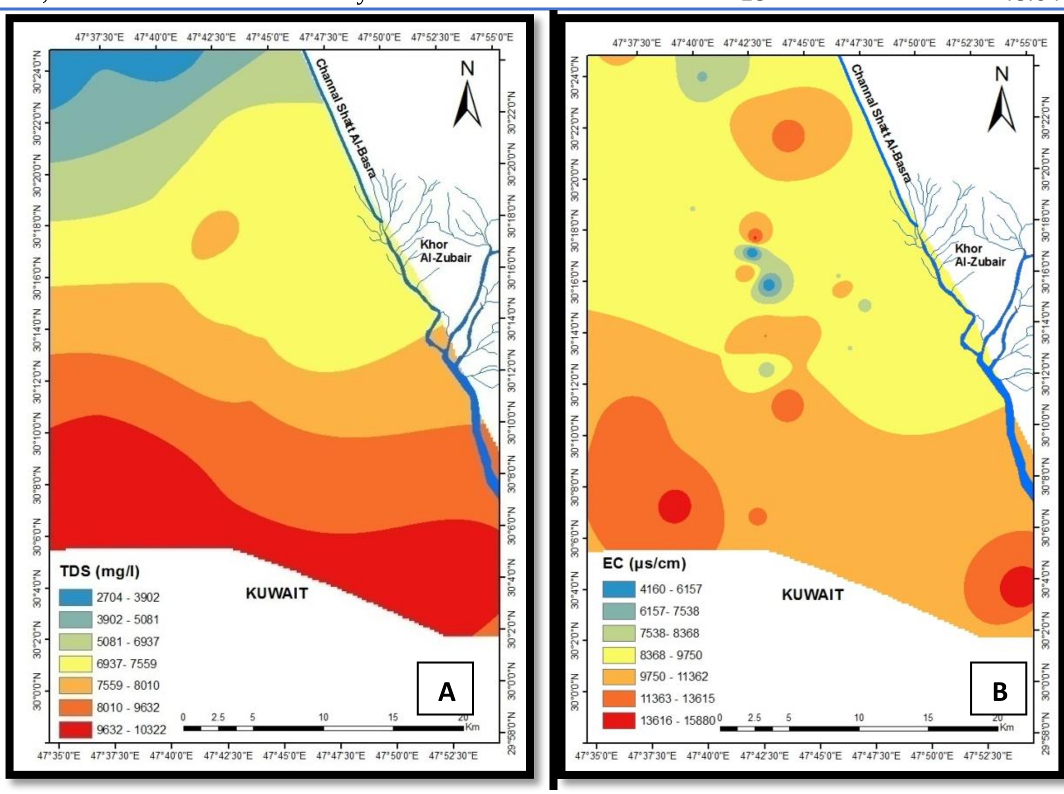


Figure 6: Spatial distribution of (A) the total dissolved solids (TDS mg/l) and (B) electrical conductivity (EC µs/cm)

Calcium concentration Ca^{2+} can be present in groundwater as a result of dissolving gypsum, calcite and anhydrite minerals; the main source of calcium ion is the erosion of pyroxene, amphibole, and feldspar minerals depending on the solubility of sulfide, calcium carbonate, and chloride [18]. The Ca^{2+} concentrations of the present samples

are ranged from 340 to 989 mg/l with an average 601.6 mg/l, (Table 2). The spatial distribution Ca^{2+} shows wide variation along the study area, where the high concentration at the south and center parts of the study area, while the northern part was characterized by low concentration, (Figure 7-A).

Magnesium content in the present groundwater samples is varied from 65 to 700 mg/l with an average 285.05 mg/l, table (2). The concentration of Mg^{2+} may be derived to groundwater from leaching process of calcite minerals such as dolomite and calcite [19]. The spatial distribution of Mg^{2+} shows wide variation along the study area, the concentration was decrease toward Khor al-Zubair the drainage area; (Figure 7-B).

The concentration of Na^{+} in the present samples was ranged between 100 to 1500 mg/l with an average 474.59 mg/l, (Table 2). The main source of sodium concentration was halite mineral (NaCl) because of high solubility [20] and the ion-exchange of clay minerals [21]. The spatial distribution of Na^{+} shows that along the study area, the higher concentration of sodium at central and north parts of the study area, (Figure 8-A).

Potassium concentration is ranged from 15 to 95 mg/l with an average 33.26 mg/l, (Table 2). The lower concentration of K^{+} in groundwater samples is due to the adsorption of potassium and involvement in the crystalline structure of some clay minerals such as illite [22]. The extreme used of fertilizes are the main source for increase K^{+} in groundwater by irrigation results that infiltrate downward recharging groundwater. The higher concentration of K^{+} was near Jabal Sanam due to increase agricultural activates at this region, (Figure 8-B).

The concentration of HCO_3^- ranged between 2 to 579.5 mg/l with an average 129.22 mg/l, (Table 2). The dissolution of calcareous minerals leads to increase of the concentrations of bicarbonates in the groundwater [23]. The spatial distribution of $HCO3^-$ shows wide variation along the study area where the higher concentration was at northern parts, while it is decreased in other parts of the area, (Figure 9-A).

The concentration of Cl^- in groundwater samples ranged from 129 to 2545 mg/l with an average 1427.4 mg/l, (Table 2). The higher concentration of chloride in groundwater may be by chemical fertilizers, chloride treatment, irrigated water and sewage [24]. The spatial distribution of Cl^- shows that the higher concentration was concentrated at the middle parts decreasing towards the northern parts of the study area, (Figure 9-B).

