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Hydrogeochemical Investigations and Water Uses for Qaladze-Sangaser Area, Sulaymaniyah Governorate, Kurdistan Region of Iraq

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ABSTRACT

The main supply of drinking water in the Qaladze-Sangaser in the Iraqi Kurdistan region is groundwater. More water is needed as an increase in the number of populations for home, industrial, environmental, recreational, and agricultural uses. The importance of a hydrochemistry study is highlighted by the fact that the chemistry of groundwater can be strongly related to the climate, geology, and water source of the area. Two periods are selected to collect 72 groundwater samples as a total at maximum and minimum recharge periods for analyzing the physicochemical parameters including pH, EC, total dissolved solids (TDS), major cations and anions to evaluate the groundwater quality and potential ions source in the groundwater. The groundwater is of type calcium-magnesium bicarbonate. With the exception of one groundwater sample, all water samples are fit for human consumption, and suitable for industry, livestock, poultry, and agriculture purposes. The samples exhibit low RSC (< 1.5 meq/l) and low sodium hazard (SAR < 9) which is of good quality and suitable for using in irrigation purposes. The permeability index of all groundwater samples is rated as excellent to good, indicating good water quality for irrigation. According to RSC results, there is no risk from sodium since it is less than 1.5 meq/l, which is within the permissible limit.

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الدراسات الهيدروجيوكيميائية واستخدامات المياه لمنطقة قلادزة –سنجازر، محافظة السليمانية، إقليم كردستان العراق

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المصدر الرئيس لمياه الشرب في قلادزي – سنجازر في إقليم كردستان العراق يأتي من المياه الجوفية. هناك حاجة إلى المزيد من المياه مع زيادة السكان للاستخدامات المنزلية والصناعية والبيئية والترفيهية والزراعية. وتبرز أهمية الدراسة الهيدروكيميائية من خلال حقيقة أن كيمياء المياه الجوفية يمكن أن ترتبط بقوة بالمناخ والجيولوجيا ومصدر المياه في المنطقة. تم اختيار فترتين لجمع ما مجموعه 72 عينة من المياه الجوفية في (فترتي التغذية القصوى والدنيا) لتحليل المعلمات الفيزيائية والكيميائية بما في ذلك الرقم الهيدروجيني، EC، المواد الصلبة الذائبة الكلية (TDS)، الكاتيونات الرئيسة والأنيونات لتقييم نوعية المياه الجوفية ومصدر الأيونات المحتملة في المياه الجوفية. ان نوع الماء لعينات المياه الجوفية هو بيكربونات الكالسيوم والمغنيسيوم. وباستثناء عينة واحدة من المياه الجوفية، فإن جميع عينات المياه صالحة للاستهلاك البشري، وصالحة لأغراض الصناعة وتربية الماشية والدواجن والزراعة. أظهرت العينات انخفاض RSC (< 1.5 ملي مكافئ / لتر) وانخفاض خطر الصوديوم (SAR < 9) وهو ذو نوعية جيدة ومناسب للاستخدام في أغراض الري. تم تصنيف المياه وفق مؤشر النفاذية لجميع عينات المياه الجوفية وتبين أنه ممتاز إلى جيد، مما يشير إلى نوعية المياه انها جيدة للري. ووفقا لنتائج RSC، فإنه لا يوجد أي خطر من الصوديوم حيث أنه أقل من 1.5 ملي مكافئ / لتر، وهو ضمن الحد القياسي المسموح به.

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Introduction

Groundwater is consumed in large quantities by industrial, agricultural, and human being (Seeyan et al., 2021). Groundwater investigation is a test that involves adding water to or taking measured amounts of water out of a well, and then measuring the changes in the aquifer's water level that occur both during and after the addition of water to bed that is saturated but not very permeable, or both. Groundwater is a major source of freshwater for domestic, agricultural, and drinking needs in many parts of the world. Groundwater quality management for the present and future requires the critical work of groundwater assessment for drinking and irrigation (Balachandar et al., 2010). Groundwater is a consistent supply of water and generally with acceptable water quality making it a popular resource for industrial and agricultural uses (Zhang et al., 2023). Understanding the hydrochemical types, characteristics, and influencing variables of groundwater chemistry is essential for groundwater resource development and preservation (Gang et al., 2023).

The relationship between the chemistry of groundwater and the climate, geology, and water` source is a crucial hydrochemical study, because groundwater chemistry is heavily influenced by the mineral composition of the aquifer it flows through, hydrochemical data are helpful for identifying different groundwater aquifers, classifying water for various uses such as irrigation, agriculture, drinking, and industrial purposes, and studying various chemical processes (Karanath, 1987; Saxena et al., 2003; Sarwade et Al., 2007; Pradhan and Pirasteh, 2011; Sridhar et. al, 2013). The rapid expansion of industrial and agricultural businesses along with climate change, may have detrimental effects on groundwater quality. In the Kurdistan Region of Iraq, evaluating the quality of the groundwater is crucial to determining the suitability of water for agriculture and other uses (Seeyan et al., 2022). Water scarcity occurs when demand for water exceeds available supply due to natural factors such as drought or human activity such as overuse and pollution (Dastorani, 2022). Groundwater exploitation has become increasingly important for the study area due to the increasing need for fresh water caused by population growth rising, the creation of industrial and agricultural projects. This study aims to understand the hydrogeological processes and hydrochemical properties of groundwater by examining irrigation water parameters such as major cations and anions. Additionally, the study sought to explore potential sources of ions in the groundwater and determination the water suitability for different purposes.

Study area Description

The study area is located in the northeastern part of the Dukan lake at a distance about 11 km, and northwest of Sulaymaniyah City at about 75 km extending between (44^{o} 50' 34.8'' - 45^{o} 18' 27.6'' E) and (36^{o} 07' 21.6'' - 36^{o} 26' 37.2'' N). The area covers about 730 km^2, and the elevation ranges from 280-1200 m above sea level (Fig. 1). The area lies within the Unstable Shelf, High Folded Zone (Jassim and Goff, 2006; Stevanovic and Markovic, 2003), having a semi-arid climate, which is characterized by cold and rainy winter; but hotand dry summer.

