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Hydrochemical Assessment of Groundwater in Al-Nahrawan Area, Eastern Baghdad, Iraq

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Abstract

The hydrochemical study of groundwater in the Nahrawan region involves interpreting the physical, chemical, and biological properties of 17 samples collected from 17 wells in October 2024. Groundwater samples are characterised as slightly alkaline, excessively mineralised, and brackish, except for W3, W4, W5, W7, and W8, which are salty waters. The results showed that the dominant groundwater is sodium sulfate, except for the sixth sample, which is sodium chloride type. To evaluate groundwater suitability for irrigation, sodium adsorption ratio (SAR), soluble sodium percentage (Na%), pH, total dissolved solids (TDS), and electrical conductivity were measured. According to the results, groundwater sodium adsorption percentage values in the majority of samples are permissible; the fourth, fifth, seventh, and eighth samples are doubtful, and the fifteenth sample is good. The percentage of sodium within the allowable limits, except for the fifteenth sample, is satisfactory. The pH values are within the allowable limits; however, they are unsuitable for electrical conductivity and total dissolved solids due to the high salinity of sodium, sulfate, and chlorine ions. Based on the results, the water in the study area is unsuitable for use due to the high levels of certain parameters.

Keywords: Hydrochemical, Groundwater, Al-Nahrawan, SAR.

التقييم الهيدروكيميائي للمياه الجوفية في منطقة النهروان، شرق بغداد، العراق

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قسم علم الأرض، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة

تتضمن الدراسة الهيدروكيميائية للمياه الجوفية في منطقة النهروان تفسير الخصائص الفيزيائية والكيميائية والبيولوجية بناء على 17 عينة تم جمعها من 17 بئراً في أكتوبر 2024. تميزت عينات المياه الجوفية بأنها قلوية قليلاً، شديدة التمعدين، قليلة الملوحة باستثناء العينة الثالثة، الرابعة، الخامسة، السابعة، والثامنة هي مياه مالحة. وأظهرت النتائج أن المياه الجوفية السائدة هي كبريتات الصوديوم باستثناء العينة السادسة هي من نوع كلوريد الصوديوم. لتقييم ملاءمة المياه الجوفية للري، تم قياس نسبة امتصاص الصوديوم، النسبة المئوية للصوديوم، درجة الحموضة، المواد الصلبة الذائبة الكلية والتوصيلية الكهربائية. وفقاً للنتائج تتميز المياه الجوفية بنسبة

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امتاز الصوديوم في غالبية العينات مسموح بها والعينة الرابعة، الخامسة، السابعة، والثامنة مشكوك فيهم، اما العينة الخامسة عشر فهي مرضية. النسبة المئوية للصوديوم ضمن الحدود المسموحة، ماعدا العينة الخامسة عشر فهي مرضية، قيم الرقم الهيدروجيني ضمن الحدود المسموح بها، ولاكنها غير مناسبة من حيث التوصيلية الكهربائية والاملاح الصلبة الذائبة الكلية بسبب الملوحة العالية المتمثلة بأيونات الصوديوم والكبريتات والكلور. بناء على النتائج، فإن مياه منطقة الدراسة غير صالحة للاستخدام بسبب ارتفاع نسبة بعض المتغيرات.

1. Introduction

Water hydrochemistry plays a crucial role in assessing groundwater resources, as water quality is just as vital as its quantity. Water quality and availability are critical indicators of sustainable development, given the pivotal role that water plays in economic development [1]. Determining the quality of groundwater suitable for human consumption is essential for the welfare of the growing population [2]. The chemical composition of groundwater results from the water that entered the reservoir and its reactions with various rocks that contain minerals [3]. Chemical composition of groundwater is affected by the physical and chemical processes interconnected within the porous medium, as well as changes like nutrition, the rock, and depth of the underground reservoir, as well as the temperature of the porous medium, which play an additional role in the variation in the chemical composition of groundwater, resulting in variation in hydrochemical properties [4]. Population increase, economic and agricultural development, drought, and a lack of rainfall all contribute to the region's growing demand for groundwater, which can lead to excessive consumption and a decline in both quantity and quality. Urban management practices often degrade groundwater, making it unusable for future use [5]. In addition to lowering water quality, groundwater pollution affects economic development, human health, and social prosperity [6]. The groundwater quality is essential, depending on its use. The spatial distribution of agricultural activities, human settlements, and factories in the study area is as follows: brick and tanning factories are concentrated in the NE. In contrast, farming and urban areas are located in the northwest (NW) and southwest (SW), and power plants are located in the southwest (SW) of the region (Fig. 1).

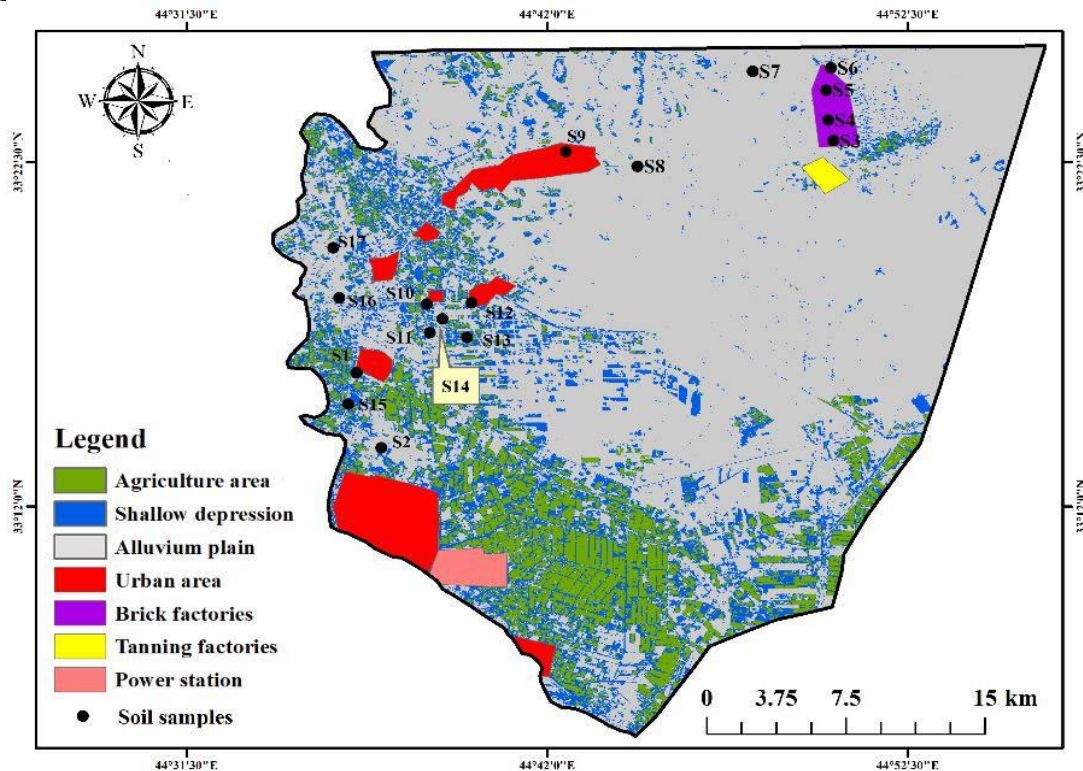


Figure. 1: Geographical distribution of factories, human activities, and agricultural activities

1.1 Study area

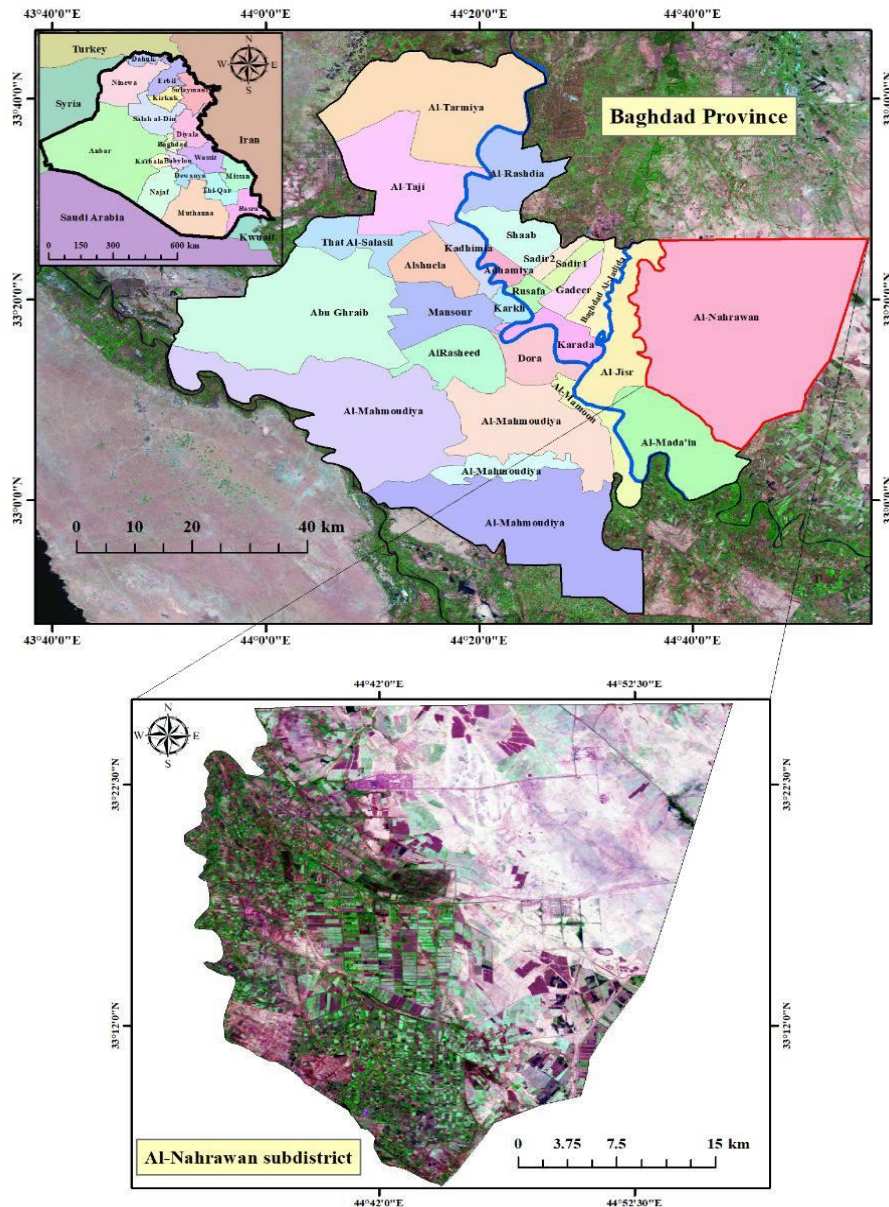


Figure 2: The study area map

Al-Nahrawan is located 33 km southeast of Baghdad, the capital of Iraq [7]. A blend of residential neighbourhoods, agricultural land, and industrial operations distinguishes the region. The river's presence in the study area significantly impacts the local groundwater system, affecting its quality and availability. This makes it an essential location for evaluating the effects of both human activity and nature on the environment. The study region is confined by latitudes 32° 90"-33° 40" and longitudes 44° 55"- 44° 03" (Figure 2).