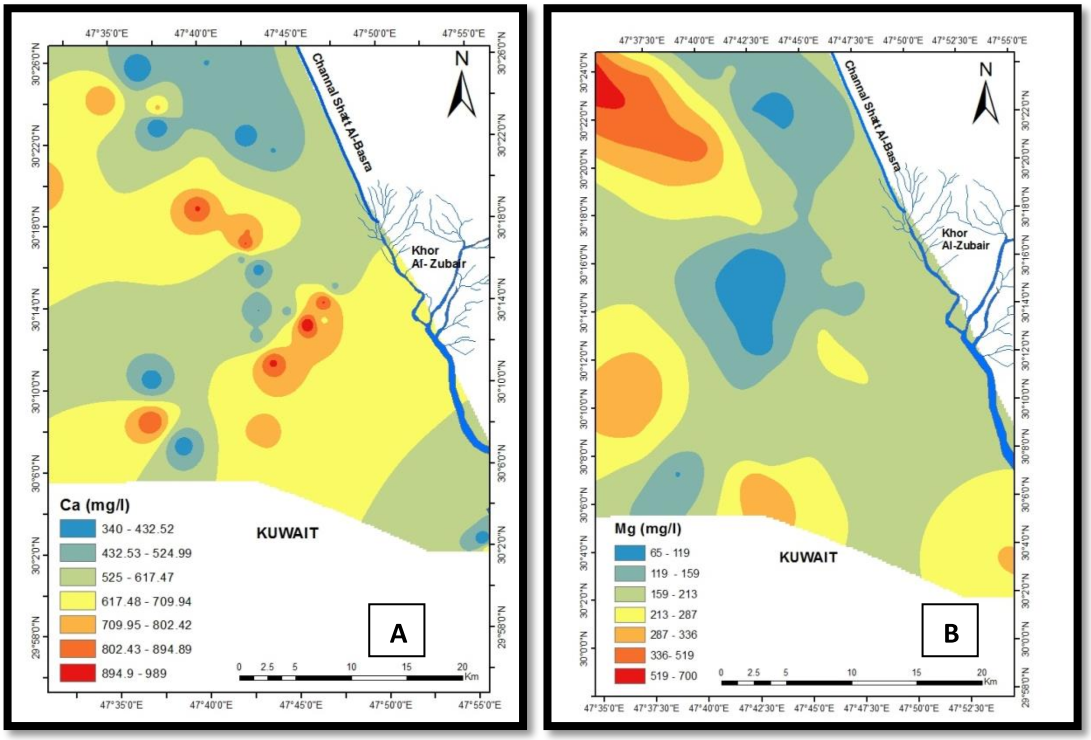


Figure 7: Spatial distribution of (A) Ca^{2+} and (B) Mg^{2+} in the study area

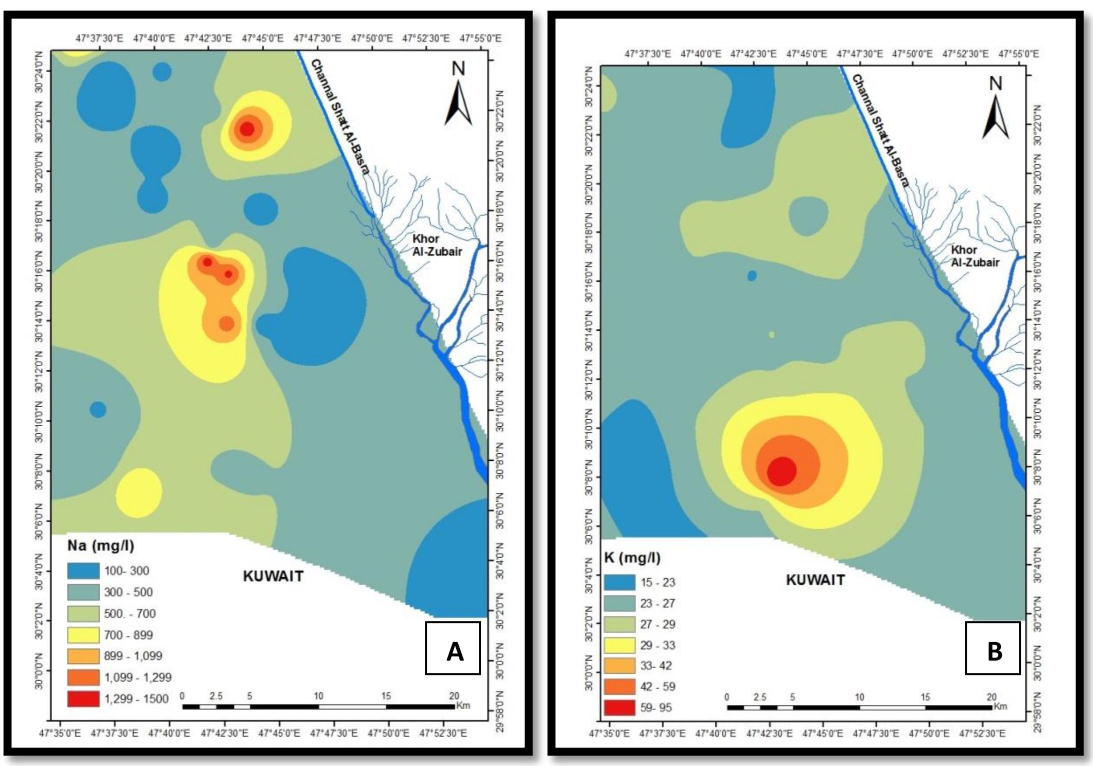


Figure 8: The spatial distribution of cations (A) Na^{+} and (B) K^{+} in the study area