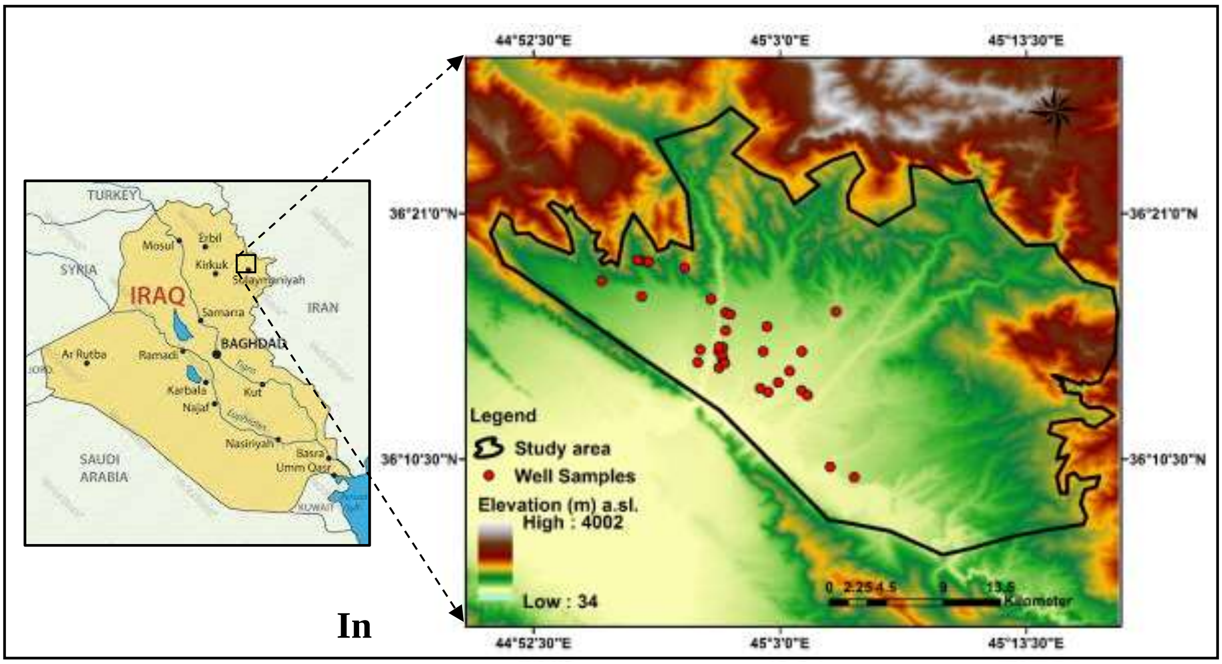


Fig. 1. Map of the study area with digital terrain model and groundwater samples' locations.

Four types of deposits constitute the study area; they are: 1) Pliocene deposits represented by Bai Hassan and Muqdadeya formations; 2) Cretaceous deposits represented by Dukan Formation; 3) Jurassic deposits represented by Naokelekan and Barserin formations; 4) Triassic and Thrust Mountain and marginal belt zone. The Pliocene deposits represent intergranular aquifer. The Cretaceous and Jurassic deposits represent karstic aquifer, and the Triassic deposits represent karstic-fissured aquifer (Fig. 2).

The study area is a part of a region, which is affected by Mediterranean climatological system, so its rainfall occurs during winter and spring seasons. Meteorological data obtained from Dukan meteorological station for the period between (2002 to 2020) reveal that the mean annual rainfall is about 636.13 mm, the maximum and minimum mean monthly relative humidity were 67.61% in January and 22.18% in July with an average of 45.47%, the maximum monthly temperature was 35.15 °C in July, and the minimum monthly temperature was 6.98 °C in January with an average of 20.16 °C, the maximum and minimum evaporation are 125 mm and 15 mm in July and January respectively, and finally the mean monthly windspeed and sunshine duration are 2.72 m/sec and 7.83 h/day respectively (Fig. 3).

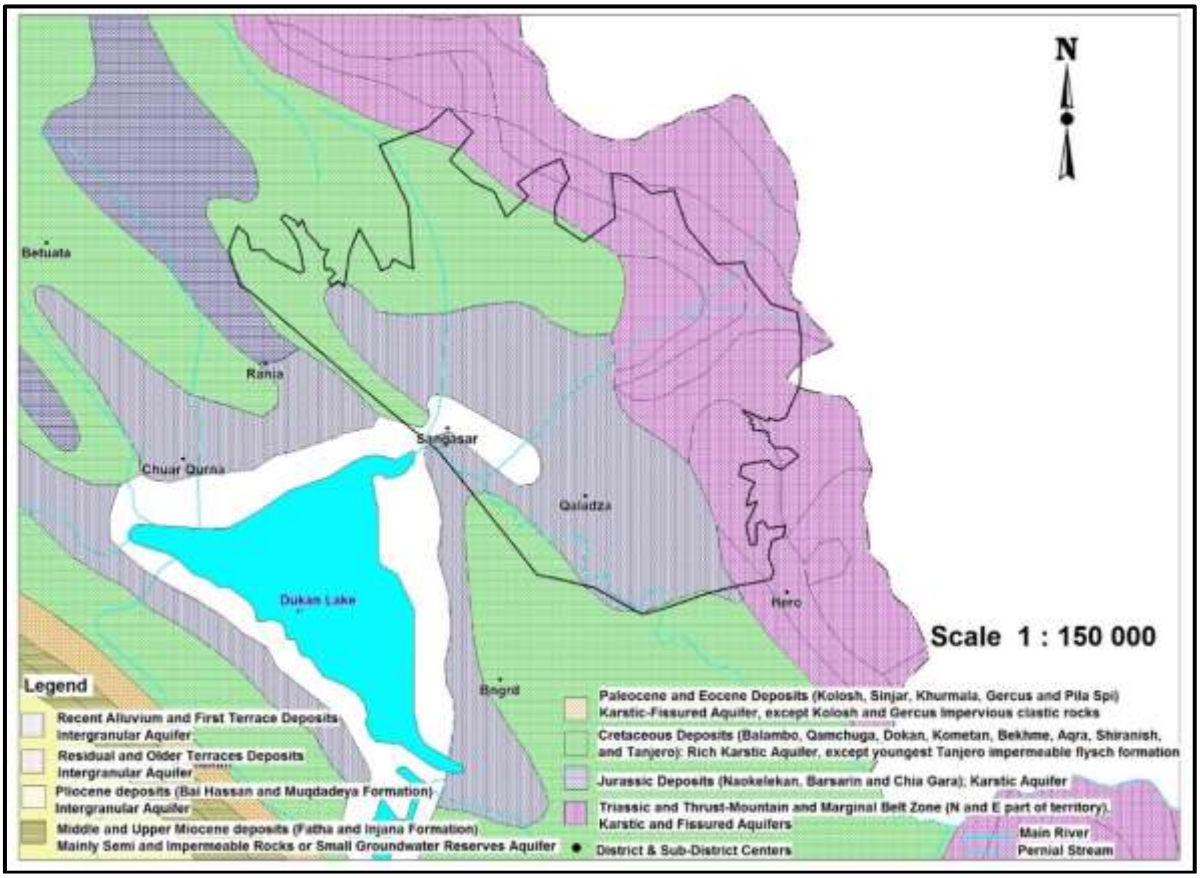
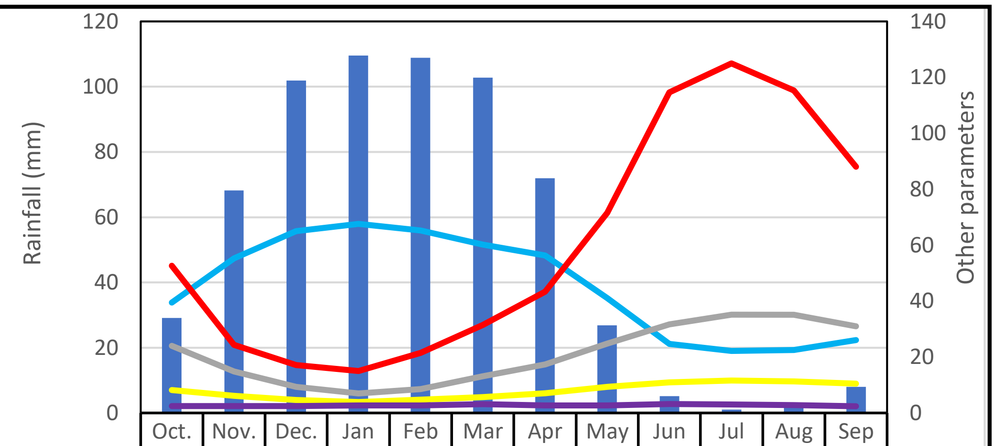


Fig. 2. Aquifer system and type of deposits in the study area (After Stevanivic, 2003).