1.2 Materials and methods

Water samples from 17 wells were collected in 2024, and the laboratory work involved their physical, chemical, and biological analysis. The Ministry of Water Resources' General Authority for Groundwater analysed these samples to determine their major cations (Ca^{2+} , Mg^{2+} , Na^{+} , and K^{+}), major anions (Cl^{-} , HCO_3^{-} , $\text{SO}_4^{=}$, and $\text{CO}_3^{=}$), while trace elements (Pb, Cd, Ni, Cu, Cr, Fe, and Cd), dissolved oxygen (DO), chemical oxygen demand (COD), and biological oxygen demand (BOD) were analysed in Research and Technology Centre of

Environment, Water and Renewable Energy. Water classification and deterrent water type were done using RockWare AqQa version 1.1. The GPS instrument type was used to measure the longitude, latitude, and elevation of each sample. After sampling, a portable meter (Yieryi meter) was used to test the pH, temperature, electrical conductivity (EC), total suspended solids (TSS), and total dissolved solids (TDS) in situ. The following equation was used to verify the results' accuracy [8]:

$$U\% = \frac{r\sum C - r\sum A}{r\sum C + r\sum A} \times 100 \quad (1)$$

$$A = [100 - U] \quad (2)$$

Where:

U%: Reaction error, A: Accuracy, $r\sum C$: Sum of cation, $r\sum A$: Sum of anion.

If the reaction error is within the acceptable range ($U\% \leq 5$), the results may be sufficient for interpretation. However, if ($5 < U\% < 10$), use the results with caution, while ($U\% > 10\%$), the results are unacceptable [9]. The following formula was used to determine the water type [10].

$$\text{TDS(g/l)} \frac{\text{Anions(>15 epm\%) in decreasing order}}{\text{Catons(>15 epm\%) in decreasing order}} \text{pH} \quad (3)$$

Table 1: Coordinates, site name, and the number of sampling sites

Samples No.	Site name	Latitude	Longitude	Well depth (m)
W1	Sheikh Hatem	33,26804	44,60745	20
W2	Gurff Naddaf	33,25335	44,58805	18
W3	Shahba Company	33,38607	44,83885	20
W4	Diamond quarry	33,39643	44,83622	19
W5	Wadi Diyala Company	33,41165	44,83533	22
W6	Al-Rafael Company	33,42286	44,83759	25
W7	Akili	33,44109	44,83325	15
W8	Agricultural land	33,37290	44,74377	10
W9	Hospital street	33,38028	44,70895	8
W10	Agricultural land	33,30295	44,64161	12
W11	Village 8	33,28841	44,64300	12
W12	Washing station	33,30349	44,66327	15
W13	Water filtration plant	33,28602	44,66108	12
W14	Village 8	33,29531	44,64910	7
W15	Village 5 Bismayah	33,25212	44,60348	16
W16	Najadat village (Gargle)	33,29744	44,58621	15
W17	Al-Abidat	33,30149	44,57974	7

2. Results and Discussion

The primary objective of the research is to determine the physicochemical properties that characterize water sources and the level of pollution [11].

Table 2: Accuracy of groundwater samples in the Al-Nahrawan area for two periods

Sample No.	Dry period (Oct. 2024)		Wet period (May 2025)		Acceptability
	U%	A	U%	A	
W1	4.9	95.1	4.1	95.9	Certain
W2	5.0	95.0	5.0	95.0	Certain
W3	5.0	95.0	4.9	95.1	Certain
W4	5.0	95.0	4.9	95.1	Certain
W5	4.3	95.7	5.0	95.0	Certain
W6	4.9	95.1	4.8	95.2	Certain
W7	4.1	95.9	4.9	95.1	Certain
W8	3.2	96.8	5.0	95.0	Certain
W9	4.0	96.0	0.6	99.4	Certain
W10	5.0	95.0	4.4	95.6	Certain
W11	4.7	95.3	3.4	96.6	Certain
W12	5.0	95.0	2.5	97.5	Certain
W13	3.7	96.3	4.7	95.3	Certain
W14	4.7	95.3	2.5	97.9	Certain
W15	0.9	99.1	3.2	96.8	Certain
W16	5.0	95.0	4.4	95.6	Certain
W17	4.8	95.2	5.0	95.0	Certain

Physical Properties

Table 3: Physical concentrations of groundwater samples in the study area

Sample No.	T (°C)	pH	EC (µs/cm)	TDS (ppm)	TSS (ppm)
W1	25	7.23	3590	2332	60
W2	23.9	7.19	9070	5880	32
W3	24.4	7.18	17720	11420	40
W4	25	7.12	22860	15323	25
W5	26	7.14	21442	14295	25
W6	24.5	7.16	14530	9380	40
W7	25.2	7.13	22704	15145	25
W8	20.3	7.16	20116	13225	25
W9	26	7.22	3350	2168	16
W10	24.6	7.16	9620	6230	32
W11	24.8	7.21	5150	3340	16
W12	25.3	7.17	9500	6150	32
W13	26.9	7.24	4180	2712	16
W14	26	7.23	5010	3248	16
W15	26.2	7.12	3520	2285	30
W16	25	7.17	8410	5451	30
W17	26.9	7.18	8130	5266	60
Average	25.05	7.17	11893	7677	30
[12]		6.5-8.5	1530	1000	50

Temperature (T)

The water temperature is related to air temperature and solar radiation. Temperature impacts an organism's resistance to certain pollutants and the water's capacity to retain oxygen [13]. The temperature of water samples from the Al-Nahrawan area ranges from 20.3 to 26.9°C with a mean of 25.05°C (Table 3).

Hydrogen Ion Concentration (pH)

The pH of groundwater samples in the Nahrawan area ranges between 7.12 and 7.24, with a mean of 7.17 (Table 3). The groundwater samples in the study area have low alkalinity. There are many sources of water acidity, such as dissolved carbonate and bicarbonate ions [14], sulphate ions, organic matter, mineral composition of the aquifer, and acid rain.

Total Dissolved Solids (TDS)

The TDS of groundwater samples ranges from 2168 to 15323 with a mean of 7307 (Table 3). Based on Table 4 [15], most of the groundwater samples are brackish water, except W3, W4, W5, W7, and W8, which are considered salty water (Table 3 and Fig. 2). All TDS values in the study area are greater than [12]. The high TDS concentration in the study area is attributed to human pollution, including dissolved ions released from wastewater into groundwater, as well as the leakage of factory waste and irrigation operations.

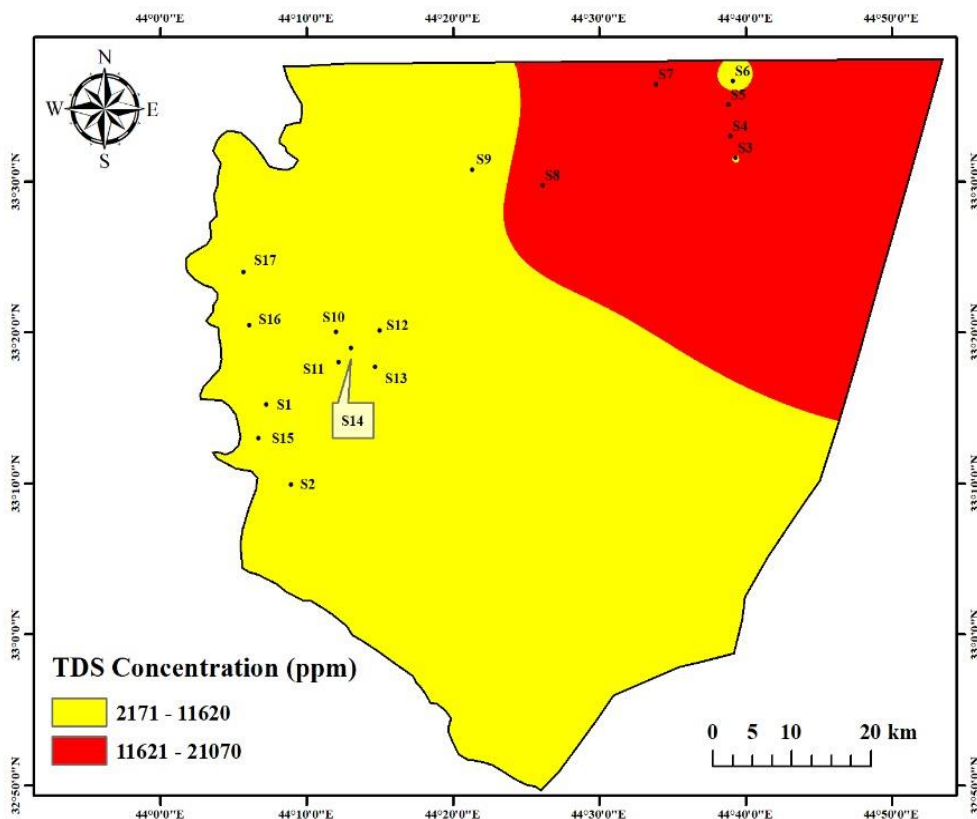


Figure 3: The TDS concentration in groundwater in the study area

Table 4: Classification of groundwater based on TDS [15]

Water Class	Todd, 2007
Fresh water	<1000
Brackish water	1000-10000
Salty water	10000-100000
Brine water	>100000

Electrical Conductivity (EC)

Electrical conductivity of groundwater samples ranges from 3350 to 22860 $\mu\text{S}/\text{cm}$ with a mean of 11155 $\mu\text{S}/\text{cm}$ (Table 3). Table 5 shows that the water of the study area is of a type (Excessively Mineralised water). EC is closely linked to the number of ionised substances in the water, and issues of excessive hardness may also be linked to it [16].