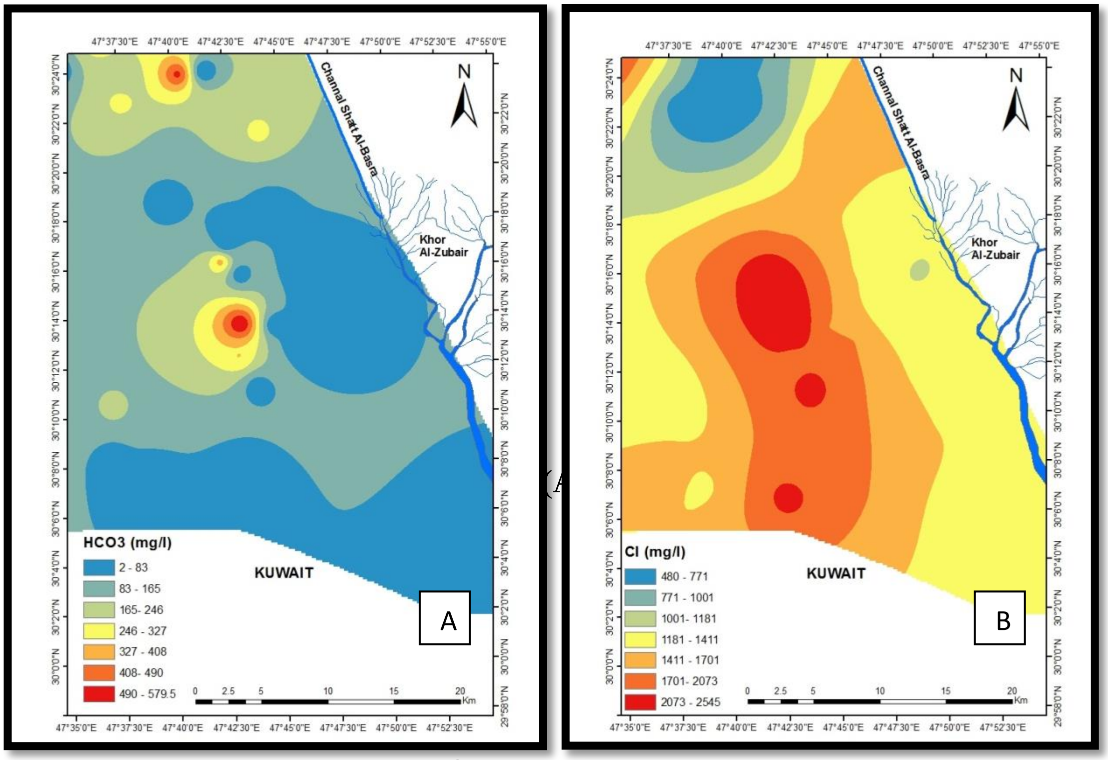


Figure 9: Spatial distribution of anions (A) HCO_3^- and (B) Cl^- in the study area

The values of sulphate of the groundwater samples ranged from 530 to 2116 mg/l with an average 1087.3 mg/l, (Table 2). The higher concentration of the SO_4^{2-} due to increasing the solubility of evaporated rocks (gypsum and anhydrite), fertilizers, detergents and pesticides [25]. Figure (10-A) shows the spatial distribution of SO_4^{2-} the higher concentration was at all parts but decrease toward Khor al-Zubair.

The nitrate NO_3^- concentration ranged from 0.1 to 25.58 mg/l with an average 9.36 mg/l, (Table 2). The Nitrate is widely found in soil and groundwater and also considered one of the most important problems of groundwater pollution because of the use of fertilizers excessively [26]. The spatial distribution of NO_3 shows that the concentration was increased in the northern and middle parts of the study area; (Figure 10-B).

Finally, the phosphate is present in surface and groundwater as a result of fertilizers, pesticides, domestic sewage and industrial waste [27]. The value of PO_4^{2-} concentration in the groundwater samples ranged between 0.54-1.30 mg/l with an average 0.64 mg/l, (Table 2). The spatial distribution of PO_4^{-2} shows that the higher concentrations were at the northern and southern parts, while the low concentration of the PO_4^{-2} constructed at the middle parts of the study area because of increasing fertilizers, pesticides, domestic sewage and industrial waste, (Figure 11).

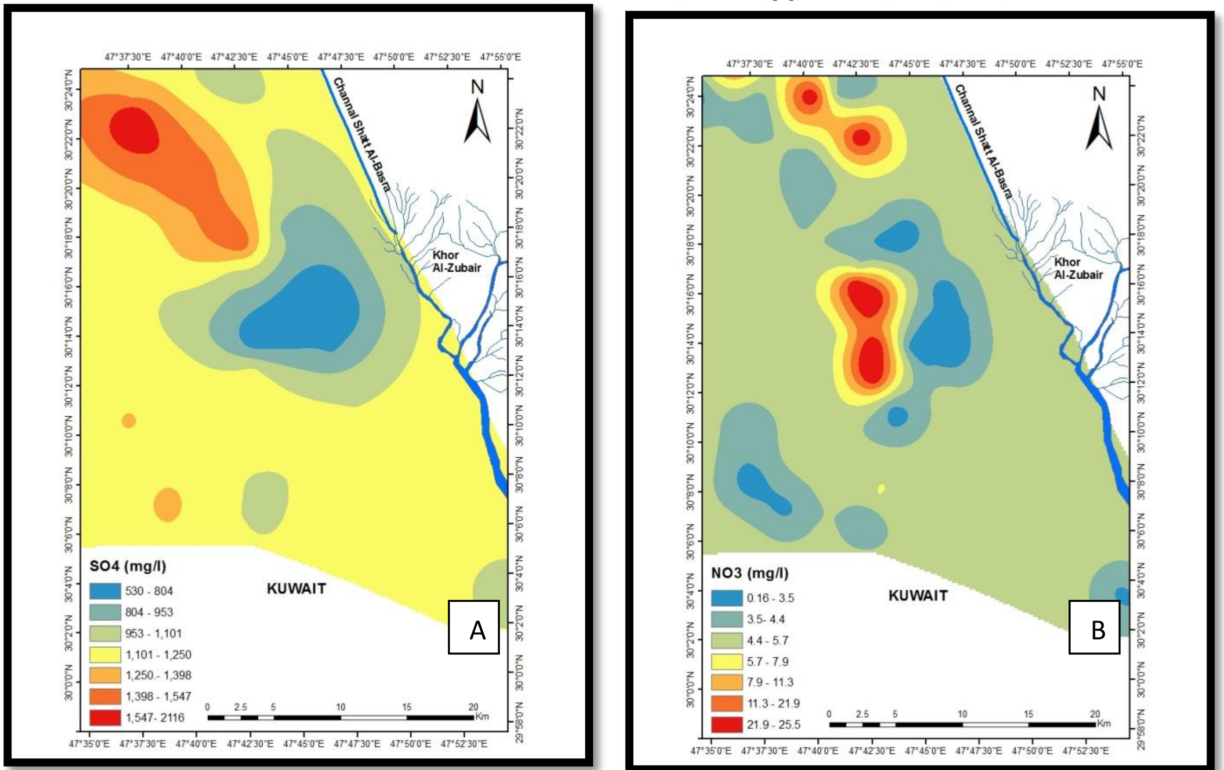


Figure 10: Spatial distribution of anions (A) SO_4^{2-} and (B) NO_3^-) in the study area