	Oct.	Nov.	Dec.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Rainfall (mm)	29.1	68.25	101.86	109.5	108.89	102.77	71.93	26.86	5.12	1	2.85	8
Relative Humidity (%)	39.5	55.33	65	67.61	65.2	60.2	56.34	41.12	24.64	22.18	22.5	26.1
Temperature (C)	23.95	14.85	9.34	6.98	8.59	13.1	17.4	24.8	31.68	35.15	35.1	31.01
Evaporation (mm)	52.7	24.32	17.1	15	21.43	31.44	43.4	71.5	114.61	125	115.3	88
Sunshine Duration (h/day)	8.2	6.1	4.6	3.91	4.77	5.7	7.1	9.3	10.9	11.6	11.3	10.5
Wind Speed (m/sec)	2.5	2.46	2.5	2.66	2.7	3.1	2.66	2.7	3.2	3	2.8	2.4

Fig. 3. Mean monthly meteorological parameters data for the period (2002-2020) from Dukan meteorological station.

Materials and Methods

Data collection and analysis

To analyze seasonal fluctuation, 72 groundwater samples are obtained from several aquifers in the study area during the maximum recharge period, which is the wet season, and the minimum recharge period, which is the dry season. The coordination of these samples was done using a GPS device (Garmin eTrex 20) with spatial accuracy of ± 4 m (Table 1).

Table 1: Wells' locations in the study area with UTM Coordination system.

S. N	Name of Wells	Easting	Northing	Elevation (m) a.s.l
1	Gwezila	507714	4002733	536
2	Binawshan	509246	4001922	602
3	Zharawa1	503231	4008932	559
4	Zharawa2	505886	4008768	559
5	Qadrawa1	501032	4014920	633
6	Qadrawa2	501032	4013487	634
7	Qadrawa3	501321	4014773	625
8	Bastasteni Saro	503667	4013818	611
9	Zurkan	522819	4014921	631
10	Bastasteni Xwarw	503424	4011839	578
11	Zudani Tazaw Sherwet	508072	4014998	615
12	Sangasar 1	505886	4011840	580
13	Grtik	500097	4015979	703
14	Sangasar2	500582	4011845	581
15	Maxo Maznan	495615	4019000	816
16	Ashuran	495423	4019050	730
17	Sangasar 10	500830	4011240	575
18	Sangasar 11	500845	4011250	574
19	Sangasar 12	500820	4011230	572
20	Sangasar 9	500810	4011220	573
21	Zanglan	493113	4017418	762
22	Mamkan	498404	4018462	832
23	Twa Suran1	499396	4011976	572
24	Twa Suran2	499257	4010994	566
25	Swltana Deiy Taza	503744	4008641	552
26	Dola Bafra	504388	4009394	535
27	Sangasar 6	500603	4010550	556
28	Sangasar 7	500982	4010903	560
29	Sangasar 8	500850	4012180	577
30	Sangasar 5	500801	4011571	575
31	Sangasar 4	500851	4012182	577
32	Sangasar 3	500609	4012200	579
33	Mujamah Zharawa	506248	4008373	559
34	Khandaka	505105	4010293	549
35	Dwgoman1	495666	4916180	735
36	Dwgoman 2	351710	445733	620

Temperature, pH, and electrical conductivity (EC) which represent the physical parameters are measured in situ in the field during the sampling using portable devices. Chemical parameters for the samples include the major anions (Cl^-, NO_3^- SO_4^{2-} and HCO_3^-) and the cations (Na^+, Ca^{2+}, Mg^{2+}, and K^+) measurements carried out in the laboratory of Erbil Health Directorate in Erbil City.

Groundwater quality evaluation parameters

Sodium percentage (%Na), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage possible (SSPP), Total hardness (TH), potential salinity (Ps), permeability index (PI), monovalent cation adsorption ration (MCAR), Cation Ratio of Structural Stability (CROSS), residual sodium bicarbonate (RSBC), and magnesium ratio (MR) are calculated by the formulas shown in table (2):

Table 2: Determination equations of the hydrochemical indexes with references.

S. N	Index Name	Formula	Units	References
1	Na%	$[Na^+ + K^+ / Ca^{2+} + Mg^{2+} + Na^+ + K^+] * 100$	meq/l	Wilcox, 1955
2	SAR	$Na^+ / [Ca^{2+} + Mg^{2+} / 2]^{0.5}$	meq/l	Richard, 1954
3	RSC	$(CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+})$	meq/l	Richard, 1954
4	SSPP	$[Na^+ / (Ca^{2+} + Mg^{2+} + Na^+) – (CO_3^{2-} + HCO_3^-)] * 100$	meq/l	Eaton, 1995
5	TH (as $CaCO_3$)	$(Ca^{2+} + Mg^{2+}) \times 50$	mg/l	Hem, 1985
6	Ps	$Cl^- + \sqrt{} SO_4$	mg/l	Doneen, 1954
7	PI %	$[[Na^+ + \sqrt{} HCO_3^-] / [Ca^{2+} + Mg^{2+} + Na^+]] \times 100$	meq/l	Doneen, 1964
8	MCAR	$Na^+ + K^+ / (Ca^{2+} + Mg^{2+}/2)^{0.5}$	mg/l	Smiles and Smith, 2004
9	CROSS	$C_{Na} + 0.56\ C_K / [(C_{Ca} + 0.60\ C_{Mg})/2]^{0.5}$	mg/l	Rengasamy and Marchuk, 2011
10	RSBC	$HCO_3^- – Ca^{2+}$	meq/l	Richard, 1954
11	MR	Mg^{2+} / Ca^{2+}	meq/l	Szabolcs and Darab, 1964

Soil Permeability Hazard.

Soil permeability hazards typically refer to the potential risks associated with the permeability characteristics of soil. The ability of soil to transfer liquids such as water is known as soil permeability. It is an important factor in various environmental and engineering applications such as agriculture, construction, and environmental management. Permeable soils may contribute to the contamination of groundwater if pollutants can easily penetrate through the soil and reach the water table. This is a concern for drinking water supplies. The hazard associated with soil permeability is evaluated using the cation ratio of structural stability (CROSS) according to the formula in table (2).

Permeability Index (PI)

The permeability index is a measure that indicates the relative permeability of a soil sample. It is often used in geotechnical engineering to assess the ease with which water can flow through a particular soil. Over time, soil permeability which is influenced by the amounts of salt, calcium, magnesium, and bicarbonate in the soil also impacts the quality of irrigation water (Seeyan et al., 2022). Nagaraju et al. (2014) classified water quality on the basis of PI into three classes (I, II, and III). Classes I and II indicate good water quality for irrigation purposes, while Class III water is unsuitable for irrigation.

Groundwater uses for different purposes

Groundwater serves various essential purposes and is a vital resource for both human activities and ecosystems. Some common uses of groundwater include:

Drinking purposes: many communities rely on groundwater as a source of drinking water. Wells are drilled to tap into underground aquifers, providing a consistent and often high-quality water supply. Groundwater uses for drinking water are determined by comparing water samples with different standards like Davis and DeWiest (1966), IRS (1996), WHO (2003), IRS (2004), USEPA (2006), and WHO (2011).

Industrial purposes: numerous industries use groundwater in their processes such as manufacturing, energy production, and mining. Groundwater can be used for cooling purposes or as a component in various industrial processes. Water is necessary for industrial reasons for determining qualities for each kind of industry. Water's suitability for use in various industries requires varying quality depending on its type. Groundwater samples are compared with Hem (1985) water quality uses for Industrial purposes.

Livestock and Poultry Purposes: for these purposes, the samples are compared with Altoviski (1962) and Ayers and Westcott (1989) classifications to evaluate the water quality.