Table 5: The relationship between Electrical conductivity and Mineralization water [11]

EC ($\mu\text{S}/\text{cm}$)	Mineralization
<100	Very Weakly Mineralized water (Granite terrain's)
100-200	Weakly Mineralized water
200-400	Slightly Mineralized water (Limestone terrain's)
400-600	Moderately Mineralized water
600-1000	Highly Mineralized water
>1000	Excessively Mineralized water

Total Suspended Solids (TSS)

TSS in the groundwater in the study area ranges from 16 to 60 ppm with a mean of 30 ppm (Table 3). High TSS concentrations in the study area are attributed to industrial effluents containing suspended solids, including heavy metals and dust, as well as to agricultural activities such as irrigation and rainwater runoff, which transport soil, chemicals, and wastewater.

Chemical Properties

The dissolution process increases ion concentrations in groundwater, whereas ions bonding into a single compound lowers them.

Table 6: Concentrations of major ions of groundwater in the study area

Sample No.	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺		SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻	
	ppm epm epm%	ppm epm epm%	ppm epm epm%	ppm epm epm%	SUM	ppm epm epm%	ppm epm epm%	ppm epm epm%	SUM
W1	202	119	388	12	721	719	428	405	1552
	10.1	9.8	16.9	0.3	37.1	15	12	6.6	33.6
	27.2	26.4	45.5	0.8	100	44.6	35.7	19.6	100
W2	525	319	951	71	1866	1911	1241	731	3883
	26.3	26.4	41.3	1.9	95.9	39.8	35	12	86.8
	27.4	27.5	43.0	1.9	100	45.8	40.3	13.8	100
W3	1055	718	1681	200	3654	3798	2561	1277	7636
	52.8	59.3	73.1	5.3	190.5	79.1	72	21	172.1
	27.7	31.1	38.3	2.7	100	45.9	41.8	12.2	100
W4	1533	735	2510	338	5116	4947	3571	1660	10178
	76.7	60.7	109	8.9	255.3	103.1	101	27	231.1
	30.0	23.7	42.6	3.4	100	44.6	43.7	11.6	100
W5	1380	710	2290	320	4700	4723	3351	1440	9514
	69	58.7	99.6	8.4	235.7	98.4	94	24	216.4
	29.2	24.9	42.2	3.5	100	45.4	43.4	11.0	100
W6	840	530	1495	102	2967	2703	2147	1360	6210
	42	43.8	65	2.7	153.5	56.3	60	22	138.3
	27.3	28.5	42.3	1.7	100	40.7	43.3	15.9	100
W7	1510	675	2500	335	5020	4936	3561	1580	10077
	75.5	55.8	109	8.8	249.1	102.8	100	26	228.8
	30.0	22.4	43.7	3.5	100	44.9	43.7	11.3	100
W8	1251	633	2034	220	4138	5450	2271	1145	8866
	62.6	25.3	88.4	5.8	209.1	113	64	18.8	195.8
	29.9	25	42.2	2.7	100	57.7	32.6	9.6	100
W9	196	104	364	12	676	688	404	374	1466
	9.8	8.6	15.8	0.3	34.5	14.3	11	6.1	31.4
	28.4	24.9	45.7	0.8	100	45.5	35.0	19.4	100
W10	595	290	1001	62	1948	1908	1297	802	4007
	29.8	24	43.5	1.6	98.9	39.8	37	13	89.8
	30.1	24.2	43.9	1.6	100	44.3	41.2	14.4	100
W11	300	185	530	6	1021	1122	680	377	2179
	15	15.3	23	0.2	53.5	23.4	19	6.2	48.6
	28.0	28.5	42.9	0.3	100	48.1	39.0	12.7	100
W12	575	300	991	50	1916	1898	1287	787	3972
	28.8	24.8	43.1	1.3	98	39.5	36	13	88.5
	29.3	25.3	43.9	1.3	100	44.6	40.6	14.6	100
W13	224	159.0	446	37	866	1050	614	143	1807
	11.2	13.1	19.4	1	44.7	21.9	17	2.3	41.2
	25.0	29.3	43.4	2.2	100	53.1	41.2	5.5	100
W14	313	170	520	6	1009	1100	675	357	2132
	15.7	14	22.6	0.2	52.5	22.9	19	5.9	47.8
	29.9	26.6	43.0	0.3	100	47.9	39.7	12.3	100
W15	228	126	291	13	658	752	532	217	1501
	11.4	10.4	12.7	0.3	34.8	15.7	15	3.6	34.3
	32.7	29.8	36.4	0.8	100	45.7	43.7	10.4	100
W16	520	290	868	68	1746	1780	1168	671	3619
	26	24	37.7	1.8	89.5	37.1	33	11	81.1
	29.0	26.8	42.1	2.0	100	45.8	40.6	13.5	100
W17	500	296	840	50	1686	1752	1140	649	3541
	25	24.5	36.5	1.3	87.3	36.5	32	11	79.5
	28.6	28.0	41.8	1.4	100	45.9	40.2	13.8	100
[12]	100	125	200	12		250	250	200	

Calcium (Ca^{2+})

Concentration of Ca^{2+} ion in the study area ranges between 196 and 1533 ppm with a mean 691 ppm (Table 6; Fig. 5). The reason of the increase concentration of Ca^{2+} in the water of the study area, is due to the effect of evaporation processes because the water in the study area is close to a surface (low-depth), the effect of ion exchanges between Na^+ and Ca^{2+} , agricultural activities like use (calcium nitrate $\text{Ca}(\text{NO}_3)_2$ and agricultural lime CaCO_3), as well as the effect of brick factories residues that leak into groundwater (the main source of Ca in brick factories is limestone (calcium carbonate) which is converted to lime (CaO or $\text{Ca}(\text{OH})_2$)).

Magnesium (Mg^{2+})

The Mg^{2+} concentration of groundwater ranges between 104 and 735 ppm with a mean of 374 ppm (Table 6; Fig. 6). The high concentration of Mg^{2+} in the waters of the study area is due to the impact of ion exchange between Mg^{2+} and Na^+ , evaporation processes, agricultural pollution, wastewater, or industrial water, as well as geological units in Al-Nahrawan area.

Sodium (Na^+)

The Na^+ concentration of groundwater samples ranges between 291 and 2510 ppm with a mean 1158 ppm (Table 6; Fig. 7). This increase in the concentration of Na^+ ion is due to the evaporation, water of exhaust factories, agricultural activities due to the use of fertilizer and pesticides containing Na^+ compounds as well as the dissolution of Na^+ salts concentrated in the soil, clay mineral.

Potassium (K^+)

The K^+ concentration in groundwater samples ranges from 6 to 338 ppm, with a mean of 111 ppm (Table 6, Fig. 8). The high K^+ concentration is due to industrial pollution and the use of chemical fertiliser.