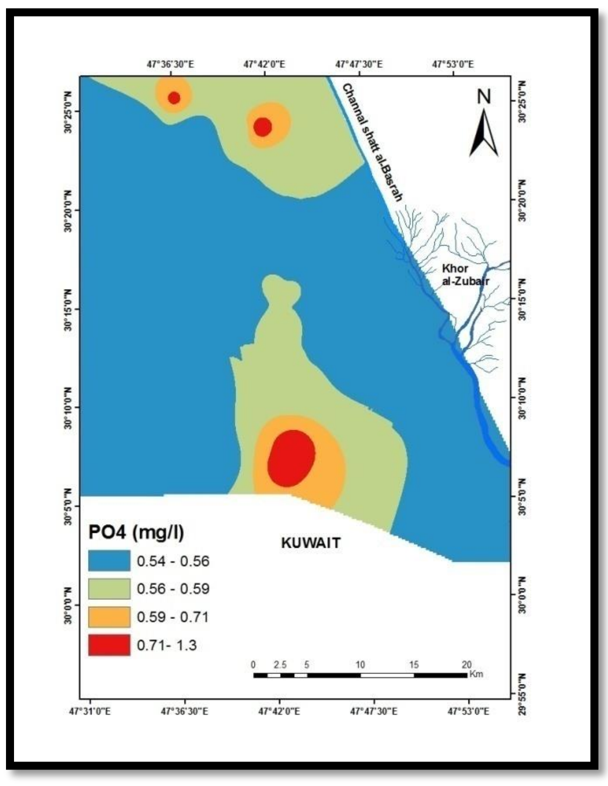


Figure 11: Spatial distribution of PO_4^{2-} in the study area

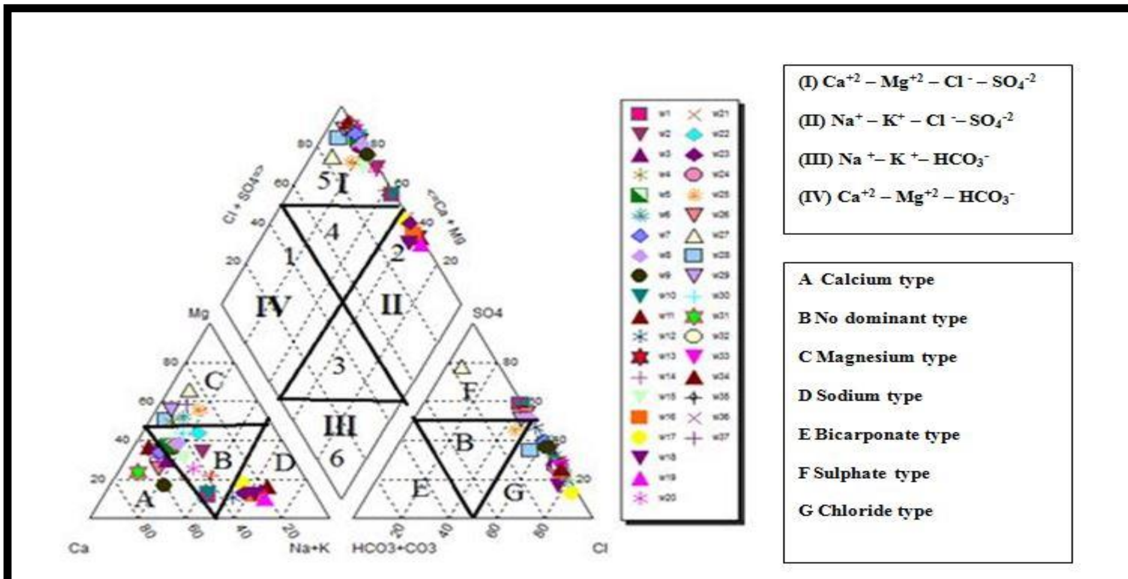
Groundwater classification

Piper classification

A Piper diagram (1944) was adopted to find the chemical quality of groundwater of the study area [28]. This diagram is based on the dissolved of the natural water content which it cations and anions in (meq/l) unit [29]. Aquachem v.2014 software was used for plotting the Piper diagram, figure (12), where 81% of groundwater samples fall in the field of alkaline earth in which (Ca, Mg) are dominant, and equal to strong acid where Cl and SO_4 are dominant, 18.9% fall into NaCl types, which in turn refers to Na^+- K^+- Cl^- - SO_4^{2-} . For cations and anions triangular, about 40.5% of groundwater samples belong to the zone of Ca^{2+} type, while about 13.5%, 16%, 13.5 and 86% of groundwater samples fall in zones of Na^+ type, Mg^{2+} type, SO_4^{2-} type and Cl^- type respectively.

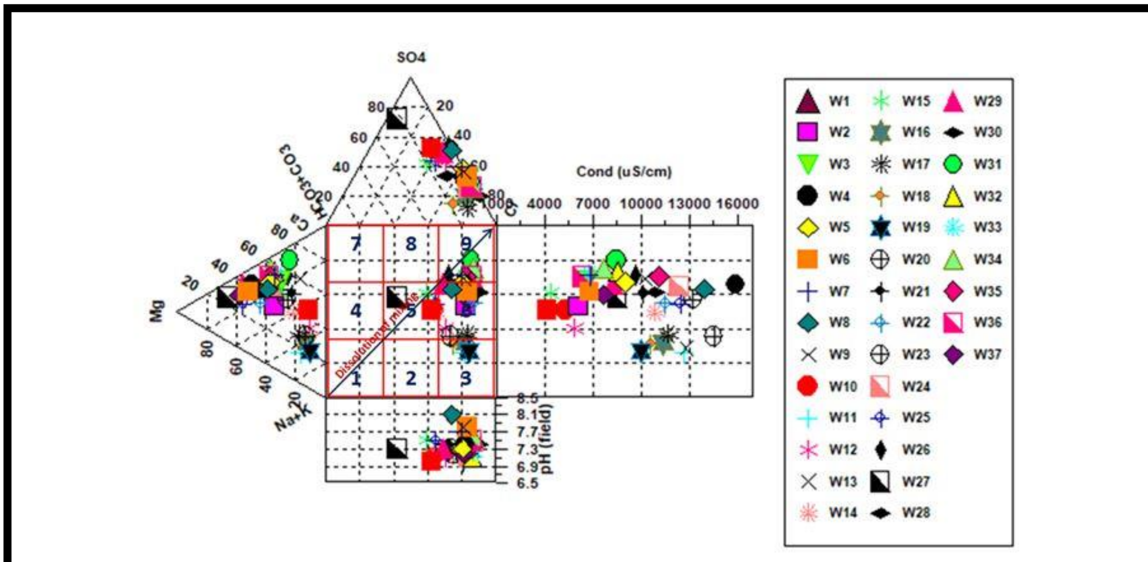
Geochemical evaluation of groundwater in the study area