Agricultural Purposes: groundwater is a significant source of water for agricultural irrigation. Farmers use wells to extract groundwater for crop irrigation, especially in areas where surface water may be scarce or unreliable. The resistance of vegetation varies with electrical conductivity and total dissolved solids (Todd, 1980). For this purposes, Todd's classification for agricultural crops is used for comparison with groundwater samples (Todd, 1959).

Irrigation Purposes: field irrigation has long been a prevalent technique, considerably increasing farmland productivity. Without irrigation, farming would not have been possible in some locations. The variables that determine the classification of irrigation water include: Total Dissolved Solids (TDS) depending on Train classification (1979); Sodium percent; Sodium Adsorption Ratio depending on Bauder and Davis (2004); Residual Sodium Carbonate depending on Eaton (1995); and Chloride depending on Bauder and Davis classification (2004).

Distribution of ionic concentrations of elements in groundwater

Plotting the distribution of ions is done using the spatial interpolation approach by the inverse distance weighting (IDW) method by the Arc GIS program because this method is easier to use than the other methods (Esmael and Seeyan, 2023).

Results and Discussion

Physical and Chemical Compositions Characteristics of Groundwater

The physical attributes and chemical analyses for the water samples in both periods are shown in Tables (3) and appendixes (A and B). EC for the examined groundwater samples ranges from 280-520 µs/cm in first period and 350-740 µs/cm in second period. TDS for the groundwater samples ranges from 179.2 to 332.8 mg/l in the first period, and 224 – 473.6 mg/l in second period. The pH in first and second periods ranges from 6.78-7.32 and 7.14-8.42 respectively.

The temperature of the groundwater ranges from 17.7 to 21.8 in first period and 18.5 to 26.3 in second period. The Statistical results of chemical analysis and physical parameters are shown in Table (3). The spatial distributions of the physical parameters are shown in Figures (4 and 5). Based on groundwater flow from the surrounding mountains, the spatial distribution of TDS and EC maps indicate that the low values are basically found in the eastern and some center parts of the study area, while the high values are found in the western and southwestern parts of the area. The high TDS values of the groundwater samples in the region could be attributed to a lengthy residence duration and an intensified water-rock interaction.

Table 3: Statistical analysis for physical and chemical analysis results of the groundwater samples in the study area for both periods

Parameters	First Period				Second Period			
	Maximum	Minimum	Average	S.D*	Maximum	Minimum	Average	S.D*
EC (µc/cm)	520	280	378.33	54.38	740	350	514.17	80.83
TDS (mg/l)	332.8	179.2	242.13	34.80	473.6	224	329.07	51.73
T (C^o)	21.8	17.7	19.07	0.97	26.3	18.5	20.73	1.83
pH	7.32	6.78	7.02	0.14	8.42	7.14	7.54	0.25
TH (mg/l)	250.24	175.39	202.84	24.43	281.24	179.60	239.32	31.64
Ca^{2+} (mg/l)	56.35	26.97	42.17	8.26	54	22	35.88	6.18
Mg^{2+} (mg/l)	32.88	8.46	21.21	5.71	46.38	24	35.23	4.62
Na^{+} (mg/l)	24.50	1.90	5.63	3.75	38.5	1.62	7.05	6.29
K^{+} (mg/l)	2.25	0.75	1.31	0.40	37	5.7	14.63	7.16
HCO_3^- (mg/l)	169.60	88.40	122.29	15.35	286.4	141.6	183.74	29.76
SO_4^{2-} (mg/l)	111.50	52.30	69.17	12.52	120	66	84.51	10.92
NO_3^- (mg/l)	24.00	3.00	13.29	6.09	62	5.9	18.61	11.95
Cl^- (mg/l)	35.50	13.85	22.08	5.03	63.9	15.97	30.22	9.75
SAR	0.80	0.06	0.18	0.12	1.10	0.04	0.20	0.18
Na%	24.27	2.46	6.82	3.63	37.11	4.61	13.48	7.15
RSC	-0.90	-2.67	-1.84	0.42	-0.44	-3.09	-1.69	0.57
MR	1.47	0.25	0.88	0.32	2.50	1.22	1.66	0.30
RSBC	0.55	-0.93	-0.09	0.35	2.13	0.26	1.20	0.44
PI	23.66	2.39	6.40	3.59	26.67	1.55	6.48	4.58

MACR	4.70	0.45	1.24	0.69	10.23	1.42	3.69	1.92
CROSS	4.65	0.42	1.22	0.70	8.52	1.01	2.91	1.66

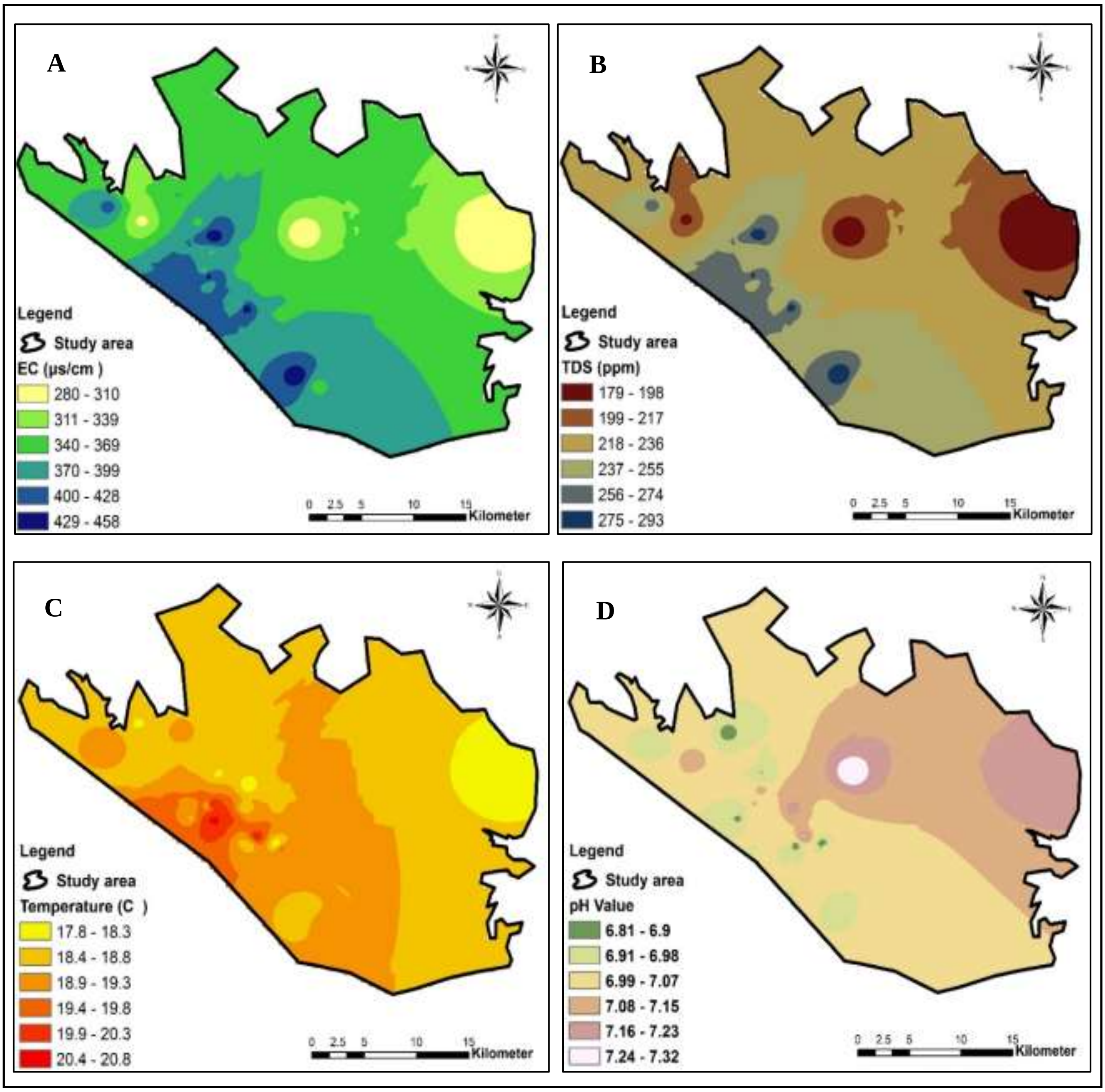


Fig. 4. Distribution Map of Physical Parameters is First Period; A-Electrical Conductivity, B- Total Dissolved Solid, C- Temperature, and D- pH Value.