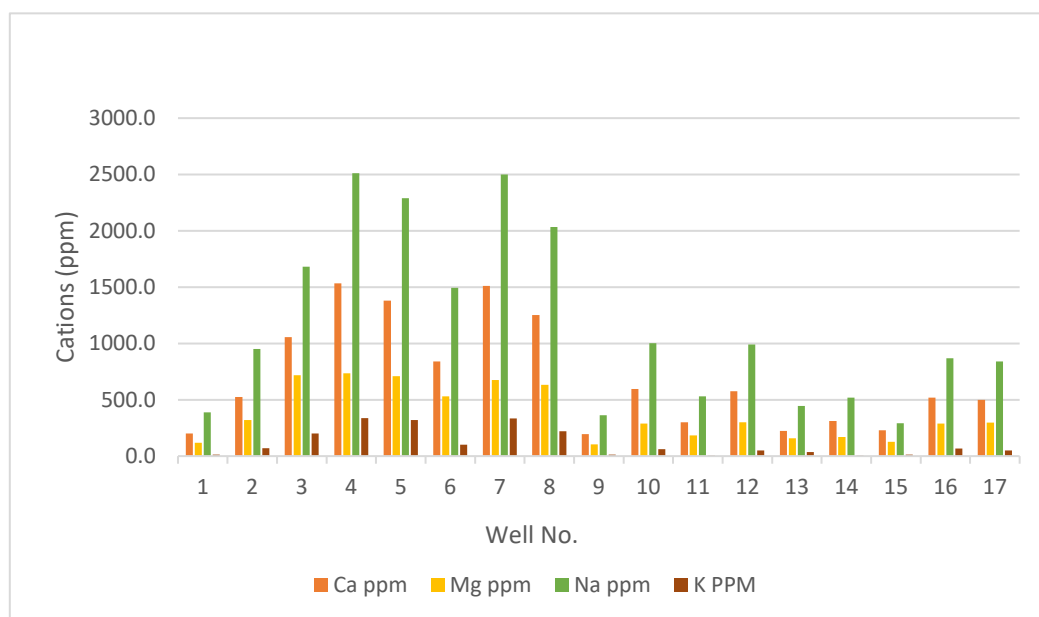


Figure 4: Concentrations of cations in groundwater of the study area

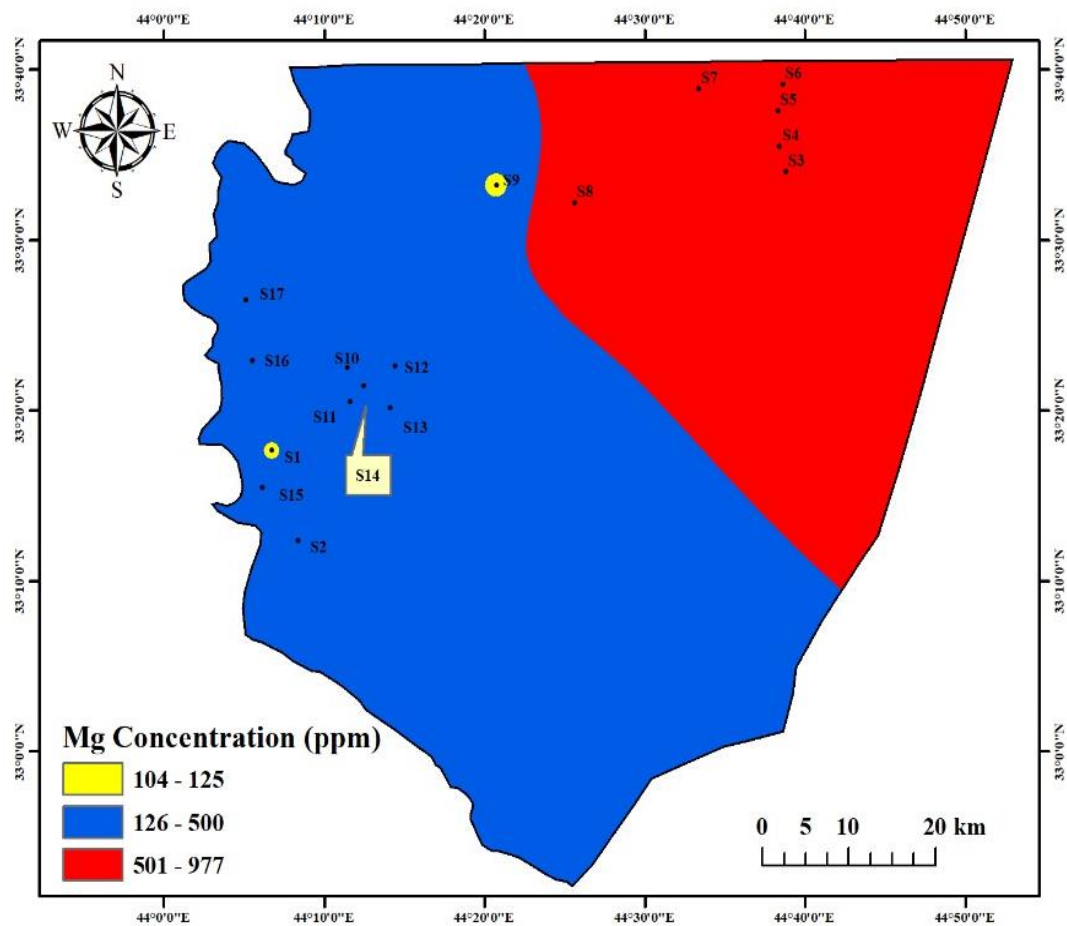


Figure 5: Concentration of Ca ion in groundwater in the study area

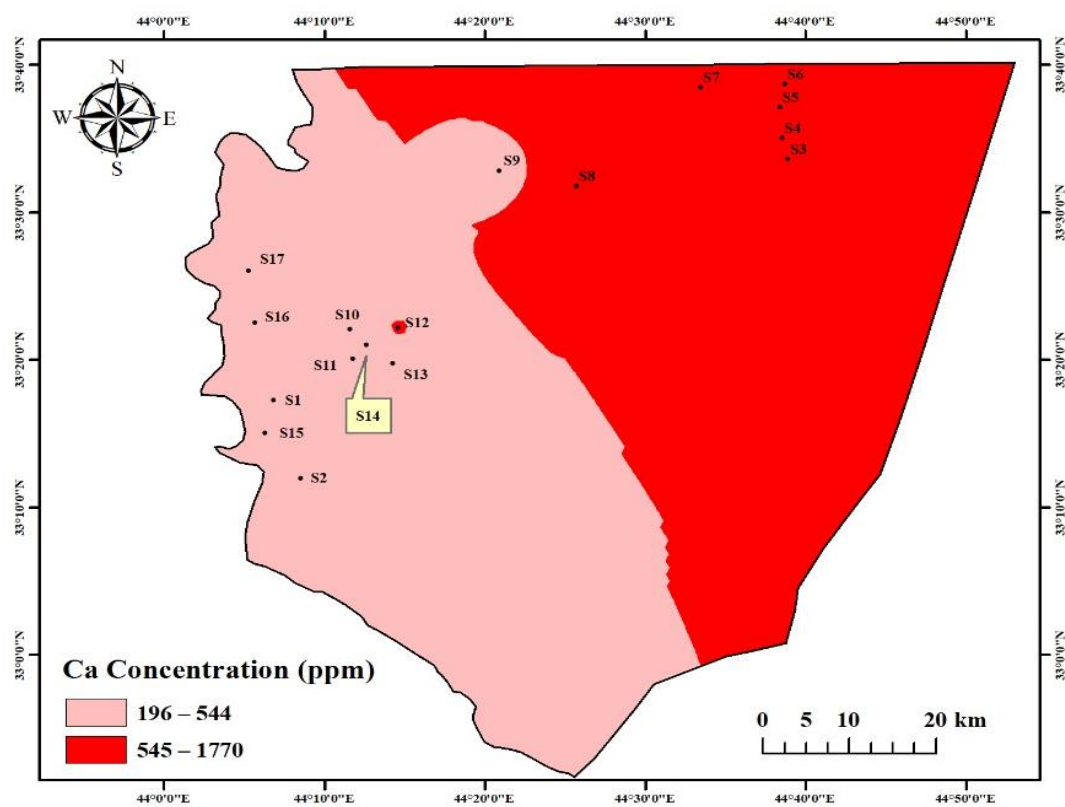


Figure 6: Concentration of Mg ion in groundwater in the study area

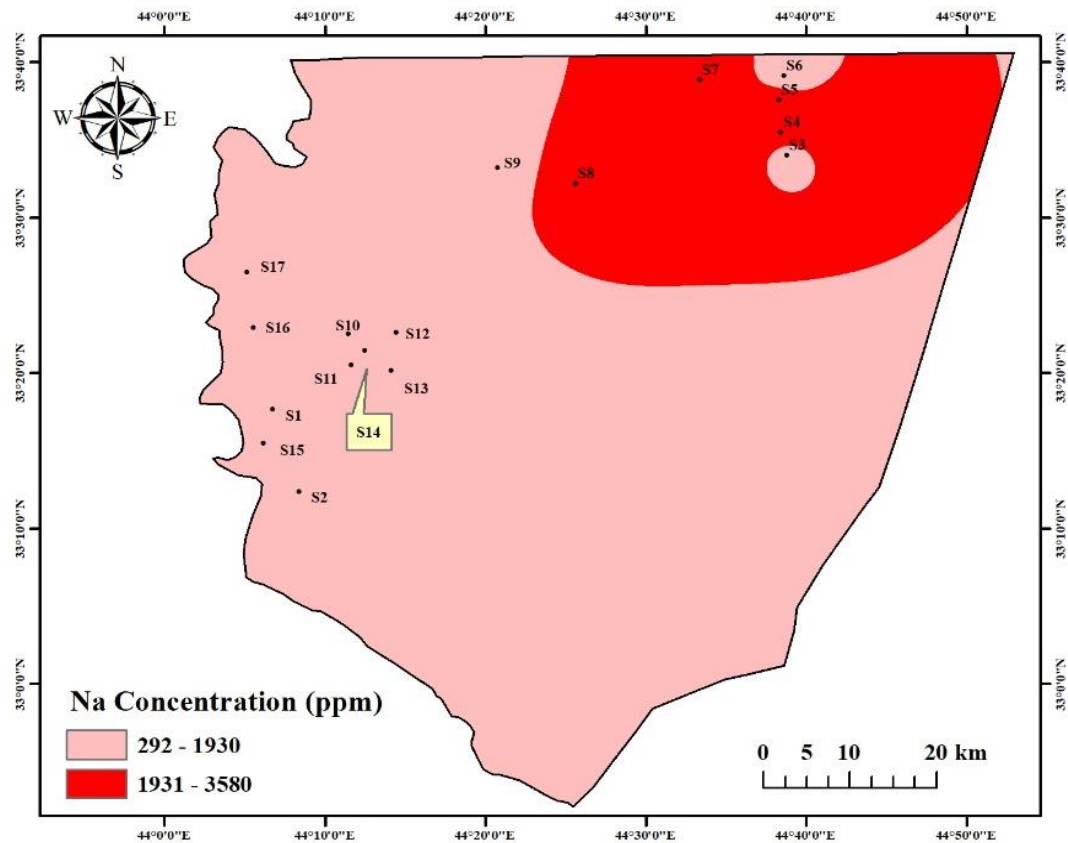


Figure 7: Concentration of Na ion in groundwater in the study area

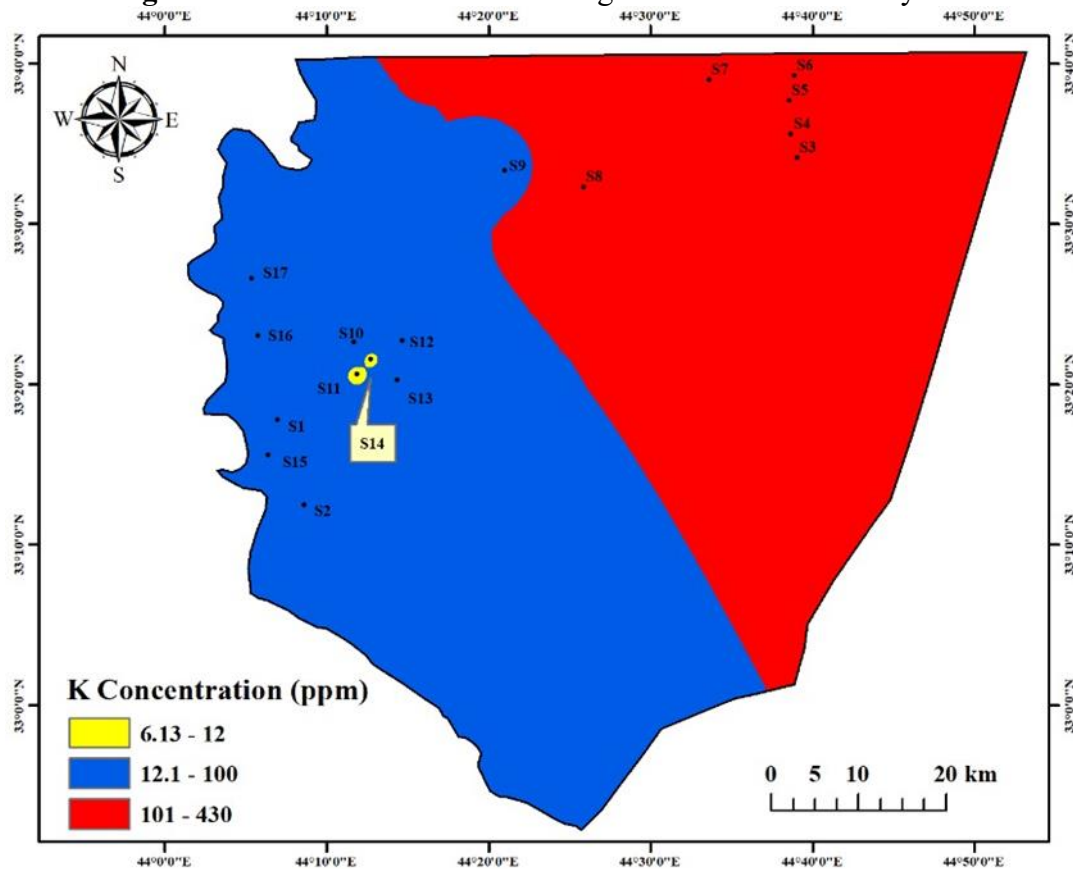


Figure 8: Concentration of K ion in groundwater in the study area

Sulfate (SO_4^{2-})

The SO_4^{2-} concentration in the study area ranges between 688 and 5450 ppm with a mean 2425 ppm (Table 6; Fig. 10). The high concentration of SO_4^{2-} in the study area is attributed to the sulfur salts, the impact of chemical fertilizers, brick factory residues, and the effect of evaporation processes, as well as Sewage discharge from homes and industrial tends to raise its concentration. [17].

Bicarbonate (HCO_3^-)

The HCO_3^- concentrations in the study area ranges between 143 and 1660 ppm with a mean 822 ppm (Table 6; Fig. 11). The high concentration of HCO_3^- in the study area is due to the leakage of sewage or industrial wastewater rich in organic compounds, due to the decomposition of these substances in the water, the use of organic fertilizer or chemical fertilizers as well as the dissolution of the sodium bicarbonate presents in the soil.

Chloride (Cl^-)

The Cl^- concentrations in the study area range from 404 to 3571 ppm with a mean of 1584 ppm (Table 6; Figure 12). High levels of chloride result from evaporation processes, and soil washing processes such as irrigation, wastewater, and industrial water infiltration.