The Durov diagram was used to the classification of groundwater and assesses of evaluation geochemical, and maybe indicates mixing of water types, ion-exchange, and reverse ion-exchange [30]. Lloyd and Heathcote (1985) [31] divided the middle of the rectangle into nine regions: (region 1) HCO_3^- and Ca^{2+} dominated frequently indicates recharging water in sandstones and limestone aquifers; (region 2) HCO_3^- and Mg^{2+} or Ca^{2+} and Na^+ indiscriminate; (region 3) HCO_3^- and Na^+ dominate ion-exchange water may be indicated; (region 4 and 5) indicating mixing water or water exhibiting simple dissolution; (region 6) indicate of probable mixing; (region 7 and 8) indicate of reverse ion-exchange reaction; and (region 9) refers to end point water [32]. According to Durov diagrams, this was plotted by used Aquachem v.2014 software. Figure (13) about 83.7% of groundwater samples fall in field No.6 (water type Ca^{2+} -Mg^{2+} - Cl^-), which is represented by probable mixing, while 8% of samples are fall in field No.5 (Ca^{2+} - Mg^{2+} - HCO_3^- - SO_4^{2-}) and indicating mixed water that affected by dissolution.



1	2	3	4	5	6
$CaHCO_3$	NaCl	Mixed $CaNaHCO_3$	Mixed CaMgCl	CaCl	$NaHCO_3$

Figure 12: Piper classification of groundwater samples



Region	1	2	3	4	5	6	7	8	9
Chemical facies of groundwater	HCO_3^- and Ca^{2+} dominate	HCO_3^- and Mg^{2+} or Ca^{2+}/Na^+ indiscriminate	HCO_3^- and Na^+ dominate	Ca^{2+} and SO_4^{2-} dominate	No domination of anion or cation	SO_4^{2-} and Na^+ dominate or anion indiscriminate	Cl^- and Ca^{2+} dominate	Cl^- dominate	Cl^- and Na^+

Figure 13: chemical facies in Durov diagram of the study area

Suitability of groundwater for drinking purpose

The suitability of drinking water depends mainly on the quality of groundwater and compared with the global and local standards such as the World Health Organization (WHO 2011) [33] and the Iraqi Standards (IQS 2009) [34], table (5) shows permissible limits results. In general, pH and NO_3^- of the samples in the study area were within permissible limits according to [33] and [34], while the values of Ca^{2+}, K^+, SO_4^{2-}, and TDS were all above the permissible limits for drinking water, 91.8%, 67.5% and 97% of the Mg^{2+}, Na^+ and Cl^- of the groundwater samples were exceed the permissible limits for drinking water, (Table 5). From previous results, all samples of groundwater in the study area were unsuitable for drinking purposes.

Table 5: The hydrochemical parameters of the samples in comparison with [33] and [34] for the standards of drinking water

Parameters	WHO(2011)	IQS(2009)	No. of samples that exceeded permissible limits	Percentage of samples	Wells number
pH	6.5-8.5	6.5-8.5	-	-	-
Ca^{2+}	75	150	37	100	All wells
Mg^{2+}	100	100	34	91.8	All wells except (W1,W2,W4)
Na^+	200	200	25	67.5	All wells except (W20.W21,W22,W23,W25, W26,W27,W28,W29,W30,W31,W32)
K^+	10	-	37	100	All wells
Cl^-	250	350	36	97.2	All wells except (W20)
SO_4^{2-}	250	400	37	100	All wells
NO_3^-	50	50	-	-	-
TDS	1000	1000	37	100	All wells

Suitability of groundwater for irrigation purpose

The suitability of groundwater for irrigation purpose is depend on the concentration of ions in water, plant type, and soil type [35], there is several parameters show the suitability of water such as EC, salinity, sodium adsorption ratio (SAR), sodium ratio (Na %), magnesium ratio (MR), permeability index (PI) and residual sodium bicarbonate (RSBC).

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is important for determining the suitability of groundwater for irrigation purposes, because sodium has ionic replacement with calcium in the soil, as well as reducing the permeability and soil structure [15] especially in the dry period where the salinity of the soil is high and thus negatively affect on the plants. The SAR is a relative ratio of sodium ions in the sample of water to sodium and magnesium ions [36] and can be calculated from the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (1)$$

Where all the ionic concentrations in epm units

The value of SAR of the groundwater samples in the study area were ranged between 0.7 and 16.27 with an average 4.75, (Table 6). The higher values of SAR indicating filtrate of salts and dissolution by precipitation, the United State salinity diagram (USSL) [37] defined by plotting the relationship between sodium adsorption ratio (SAR) and electrical conductivity (EC), (Figure 14), can be used for assessing the suitability water of irrigation. About 35.1% of groundwater samples fall within C4-S1 category and which indicate a very high salinity-low sodium, while 37.8% of the samples fall under category C4-S2 indicate a very high salinity – medium sodium, 18.9% of the samples fall C4-S4 category indicating very high salinity-very high sodium, and only 8.1% fall in C4-S3 which indicate a very high salinity-high sodium, (Figure 14). According to SAR all the groundwater samples considered as unsuitable for irrigation purpose, (Figure 15-A).

Table 6: The irrigation parameters of the groundwater samples of the study area

Well No.	SAR (meq/L)	Na %	RSBC (meq/L)	PI (%)	MR (meq/L)
w1	5.76	44.68	-14.21	50.1	21.68
w2	6.05	43.96	-17.00	48.59	24.11
w3	16.27	66.45	-10.02	69.43	51.14
w4	9.79	55.21	-17.05	59.33	24.79
w5	15.30	64.99	-14.91	68.071	38.99
w6	5.13	40.45	-13.06	45.078	38.52
w7	2.58	23.043	-11.91	29.711	42.96
w8	14.63	63.39	-17.11	66.23	34.18
w9	11.45	55.096	-15.75	58.808	41.604
w10	13.19	63.079	-8.55	67.79	35.54
w11	16.18	71.46	-16.84	69.95	33.68
w12	4.303	30.22	-23.29	30.95	51.33
w13	5.16	30.46	-40.46	31.54	39.12
w14	3.76	26.32	-33.23	28.25	33.41
w15	3.84	23.41	-31.01	24.04	59.61
w16	10.51	58.56	-17.31	59.903	33.28
w17	2.51	17.06	-38.75	18.28	45.909
w18	2.27	17.29	-14.56	19.904	69.71
w19	1.97	16.09	-34.60	16.96	32.53
w20	0.89	7.549	-10.84	10.94	74.065
w21	0.74	5.713	-29.45	7.94	56.66
w22	0.709	5.42	-27.31	6.99	61.71
w23	1.85	16.23	-26.88	17.23	38.34
w24	2.03	16.33	-23.49	16.94	55.403
w25	0.86	7.454	-40.46	7.85	27.93
w26	0.92	8.59	-27.75	9.31	40.56
w27	1.18	10.205	-31.34	10.92	40.026
w28	0.76	5.76	-44.27	6.27	41.62
w29	0.96	9.55	-22.32	10.37	44.45
w30	0.98	9.61	-22.65	10.66	44.79