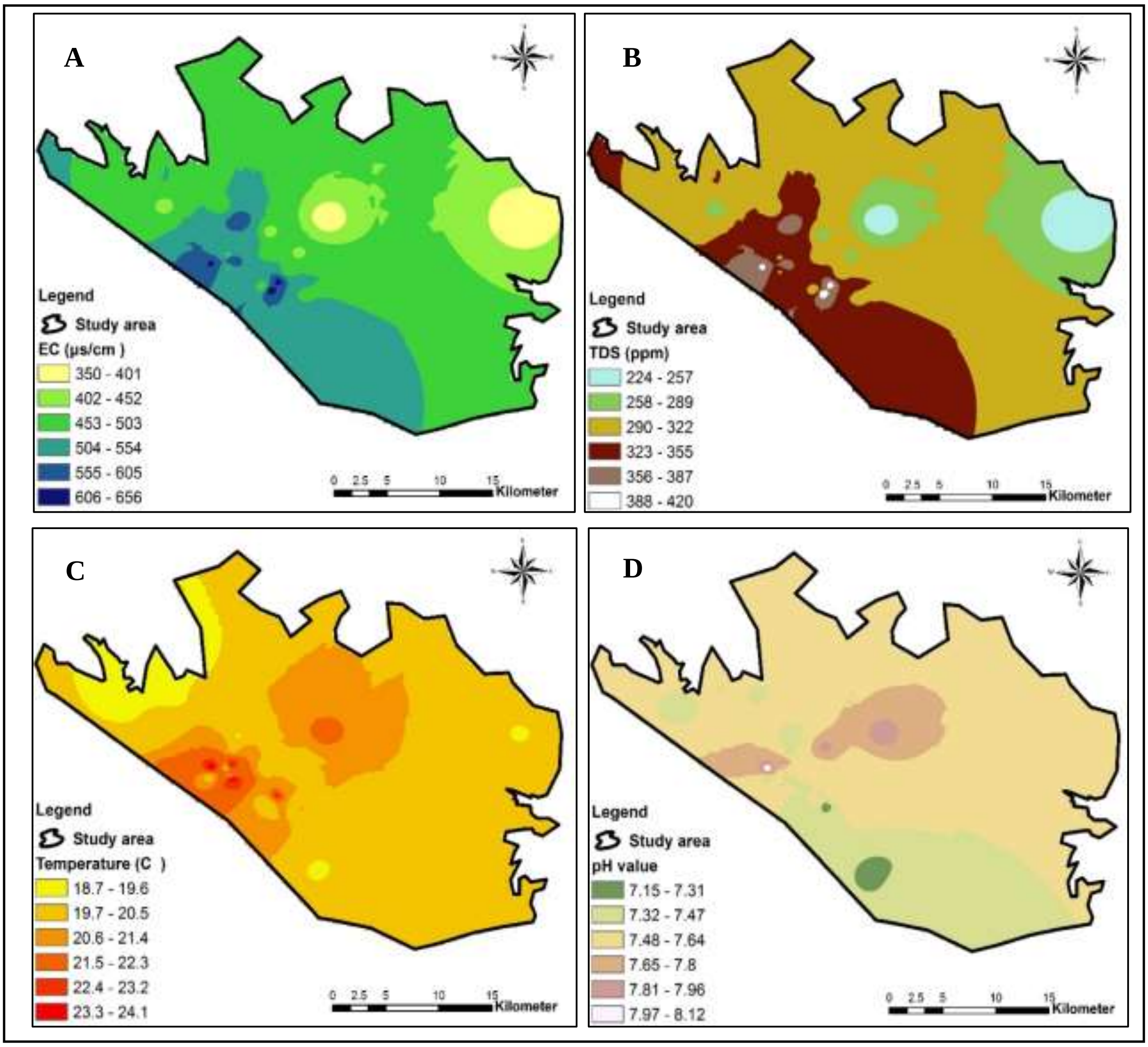


Fig. 5. Distribution map of physical parameters in the second period; A-Electrical Conductivity, B- Total Dissolved Solid, C- Temperature, and D- pH value.

Ca^{2+} and Mg^{2+} are the main cations found in groundwater. The cations concentrations of the groundwater samples show that the $Ca^{2+} > Mg^{2+} > Na^{+} > K^{+}$. Calcium concentration ranges from 26.97 – 56.35 mg/l, while the magnesium concentration ranges from 8.46 to 32.88 mg/l with mean values of 42.17 mg/l and 21.21 mg/l in first period, and ranges of 22 – 54 mg/l and 24 – 46.38 mg/l respectively, with mean values of 35.88 mg/l and 35.238 mg/l in the second period. The sodium concentration ranges from 1.90 to 24.50 and 1.62 to 38.5 mg/l in the first and second periods respectively. Potassium concentration ranges from 0.75 to 2.25 and 5.7 to 37 mg/l in the first and second periods respectively (Appendixes A and B). The spatial distribution of the cations in both periods are shown in Figures (6 and 7).

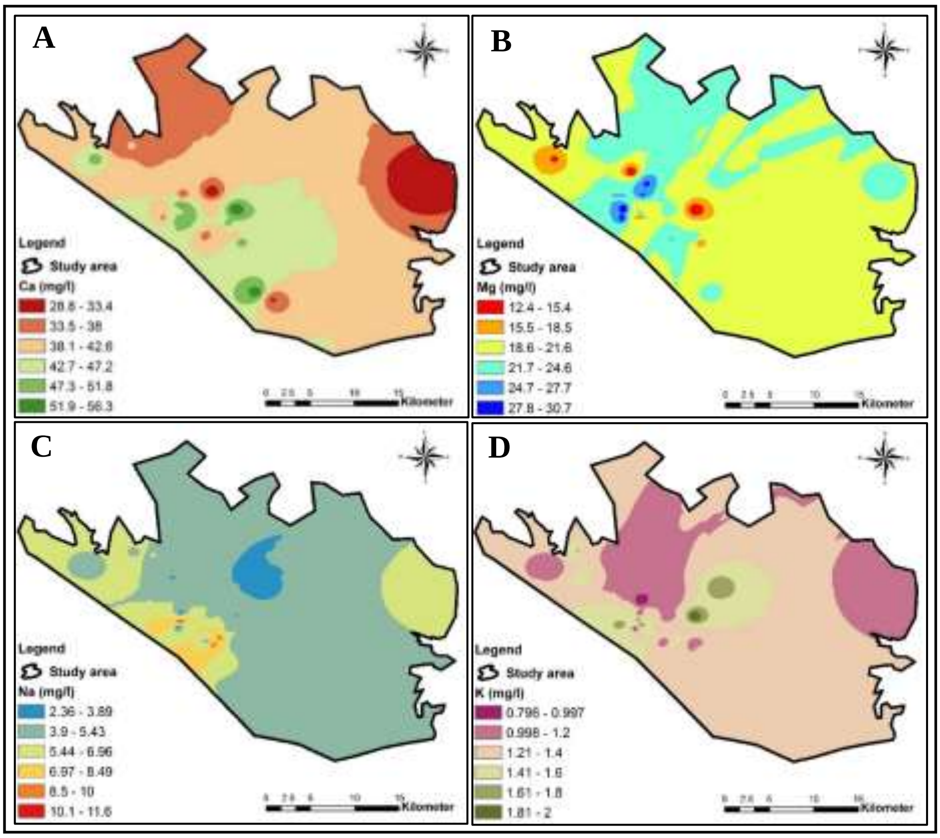


Fig. 6. Distribution map of cation concentration in the first period; A- Calcium; B- Magnesium; C- Sodium; D- Potassium.