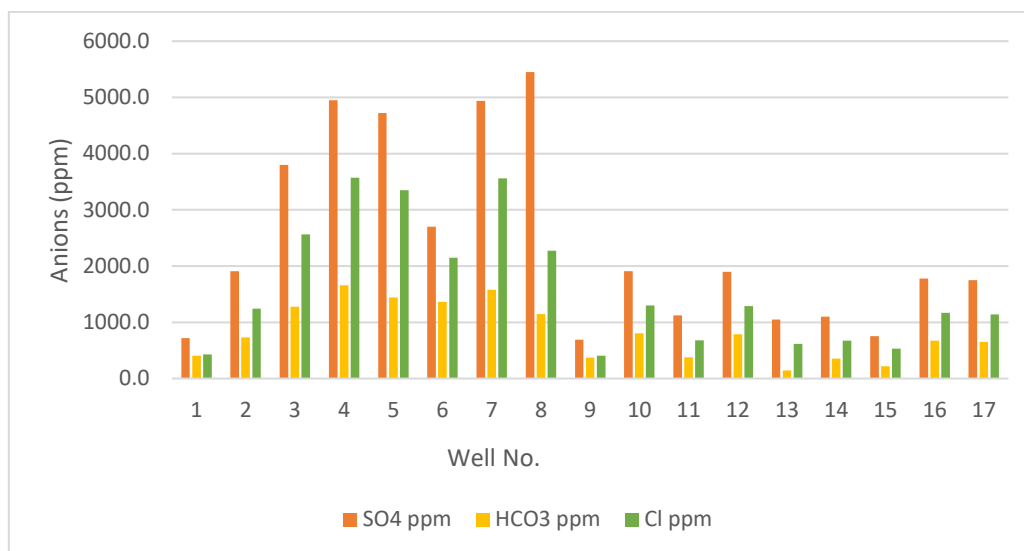


Figure 9 Concentrations of anions in groundwater of the study area

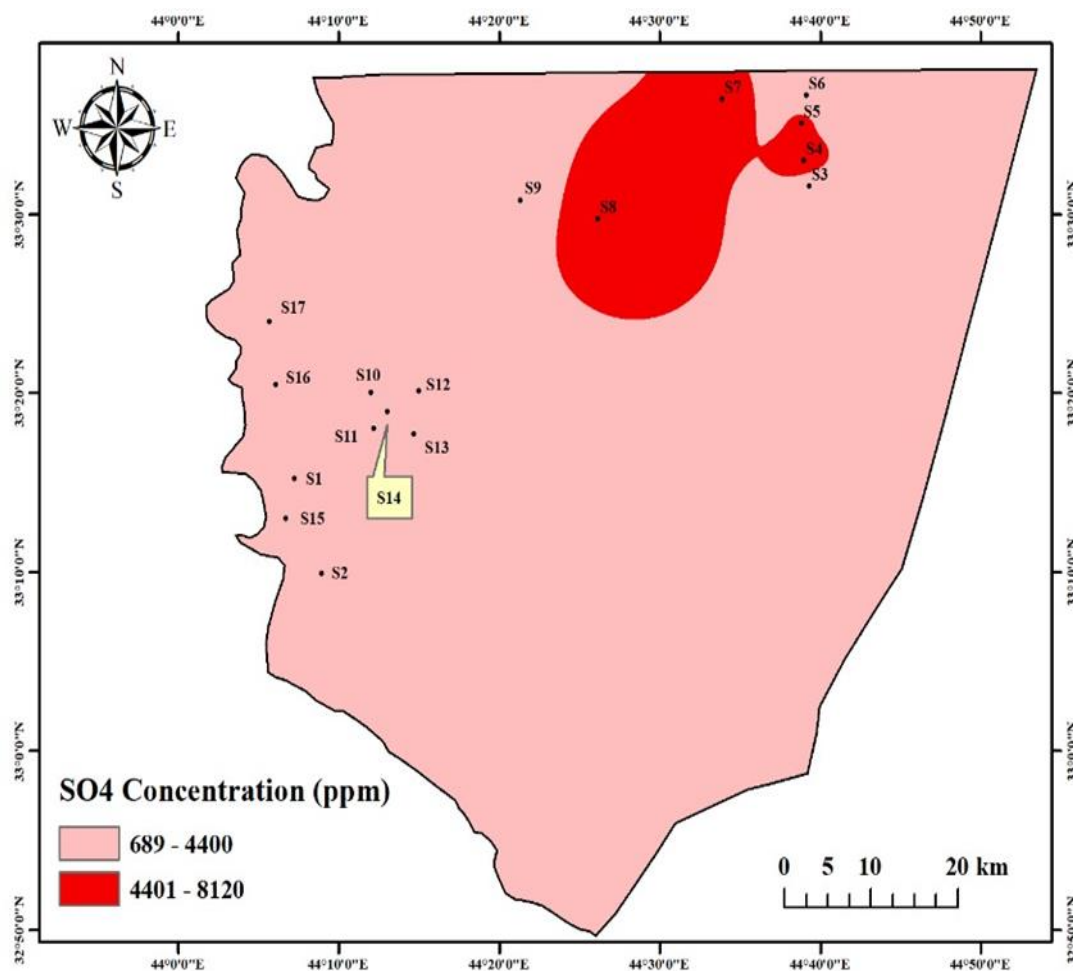


Figure 10: Concentration of SO₄ ion in groundwater in the study area

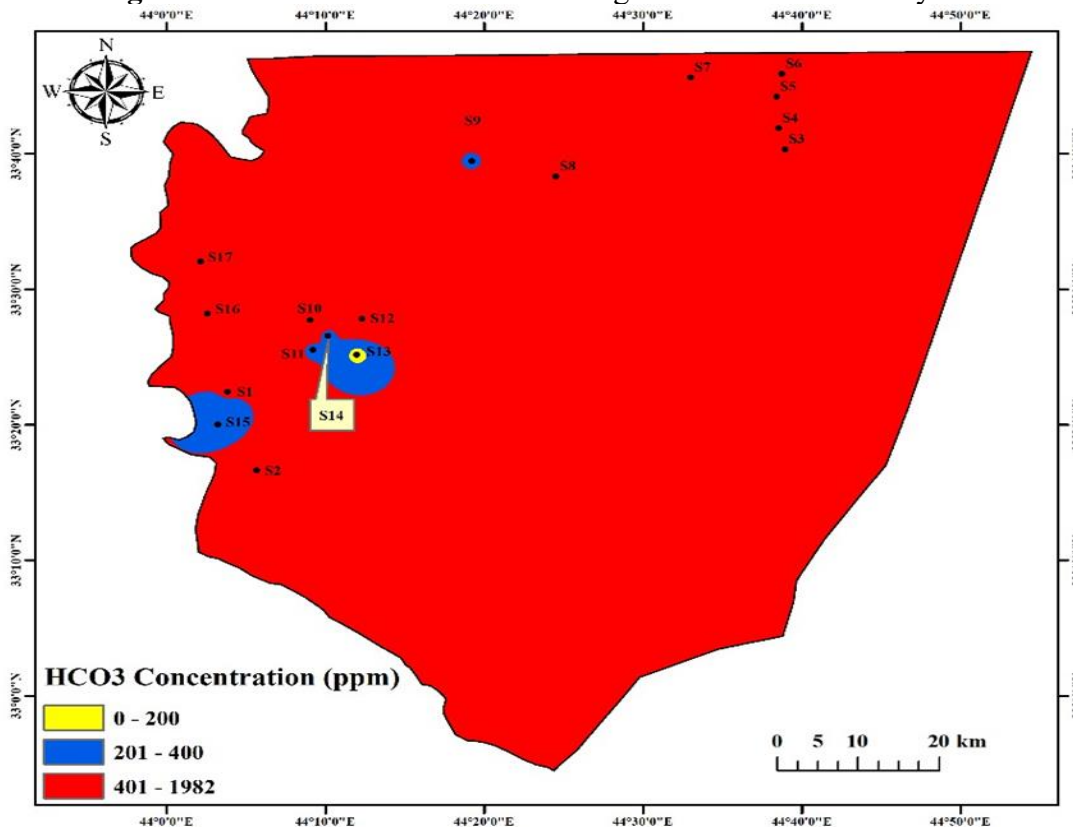


Figure 11: Concentration of HNO₃ ion in groundwater in the study area

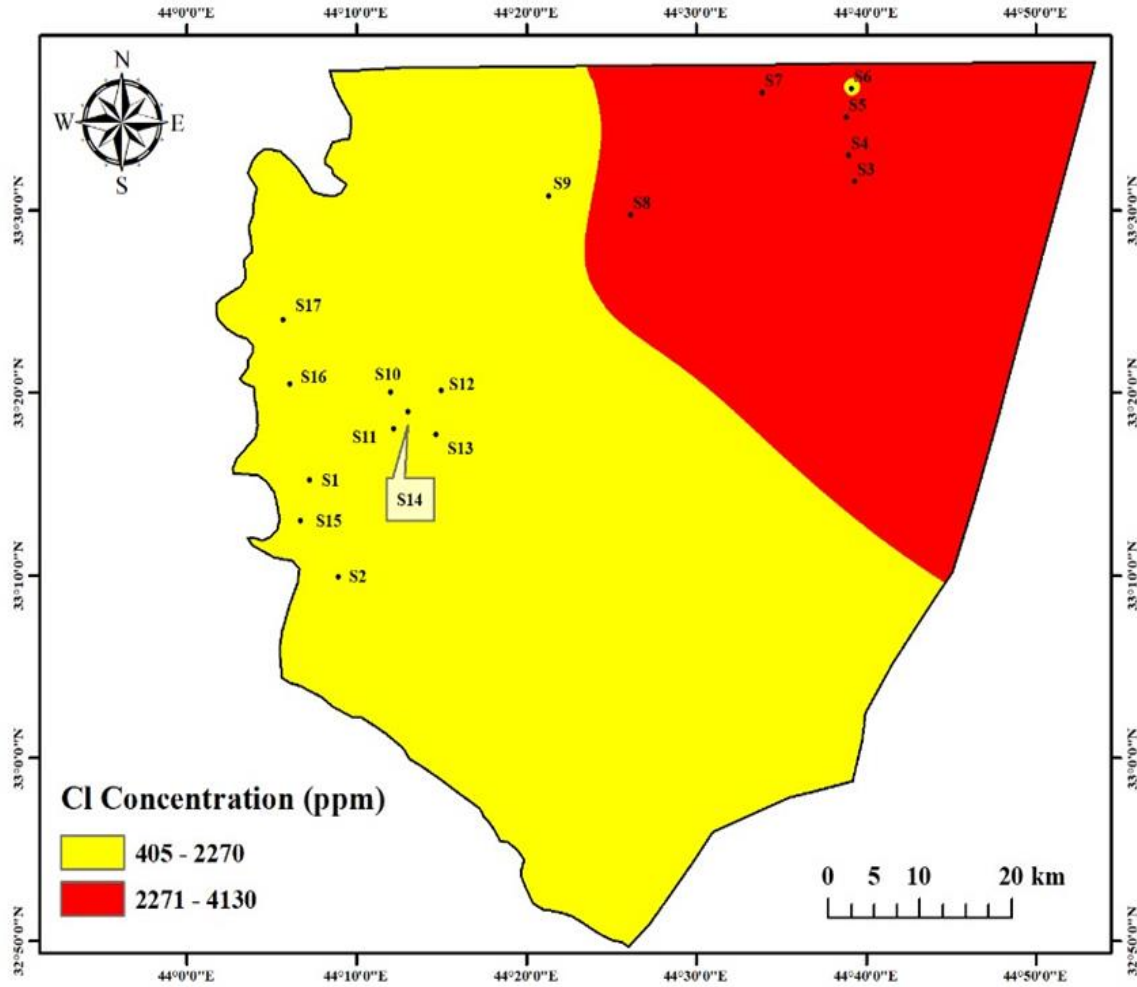


Figure 12: Concentration of Cl ion in groundwater in the study area

Trace elements

In geochemistry, any concentration below 1000 ppm is considered a trace element [18]. Human activity and weathering rocks are their primary sources [19]. Affinity, radius, and similarity of charges with other elements allow it to either adsorb into or replace these elements in the mineral composition [20]. Groundwater is analysed for Ni, Pb, Cd, Fe, Cu, Cr, and Zn. The concentrations of Cu, Zn, and Ni were lower than those in the sensing device in the studied area. Note that the percentage of sensitivity of the device to each element is Cu=0.013, Zn=0.012, Ni=0.013, and Cd=0.018, while Fe, Cr, Pb, and Cd were detected in the study area.

Table 7: Values of dissolved oxygen, chemical oxygen demand, and biological oxygen demand in the study area

Biological characteristics

Sample No.	DO	COD	BOD ₅
W1	0	156	41.6
W2	3.5	993	62
W3	5.2	1301	60
W4	4	1379	55
W5	1.8	1466	70
W6	3.6	1064	61
W7	4.5	1250	45
W8	5.2	1345	30
W9	0.6	419	30
W10	5.2	949	31
W11	1.5	1091	73
W12	0.8	811	79
W13	4.2	37	43
W14	1.9	219	69
W15	9.5	3.3	1.3
W16	2.8	307	60
W17	0.5	513	79
Average	3.2	782	52.3
[21]	7-10	<5	<5

Dissolved oxygen (DO)

The DO concentration in the study area ranges from 0 to 9.5 ppm with a mean of 3.2 ppm (Table 7).

Chemical Oxygen Demand (COD)

It is the amount of oxygen required for organic compounds to undergo a strong chemical oxidation in water [22]. The concentration of COD in groundwater in the study area ranges from 3.3 to 1466 ppm, with a mean of 782.5 ppm (Table 7). The high COD values in the study area are due to wastewater, fertiliser, insecticides, industrial waste (which contains organic materials and chemicals), and the decomposition of dead plants and algae (which consumes oxygen and thus raises the COD content).

Biochemical Oxygen Demand (BOD₅)

The BOD₅ concentration in groundwater in the study area ranges from 1.3 to 79 ppm, with a mean of 52.3 ppm (Table 7). When comparing the water samples from the study area with the classification of water based on BOD₅ value [23] (Table 8), all the samples are polluted except W15, which is clean.

Table 8: Classification of water based on BOD₅ value

BOD ₅	Water class
<1	Very Clean
1-2	Clean
2-5	May Be Clean
5-10	Critical
>10	polluted

Hydrochemical formula and water type

Used the hydrochemical formula to determine the type of water [10].

$$\text{TDS(g/l)} \frac{\text{Anions(>15 epm\%)} \text{in decreasing order}}{\text{Catons(>15 epm\%)} \text{in decreasing order}} \text{pH} \quad (4)$$