w31	1.16	10.11	-16.55	10.75	68.0
w32	1.05	8.65	-26.06	9.172	56.93
w33	1.76	14.12	-30.27	14.68	46.053
w34	1.94	12.36	-35.41	12.78	61.85
w35	1.55	11.54	-40.30	12.26	40.99
w36	2.54	17.25	-36.04	17.99	49.57
w37	3.06	22.61	-40.16	23.76	23.37
Minimum	0.709	5.42	-44.26	6.27	21.68
Maximum	16.27	71.46	-8.55	69.95	74.065
Average	4.750	27.22	-24.89	29.18	43.907

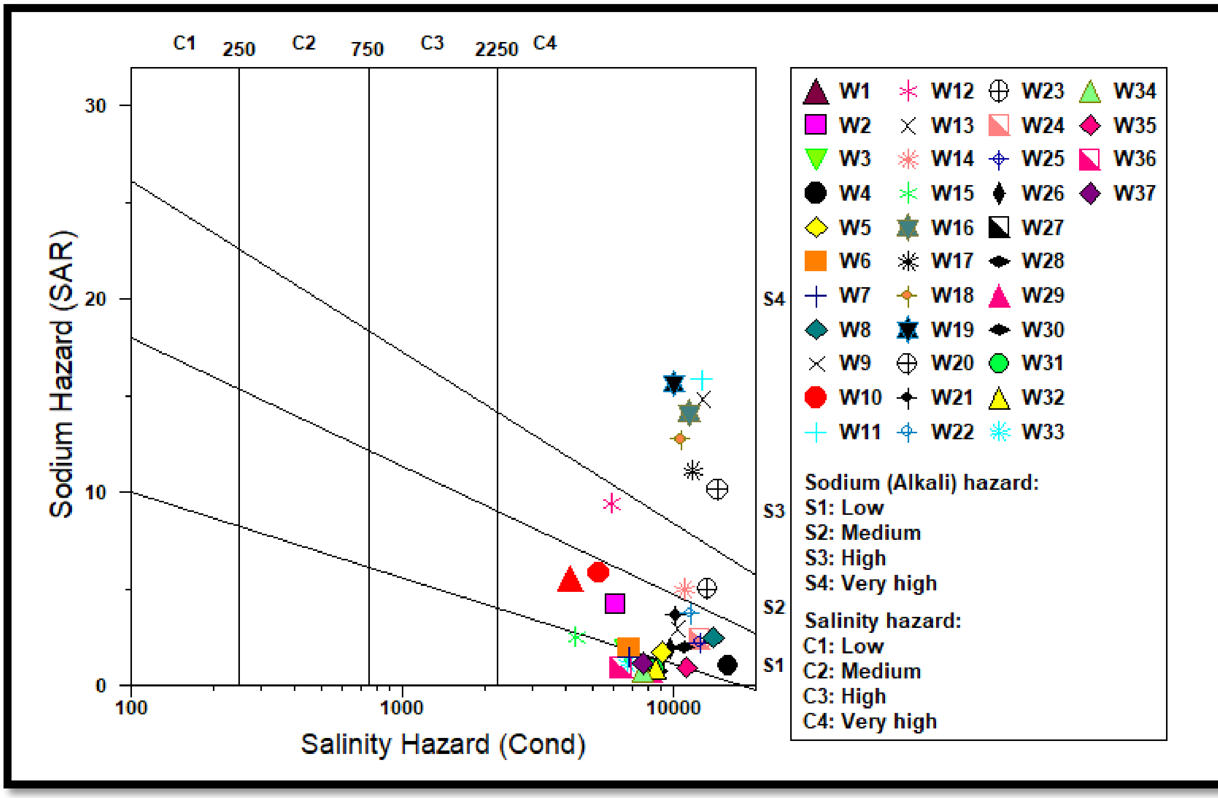


Figure 14: classification of groundwater samples in the study area for irrigation purpose depended on SAR and EC

Sodium percentage (Na %)

Sodium percentage (Na %) is an important parameter of sodium hazard, sodium content in the soil leads to reduce permeability [38]. Therefore, sodium is an important factor in assessing the suitability of groundwater for irrigation, Na % is calculated by using the following equation [39]:

Where all the ionic concentration in epm

$$\%Na = Na^{+} \times 100 \,/\, [Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}] \quad (2)$$

The values of Na% ranged between 5.4 to 68.4 % with an average 27.2 %, (Table 6) and (Figure 15-B), by plotting of the Wilcox diagram, figure (15) the groundwater samples in the study area are fall in the unsuitable category.