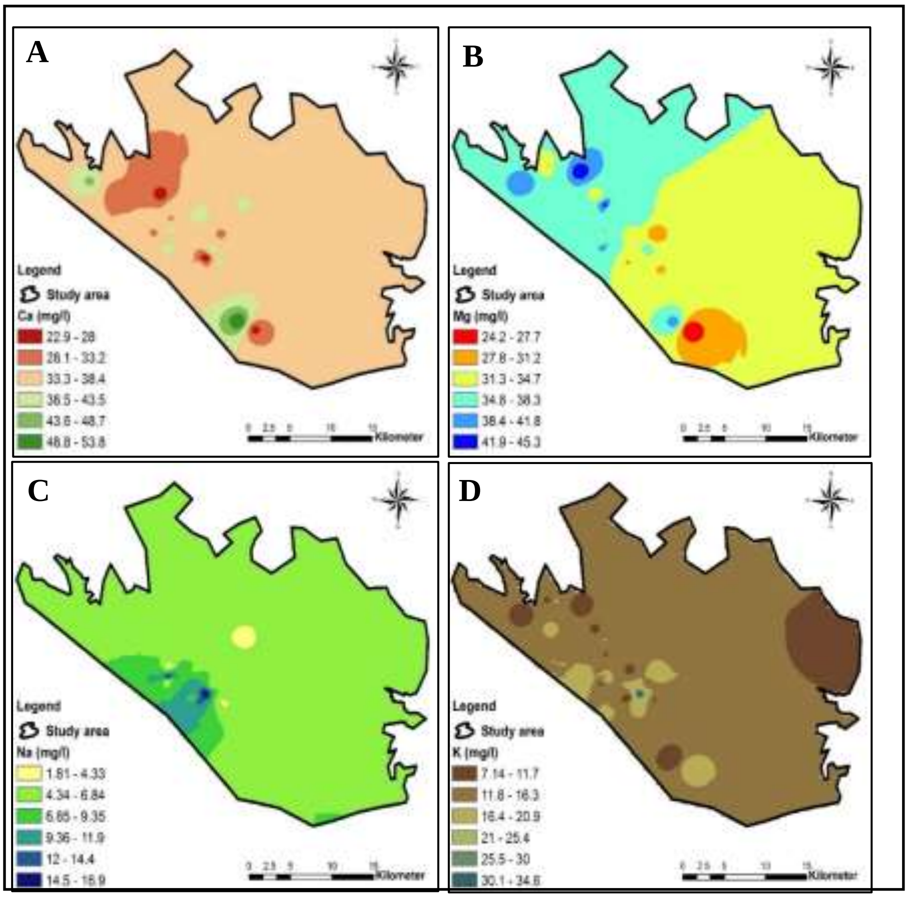


Fig. 7. Distribution map of cation concentration in the second period; A- Calcium, B- Magnesium, C- Sodium, and D- Potassium.

The majority of carbonate and bicarbonate ions found in groundwater are originated from atmospheric carbon dioxide, soil carbon dioxide, and carbonate rock solutions. The concentration of bicarbonate ranges between 88.40 - 169.60 and 141.6 - 286.4 mg/l in first and second periods respectively. Sulfate is found naturally in groundwater in a variety of minerals, such as gypsum ($CaSO_4.2H_2O$), barite ($BaSO_4$), epsomite ($MgSO_4.7H_2O$), and sulfate mineral that dissolves in evaporate (gypsum and anhydrite) from oxidation of pyrite and marcasite in clay mineral (Todd, 1980). Sulphate concentration in the study area ranges from 52.30 - 111.50 mg/l with an average of 69.17 mg/l in the first period, and ranges from 66-120 mg/l with an average of 84.51mg/l in the second period. Chloride concentration ranges from 13.85 - 35.50 and 15.97 - 63.9 mg/l in the first and second periods respectively. The majority of nitrate found in natural water originates from industrial and agricultural processes, as well as organic sources. Nitrate concentration in the area ranges from 3 - 24 mg/l with an average of 13.29 mg/l in the first period, and ranges from 5.9-62 mg/l with an average of 18.61mg/l in the second period. The spatial distribution of the cations in both periods are shown in Figures (8 and 9).

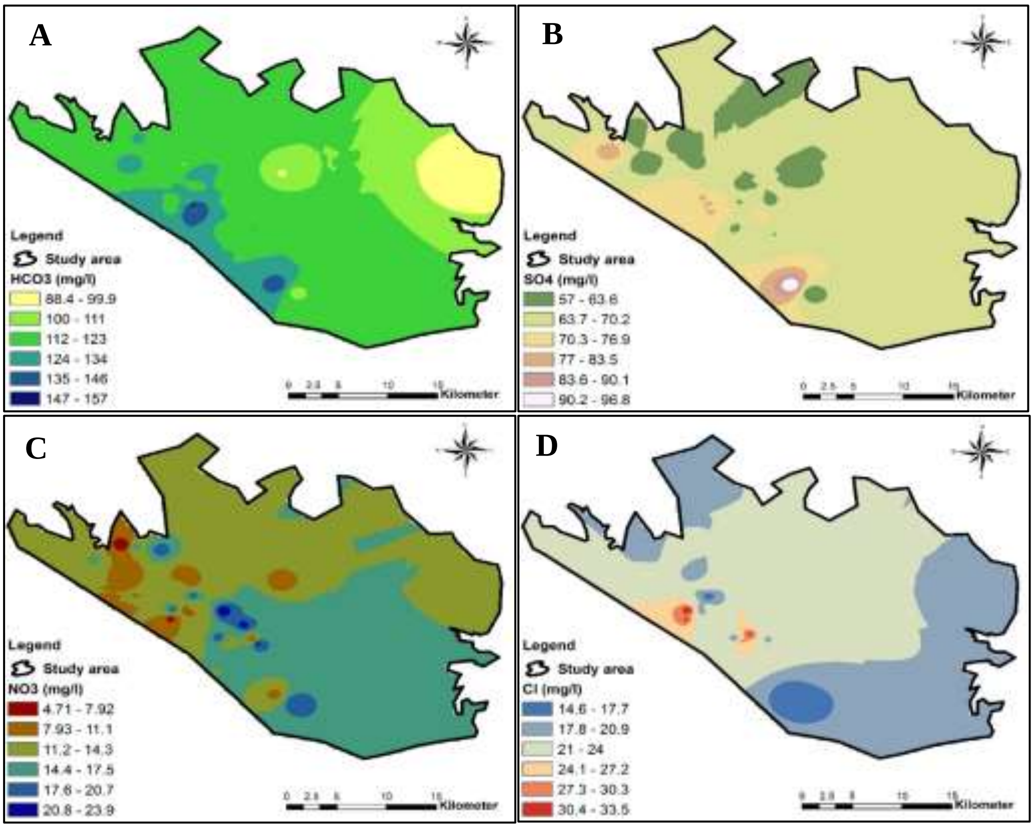


Fig. 8. Distribution map of anions concentration in the first period; A- Bicarbonate, B- Sulphate, C- Nitrate, and D- Chloride.