Table 9: The hydrochemical formula and water type of samples in the study area

No.	Hydrochemical formula	Water type
W1	$\text{TDS (2.33)} \frac{\text{SO}_4^{2-} (44.6) \text{Cl}^- (35.7) \text{HCO}_3^- (19.6)}{\text{Na}^+ (45.5) \text{Ca}^{+2} (27.2) \text{Mg}^{+2} (26.4)} (7.23)$	Na-Ca-Mg-Cl-HCO ₃ -Sulfate
W2	$\text{TDS (5.88)} \frac{\text{SO}_4^{2-} (45.8) \text{Cl}^- (40.3)}{\text{Na}^+ (43.0) \text{Mg}^{+2} (27.5) \text{Ca}^{+2} (27.4)} (7.19)$	Na-Mg-Ca -Cl- Sulfate
W3	$\text{TDS (1.142)} \frac{\text{SO}_4^{2-} (45.9) \text{Cl}^- (41.8)}{\text{Na}^+ (38.3) \text{Mg}^{+2} (31.1) \text{Ca}^{+2} (27.7)} (7.18)$	Na-Mg-Ca -Cl- Sulfate
W4	$\text{TDS (1.532)} \frac{\text{SO}_4^{2-} (44.6) \text{Cl}^- (43.7)}{\text{Na}^+ (42.6) \text{Ca}^{+2} (30.0) \text{Mg}^{+2} (23.7)} (7.12)$	Na-Ca-Mg-Cl-Sulfate
W5	$\text{TDS (1.429)} \frac{\text{SO}_4^{2-} (45.4) \text{Cl}^- (43.4)}{\text{Na}^+ (42.2) \text{Ca}^{+2} (29.2) \text{Mg}^{+2} (24.9)} (7.14)$	Na-Ca-Mg-Cl-Sulfate
W6	$\text{TDS (9.38)} \frac{\text{Cl}^- (43.3) \text{SO}_4^{2-} (40.7) \text{HCO}_3^- (15.9)}{\text{Na}^+ (42.3) \text{Mg}^{+2} (28.5) \text{Ca}^{+2} (27.3)} (7.16)$	Na-Mg-Ca-SO ₄ -HCO ₃ -Chloride
W7	$\text{TDS (1.514)} \frac{\text{SO}_4^{2-} (44.9) \text{Cl}^- (43.7)}{\text{Na}^+ (43.7) \text{Ca}^{+2} (30.3) \text{Mg}^{+2} (22.4)} (7.13)$	Na-Ca-Mg-Cl-Sulfate
W8	$\text{TDS (1.322)} \frac{\text{SO}_4^{2-} (57.7) \text{Cl}^- (32.6)}{\text{Na}^+ (42.2) \text{Ca}^{+2} (29.9) \text{Mg}^{+2} (25)} (7.16)$	Na-Ca-Mg-Cl-Sulfate
W9	$\text{TDS (2.17)} \frac{\text{SO}_4^{2-} (45.5) \text{Cl}^- (35.0) \text{HCO}_3^- (19.4)}{\text{Na}^+ (45.7) \text{Ca}^{+2} (28.4) \text{Mg}^{+2} (24.9)} (7.22)$	Na-Ca-Mg-Cl-HCO ₃ -Sulfate
W10	$\text{TDS (6.23)} \frac{\text{SO}_4^{2-} (44.3) \text{Cl}^- (41.2)}{\text{Na}^+ (43.9) \text{Ca}^{+2} (30.1) \text{Mg}^{+2} (24.2)} (7.16)$	Na-Ca-Mg-Cl-Sulfate
W11	$\text{TDS (3.34)} \frac{\text{SO}_4^{2-} (48.1) \text{Cl}^- (39.0)}{\text{Na}^+ (42.9) \text{Mg}^{+2} (28.5) \text{Ca}^{+2} (28.0)} (7.21)$	Na-Mg-Ca -Cl- Sulfate
W12	$\text{TDS (6.15)} \frac{\text{SO}_4^{2-} (44.6) \text{Cl}^- (40.6)}{\text{Na}^+ (43.9) \text{Ca}^{+2} (29.3) \text{Mg}^{+2} (25.3)} (7.17)$	Na-Ca-Mg-Cl-Sulfate
W13	$\text{TDS (2.71)} \frac{\text{SO}_4^{2-} (53.1) \text{Cl}^- (41.2)}{\text{Na}^+ (43.4) \text{Mg}^{+2} (29.3) \text{Ca}^{+2} (25.0)} (7.24)$	Na-Mg-Ca -Cl- Sulfate
W14	$\text{TDS (3.25)} \frac{\text{SO}_4^{2-} (47.9) \text{Cl}^- (39.7)}{\text{Na}^+ (43.0) \text{Ca}^{+2} (29.9) \text{Mg}^{+2} (26.6)} (7.23)$	Na-Ca-Mg-Cl-Sulfate
W15	$\text{TDS (2.29)} \frac{\text{SO}_4^{2-} (45.7) \text{Cl}^- (43.7)}{\text{Na}^+ (36.4) \text{Ca}^{+2} (32.7) \text{Mg}^{+2} (29.8)} (7.12)$	Na-Ca-Mg-Cl-Sulfate
W16	$\text{TDS (5.45)} \frac{\text{SO}_4^{2-} (45.7) \text{Cl}^- (40.6)}{\text{Na}^+ (42.1) \text{Ca}^{+2} (29.0) \text{Mg}^{+2} (26.8)} (7.17)$	Na-Ca-Mg-Cl-Sulfate
W17	$\text{TDS (5.27)} \frac{\text{SO}_4^{2-} (45.9) \text{Cl}^- (40.2)}{\text{Na}^+ (41.8) \text{Ca}^{+2} (28.6) \text{Mg}^{+2} (28.0)} (7.18)$	Na-Ca-Mg-Cl-Sulfate

Classification of groundwater

Many classifications were employed to identify the type of water, such as the Piper diagram [24], the Stiff diagram, and the Shcoeller diagram [25]. Based on the Stiff and Schoeller diagrams, it can be inferred that groundwater contains low CO₃ and HCO₃ and high SO₄ and

Cl. Na^+ is the dominant cation in the study area, and SO_4 is the dominant anion. The increase in ion concentrations in the study area is due to industrial and agricultural activities, which are considered sources of groundwater deterioration. The groundwater is obviously of the type Na-Sulfate and Na-Chloride in W6 as it shown in the Stiff diagram (Fig. 13) and Schoeller diagram (Fig. 14). Piper diagram enhances both the Schoeller and Stiff diagrams, and when the Piper diagram was applied show all of the water samples in the study area fell into (class e), which is indicative of earth alkaline water with a higher proportion of alkali and a preponderance of SO_4 and Cl^- (Fig. 15).

The diversity of current water types indicates the interplay among factors such as lithology, recharge, aquifer geochemistry, and well depth (the lower the well depth, the higher the salinity due to increased evaporation) [26].