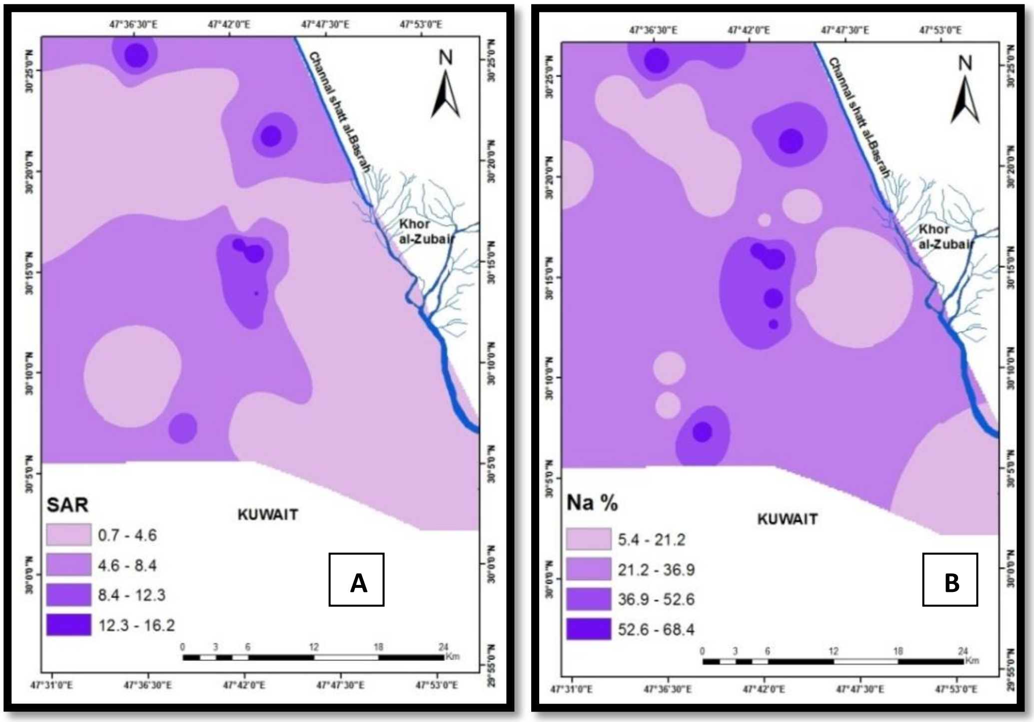


Figure 15: The suitability of irrigation water in the study area based on (A) SAR and (B) Na%

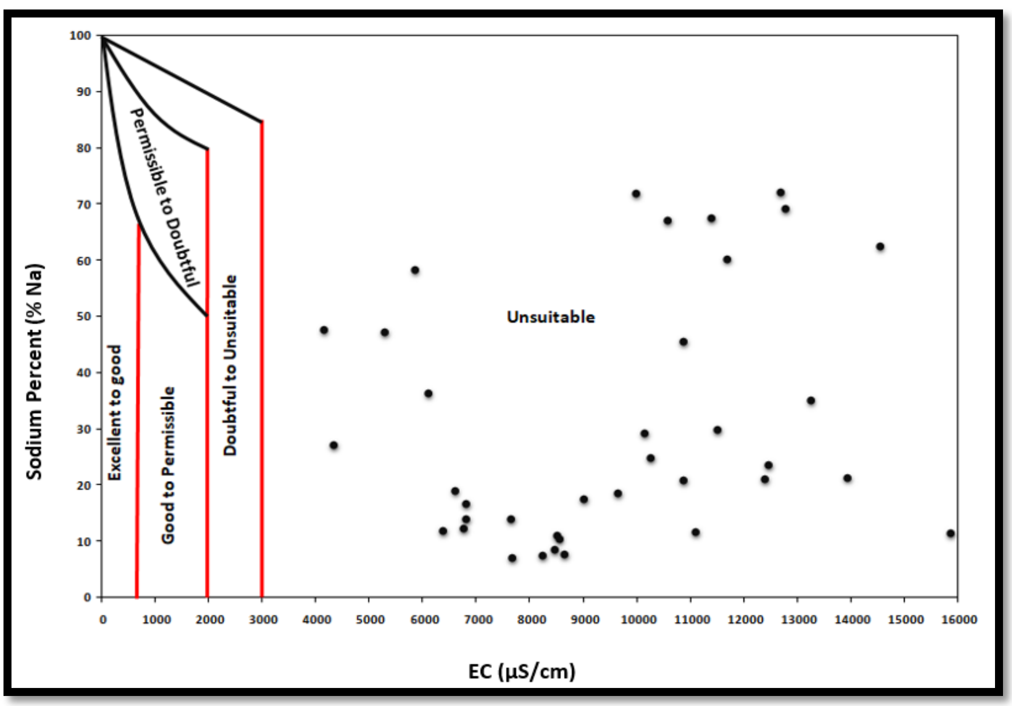


Figure 15: Classification of irrigation water in the study area depended on Na% [39]

Magnesium Ratio (MR)

The Magnesium ratio defined by the excess of magnesium concentration over Ca^{2+} and Mg^{2+}, the MR was calculated by following equation [40]:

$$MR = [Mg^{2+} / (Mg^{2+} + Ca^{2+})] \times 100 \quad (3)$$

Where all the ionic concentrations in epm units

When the values of magnesium ratio more than 50% of the soil become very alkaline and if MR less than 50% was suitable for irrigation purpose [32], 70.2% of the groundwater samples in the study area were suitable of irrigation (MR<50%) and 29.7% of samples were unsuitable (MR>50%), (Table 6) and (Figure 17-A).

Permeability index (PI)

Soil permeability is affected by the presence of sodium, calcium, magnesium and bicarbonate contents, and the soil is also affected by the long-term of irrigation water. The permeability index developed by Doneen (1962) [41] and may be calculated by the following equation:

$$PI = \frac{(Na^{+} + \sqrt{HCO_3^{-}})}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \quad (4)$$

Where all the ionic concentrations in epm units

Groundwater was classification into three classes according to permeability index (PI): class I, class II, and class III. Class I is as excellent for irrigation with PI >75%; class II is good for irrigation when PI between 25-75%; and class III is unsuitable for irrigation if PI < 25% [32]. 59.4% and 40.5% of the groundwater samples were considered as unsuitable and good classes respectively, (Table 6) and (Figure 17-B).

Residual sodium bicarbonate (RSBC)

The increase in the concentration of bicarbonate lead to increased concentrations of calcium and magnesium and is associated with an increase in sodium concentration [42], which is causing negative effects on the soil. The RSBC was classified according to Gupta and Gupta (1987) [43] into three classes: satisfactory (RSBC<5 meq/L), marginal (RSBC 5-10 meq/L), and unsatisfactory (RSBC<10 meq), the RSBC is calculated by using the equation [43]:

$$RSBC = (HCO_3 - Ca) \quad (5)$$

Where all the ionic concentrations in epm units

The RSBC result of the groundwater samples in the study area were ranged between -44.2 to -8.5 meq/L with an average -24.8 meq/L, the most RSBC values of samples are considered satisfactory (<5 meq/L), (Table 6). The almost groundwater samples in the study area are suitable for irrigation purpose, (Figure 18).