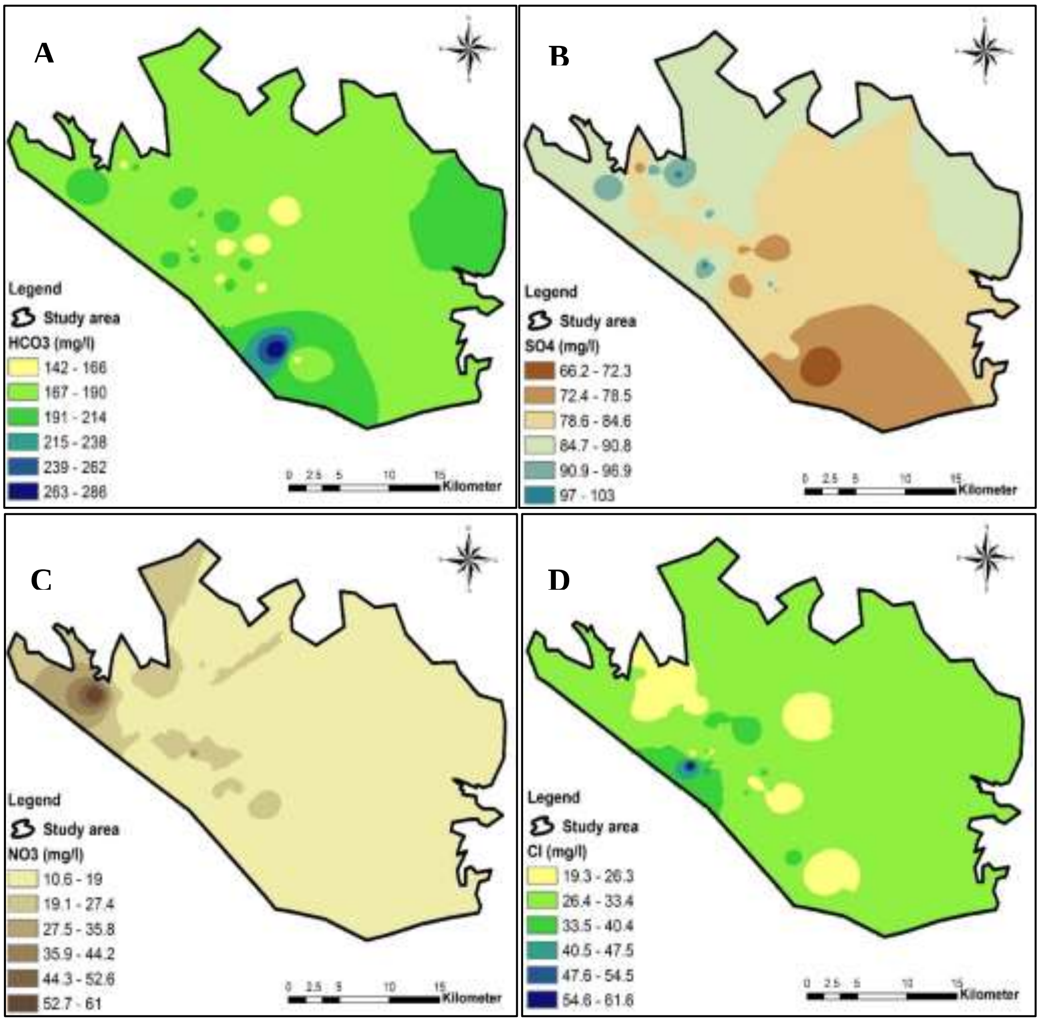


Fig. 9. Distribution map of anions concentration in the second period; A- Bicarbonate, B- Sulphate, C- Nitrate, and D- Chloride.

Water type

Water types for all the samples are hydrogen bicarbonate because of chemical weathering of the carbonate cementing materials in the sandstone layers, Ca-Mg-SO_4-HCO_3 type predominates in the groundwater samples with a few samples from the second period belonging to Mg-Ca-SO_4-HCO_3.

Groundwater Quality Assessment

The sodium adsorption ratio (SAR) ranges from 0.06 to 0.8 meq/l with an average of 0.18 in the first period, and from 0.04 to 1.10 meq/l with an average of 0.2 in the second period. The sodium percentage (Na%) ranges from 2.46% to 24.27% with an average of 6.82% in the first period, and from 4.61 to 37.11% with an average of 13.48%. As sodium percentage exceeds 60%, it is considered toxic to plants; but in the groundwater samples there is no toxic effect on the plants because all the samples have less than 60% Na. The residual sodium carbonate (RSC) ranges from -2.67 to -0.90 meq/l with an average of -1.84 meq/l in the first period, and from -3.09 to -0.44 meq/l with an average of -1.69 meq/l in the second period. Based on RSC, all the groundwater samples are suitable for irrigation because they fall below the standard limit, which is less than 1.5 meq/l. The monovalent cation adsorption ratio (MCAR) ranges from 0.45 to 4.70 meq/l with an average of 1.24 meq/l and from 1.42 to 10.23 meq/l with an average of 3.69 meq/l in the first and second periods respectively. The cation ratio of structural stability (CROSS) ranges from 0.42 to 4.65 meq/l with an average of 1.22 meq/l and from 1.01 to 8.52 meq/l with an average of 2.91 meq/l in both periods respectively. The (PI) percent ranges from 2.39 to 23.66% with an average of 6.4% and from 1.55 to 26.67% with an average of 6.48% in first and second periods respectively (Appendix C). Water quality based on permeability index according to Nagaraju et al. (2014) classified as good water quality for irrigation purposes because all groundwater samples fall in class (I), which is described as having excellent to good permeability (Fig. 10).