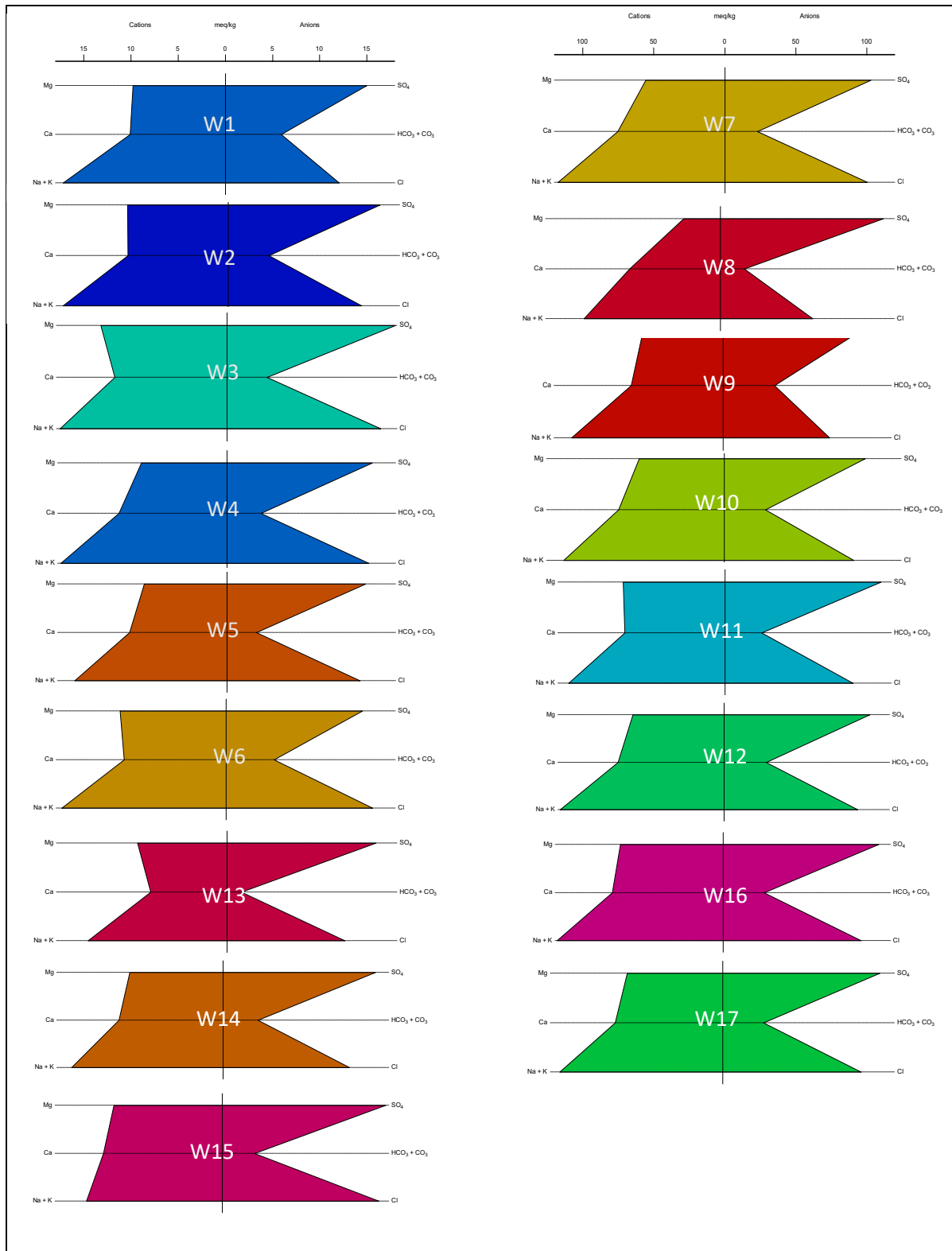


Figure 13: Stiff diagram of groundwater

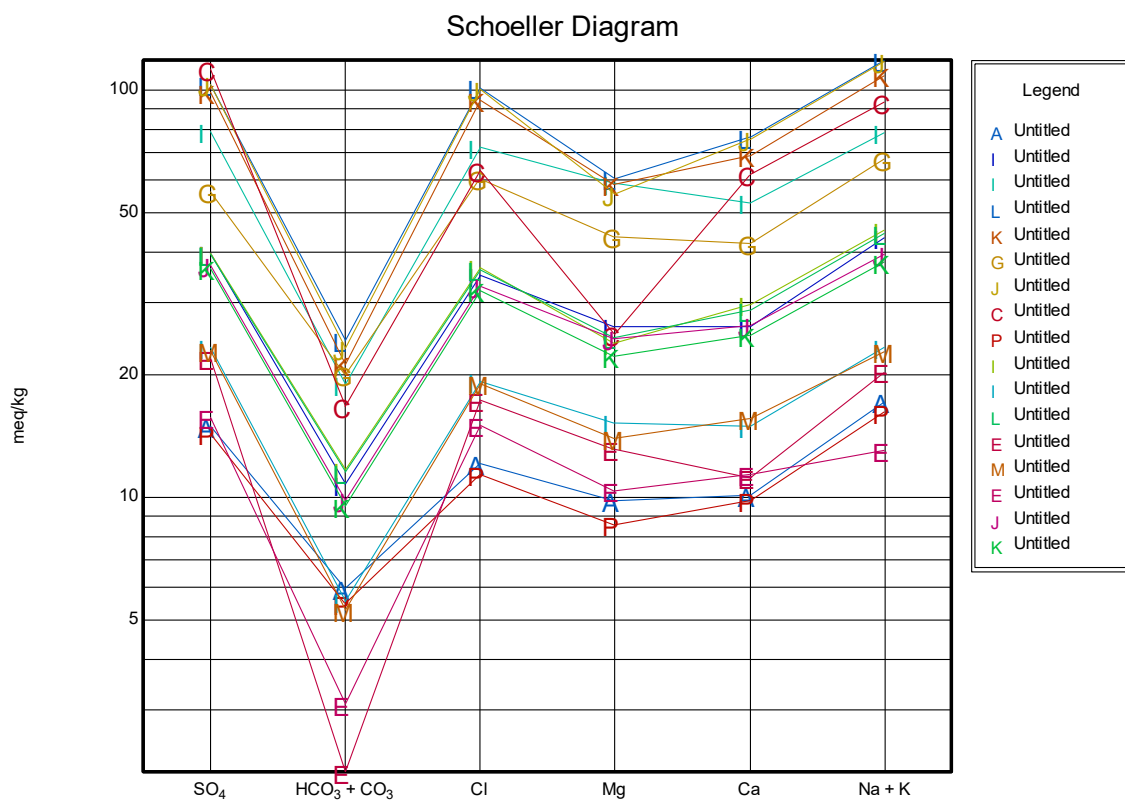


Figure 14: Schoeller diagram of groundwater

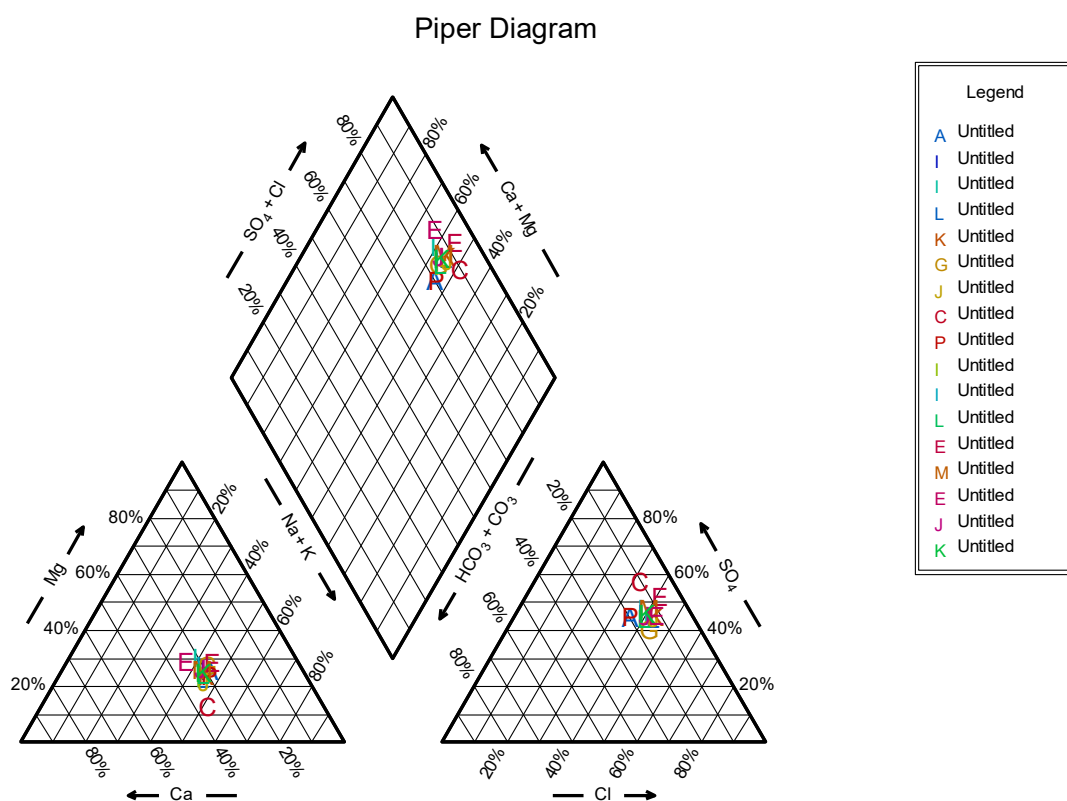


Figure 15: Piper diagram of groundwater

Groundwater assessment for irrigation

In irrigation, five parameters are commonly used for evaluating water quality. EC, pH, Na%, SAR, and TDS were examined. pH can affect the solubility of nutrients and metal compounds, thereby altering the amount of nutrients available for plant growth. Each parameter's standard categories are listed in Tables 10 and 11, which present the findings.

Table 10: The Don classification system's standard categories for evaluating water for irrigation use (1995) [27]

EC ($\mu\text{S}/\text{cm}$)	TDS (ppm)	SAR	Na%	pH	Water Quality
< 250	< 175	<3	< 20	<6.5	Excellent
250–750	175-525	3-5	20-40	6.5-6.8	Good
750–2000	525-1400	5-10	40-60	6.8-7.0	Permissible
2000–3000	1400-2100	10-15	60-80	7- 8	Doubtful
>3000	>2100	>15	<80	>8	Unsuitable

Sodium Adsorption Ratio (SAR)

Sodium adsorption ratio SAR is a measure of the amount of Na^+ that is adsorbed by soil. The ratio of Na^+ to Ca^{2+} and Mg^{2+} affected the crop's water availability [28]. The following formula is used to compute it [15], with all ions expressed in meq/l:

$$\text{SAR} = \frac{r\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}} \quad (5)$$

Where: r: Is the concentration of the ions in epm units.

SAR values in wells studied indicated that the majority of samples are permissible, and W4, W5, W7, and W8 are indicated as doubtful. According to the aforesaid classification (Table 10), W15 is marked as good.

Table 11: SAR, Na%, TDS, and EC concentrations of the groundwater of the study area

Sample No.	SAR	Na%	TDS	EC	pH
W1	5.35	46.3	2332	3590	7.23
W2	8.04	45.0	5880	9070	7.19
W3	9.76	41.1	11420	17720	7.18
W4	13.1	46.1	15323	22860	7.12
W5	12.4	45.8	14295	21442	7.14
W6	9.92	44.1	9380	14530	7.16
W7	13.4	47.2	15145	22704	7.13
W8	11.6	45.0	13225	20116	7.16
W9	5.20	46.6	2168	3350	7.22
W10	8.38	45.6	6230	9620	7.16
W11	5.90	43.3	3340	5150	7.21
W12	8.32	45.3	6150	9500	7.17
W13	5.56	45.6	2712	4180	7.24
W14	5.86	43.4	3248	5010	7.23
W15	3.84	37.3	2285	3520	7.12
W16	7.54	44.1	5451	8410	7.17
W17	7.33	43.2	5266	8130	7.18

TDS and EC

Since TDS and EC are metrics of concentration present, they are frequently used to assess water quality. Major cation salts, including Ca^{2+} , Mg^{2+} , Na^{2+} , and K^{+} , dissolved in irrigation water are detrimental to plants; excess amounts decrease the osmotic activity, which may also hinder proper aeration. The physical properties of dissolved solids are estimated using an electrical conductivity (EC). As the number of ions rises, it rises as well, and vice versa. The TDS and EC values indicate that the water is unsuitable for irrigation (Table 11).

Percentage of sodium (Na%)

Water quality for irrigation purposes was evaluated using the Na% soluble sodium percentage (SSP). Both plant development and soil quality are directly impacted by the high Na content of irrigation water [29]. Increasing Na^{+} levels reduces soil porosity and permeability. Aeration, infiltration, and soil structure may all deteriorate as a result of containing the irrigation water with more than 60% Na [30]. The following equation can be used to calculate Na% [27]:

$$\text{Na}\% = \frac{[\text{Na} + \text{Ca}] \times 100}{[\text{Ca} + \text{Mg} + \text{Na} + \text{K}]} \quad (6)$$

All concentrations of ions are in meq/l. The Na% concentration of groundwater samples indicates that all samples are permissible for irrigation except W15, which is good (Table 11).

3. Conclusion

This study provided a thorough account of the physical, chemical, and biological characteristics of groundwater in Al-Nahrawan, located east of Baghdad, Iraq. TDS concentrations indicate that the groundwater samples in the study area are brackish, except for W3, W4, W5, W7, and W8, which are considered salty water. The main sources of high TDS values in the study area are brick factories (due to the release of salts from clay, incineration waste, and industrial wastewater) and irrigation operations (due to fertiliser, excessive irrigation, agricultural wastewater, and soil salinisation). The high salinity variation is attributed to different lithology types [27]. The sediments deposited in the study area are Quaternary (recent deposits). EC values of groundwater samples in the study area indicate that the water is excessively mineralised. The mean of TDS=7307 ppm and EC=11155 ppm. So, all TDS and EC values in the study area are higher than those in the global studies. The pH values of groundwater in the study area are within the acceptable limit of global studies. The high concentrations of some TSS in the study area are due to industrial wastewater and agricultural activities. All BOD₅ concentration samples in the study area indicate pollution except for W15, which is clean.

DO values were within the acceptable range reported in national studies, while the high concentration of COD in the study area was due to wastewater, fertilisers, insecticides, and industrial waste. In the groundwater samples, Na^{+} is the dominant cation, and SO_4 is the dominant anion. The groundwater is of the Na-Sulfate type, whereas that in W6 belongs to the Na-Chloride type. The high concentrations of Na^{+} , Cl^{-} , and SO_4 are due to the anthropogenic sources, such as domestic sewage effluents, brick factories, and agricultural activities. The groundwater quality was assessed for irrigation purposes, showing that SAR values are generally permissible, though some samples, W4, W5, W7, and W8, were classified as doubtful, while W15 was indicated as good. Na% indicates permissible irrigation water. W15 is a good option; pH values are permissible, but it is unsuitable due to high TDS and EC, which indicate high salinity, as indicated by Na, SO_4 , and Cl.

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