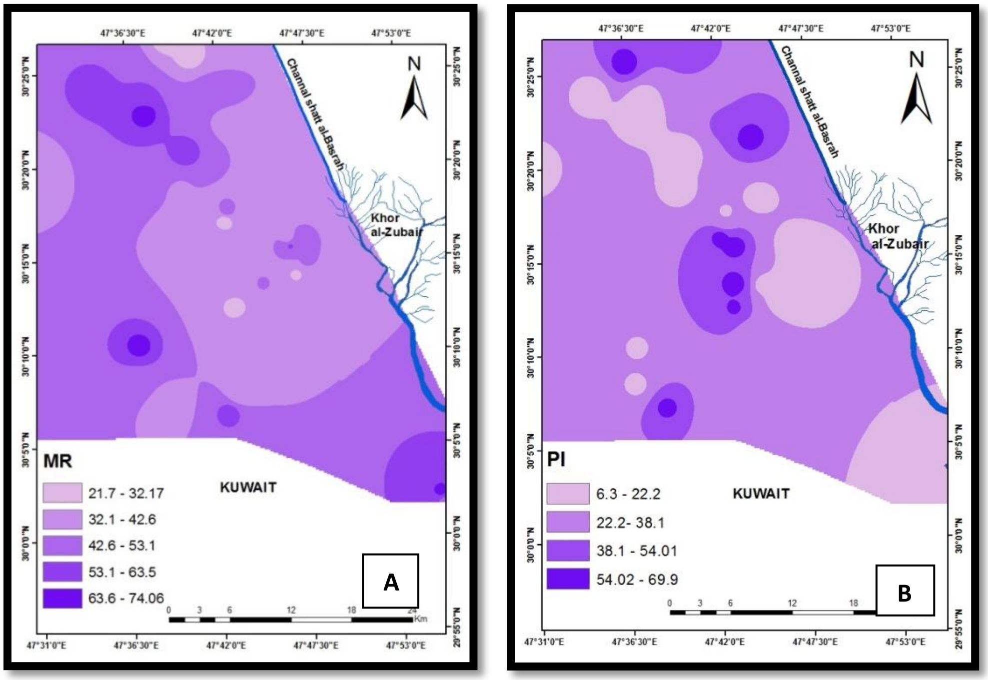


Figure 17: The suitability of irrigation water in the study area based on (A) MR and (B) PI

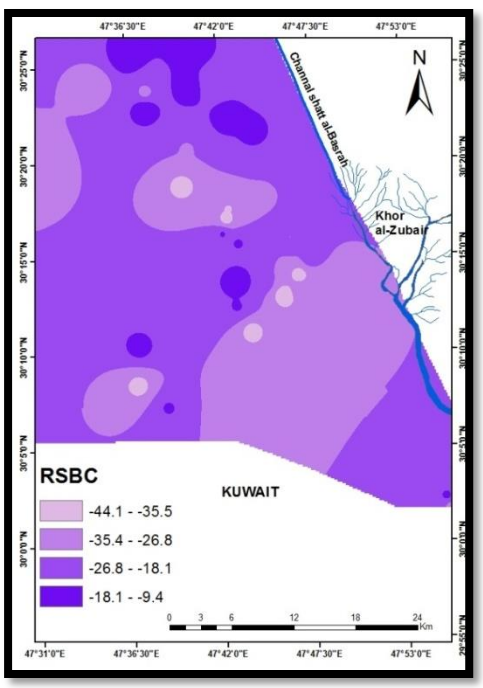


Figure18: The suitability of irrigation water in the study area based on RSBC

Conclusions

1. Agricultural and domestic activates will exceed the physiochemical parameters at the middle and southwestern parts of study area.
2. All the groundwater samples were considered as unsuitable for drinking and irrigation uses. SAR, Na% and PI shows that all the groundwater samples are unsuitable, while MR and RSBC results indicated that most of samples were unsuitable whereas 29.7% of groundwater samples were considered as good irrigation purpose.
3. Deterioration in groundwater quality were found according to increase the mixing probable due to dissolution caused by the increased in pumping operation and drilling many wells without any management plane.

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تقييم نوعية المياه الجوفية والعمليات الهيدروجيوكيميائية لخزان الدبدبة الضحل في محافظة البصرة ,جنوبي العراق

المستخلص:

تم تجميع 37 نموذج ماء من ابار المياه الجوفية الموزعة في منطقة سفوان– الزبير ضمن خزان الدبدبة الرملي وذلك لغرض تقيمها نوعيا".

تضمنت الدراسة الحالية اجراء بعض التحاليل الفيزيوكيميائية التي اشتملت على قياس كل من التوصيلية الكهربائية (EC), الاملاح الذائبة الكلية(TDS) , pH و الايونات السالبة والموجبة للعناصر. اظهرت النتائج بان حوالي 81% و 18% من نماذج المياه الجوفية في المنطقةهي من نوع CaCl و NaCl. كما اوضح التوزيع المكاني لتراكيز العناصر الفيزيائية والكيميائية في المنطقة ان التراكيز تزداد في وسط وجنوب–غرب منطقة الدراسة وان سبب الزيادة في هذه الاجزاء يعود الى زيادة الانشطة والفعاليات الزراعية والصناعية في المنطقة. كما اوضح التطور الهيدروجيوكيميائي لنماذج المياه الجوفية ان 83.7% من النماذج هي مياه ناتجة من عمليات المزج ومتاثرة بعمليات الاذابة.

جميع نماذج المياه الجوفية كانت غير صالحة للشرب حسب المواصفات العراقية (IQS 2011) و منظمة (WHO 2009) بسبب قيم الملوحة العالية التي تراوحت.(2704 to 10322 mg/l) . كما بينت الدراسة ان المياه الجوفية غير صالحة لاغراض الري بسبب القيم العالية لنسبة امتزاز الصوديوم (SAR) و النسبة المؤية للصوديوم (Na%), وبالاعتماد على قيم دليل النفاذية (PI) فان حوالي 59.4% من النماذج كانت غير صالحة و 40.5% جيدة لاغراض الري, وبالاعتماد على قيم نسبة المغنيسيوم (MR) و بيكاربونات الصوديوم المتبقية (RSBC) كانت المياه الجوفية بنسبة 70.2% غير صالحة و بنسبة 29.7% صالحة لاغراض الزراعة والري.