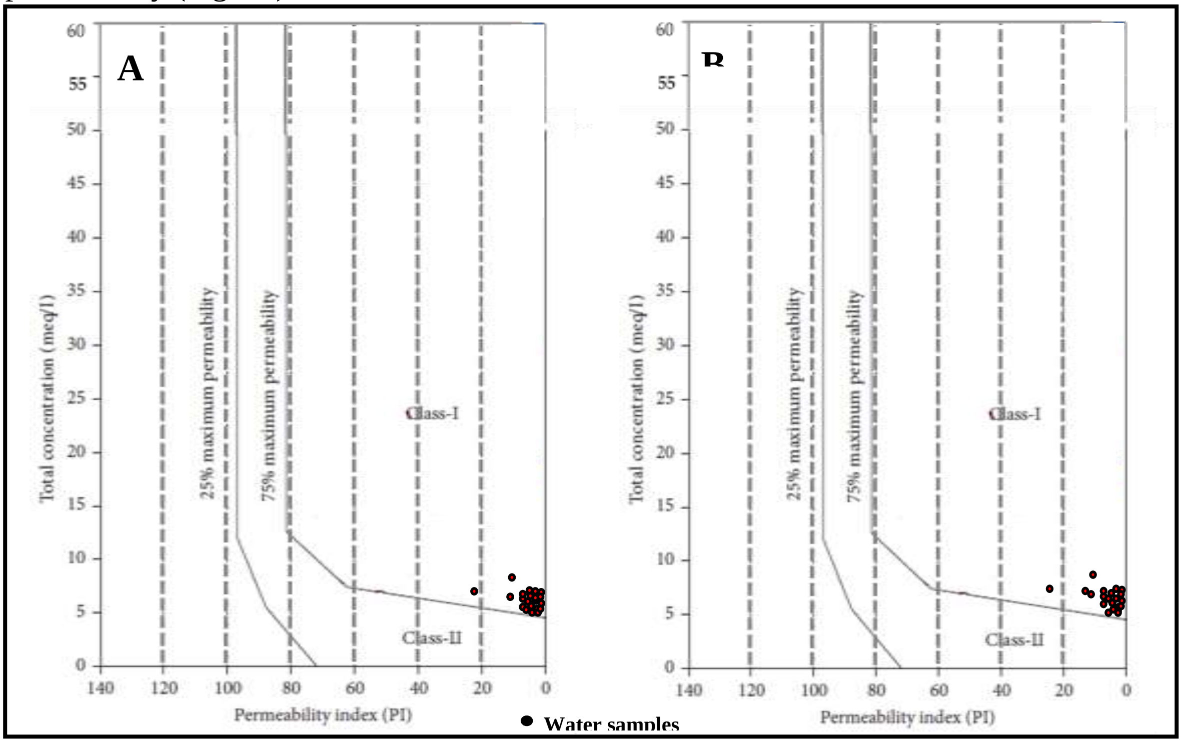


Fig. 10. Permeability index diagram classification of the groundwater quality.

Groundwater uses

Compared to surface water, the groundwater is typically less exposed to pollutants. The natural filtering process that occurs as water percolates through the soil helps in removing impurities. It is crucial to remember that human activities including improper waste disposal, agricultural runoff, and industrial discharge can still have an impact on the groundwater quality.

1-Drinking Purposes

The quality of the drinking water in the study area is determined by comparison with the WHO (2003), ESEPA (2006), Davis and Dewiest (1966), IRS (1996), IRS (2002), and WHO (2011) (Table 4). Except one water sample of the Zhanglan well, which has nitrate concentrations over the recommended limit, all the other groundwater samples are deemed safe for human consumption based on this classification.

Table 4: Standard guideline properties for drinking water compared with chemical component in the study area.

Parameters mg/l	Davis and Dewiest, 1966	IRS 1996	IRS 2002	WHO 2003	USEPA 2006	WHO 2011	Water samples	
							1st period	2nd period
Ca^{+2}	200	150	75	75-200	---	50	26.97-56.35	22-54
Mg^{+2}	125	50	125	30-150	---	50	8.46-32.88	24-46.38
Na^{+}	200	200	200	200	---	200	1.9-24.50	1.62-38.5
K^{+}	---	---	12	2-3	---	12	0.75-2.25	5.7-37
NO_3^{-}	20	50	50	50	10	50	3-24	5.9-62
Cl^{-}	250	250	250	250	250	250	13.85-35.50	15.97-63.9
SO_4^{-2}	250	250	250	250	250	250	52.3-111.5	66-120
HCO_3^{-}	500	---	200	200	---	200	88.4-169.6	141.6-286.4
TDS	1500	1000	1000	1000	500	1000	179.2-332.8	224-473.6
pH	---	6.5-8.5	6.5-8.5	7-8	6.5-8.5	6.5-8.5	6.78-7.32	7.14-8.42
Ec (µmho/cm)	---	1500	1500	1530	---	1500	280-520	350-740
T.H	---	500	500	100-500	---	500	175.39-250.24	179.6-281.24

2-Industrial Purposes

Industrial purposes require water in determinative properties for each type of industry. Water quality must vary depending on the type of application in order to be suitable for use in various industries. According to Hem (1985) classification of water quality uses for Industrial purposes, all the groundwater samples are suitable for all types of industry (Table 5).

Table 5: Water quality of groundwater samples for industrial purposes according to Hem (1985). Concentrations are in average values in mg/l.

Industry type		TDS	pH	TH	HCO_3^-	SO_4^{2+}	NO_3^-	Ca^{2+}	Mg^{2+}	Cl^{2+}
Drinking Food Canning and freezing		---	---	---	---	500	---	100	---	500
Plastic		---	6.5-8.3	350	---	---	---	80	36	---
Fruit Canning		500	6.5-8.5	250	---	250	10	---	---	250
Tanning Textile		1000	6.5-8	900	250	100	5	100	50	500
Cement		600	6.5-8.5	---	---	250	---	---	---	250
Oil Product		1000	6 - 9	350	---	---	---	75	30	300
Flog		---	6 - 8	soft	---	250	---	---	---	250
Clothes		100	2.5-10	--	0	0	0	0	0	0
Paper Industry	bleached	---	6 - 10	100	---	---	---	20	12	200
	unbleached	---	6 - 10	100	---	---	---	20	12	200
Water sample of studied area	1st Period	242.13	7.02	202.84	122.29	69.17	13.29	42.17	21.21	22.08
	2nd Period	329.07	7.54	239.32	183.74	84.51	18.61	35.88	35.23	30.22

3-Livestock and Poultry Purposes

According to Altoviski (1962) and Ayers and Westcottt (1989), all the groundwater samples are in very good class for livestock and in excellent class for poultry purposes (Tables 6 and 7).

Table 6: Water quality for livestock drinking (Altoviski, 1962) compared with groundwater samples.

Parameters (mg/l)	Very Good	Good	Permissible	Can be Used	Upper Limit	Groundwater Samples	
						1st Period	2nd Period
Na^+	800	1500	2000	2500	4000	1.9-24.50	1.62-38.5
Ca^{+2}	350	700	800	900	1000	26.97-56.35	22-54
Mg^{+2}	150	350	500	600	700	8.46-32.88	24-46.38
Cl^-	900	2000	3000	4000	6000	13.85-35.50	15.97-63.9
SO_4^{-2}	1000	2500	3000	4000	6000	52.3-111.5	66-120
TDS	3000	5000	7000	10000	15000	179.2-332.8	224-473.6
TH	1500	3200	4000	4700	54000	175.39-250.24	179.6-281.24

Table 7: Water quality for livestock and poultry (Ayers and Westcott, 1989) compared with the groundwater samples.

EC (µmhos/cm)	Class	Description	Groundwater Samples 1st Period	2nd Period
< 1500	Excellent	These waters have a relatively low level of salinity and should present no serious burden to any livestock or poultry.	280-520 µmhos/cm	350-740 µmhos/cm
1500-5000	Acceptable	These waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhea in livestock not accustomed to them, or watery droppings in poultry (especially at the higher levels), but should not affect their health or performance.		
5000-8000	Acceptable for Livestock, Un acceptable for Poultry	Cause temporary diarrhea for livestock and causing death for poultry and reducing growth.		

8000-11000	Limited for Livestock, Un acceptable for Poultry	Avoid the use of those approaching the higher levels for pregnant or lactating animals. They are not acceptable waters for poultry.	
11000-16000	Limited	Not acceptable for animals	
> 16000	Not Used	The risks with these highly saline waters are so great that they cannot be recommended for use under any conditions	

4-Agricultural Purposes

The durability of vegetation varies depending on electrical conductivity and total dissolved solids (Todd, 1980). According to Todd's classification (1959), for all varieties of agricultural crops during both periods, all water sample is appropriate (Table 8).

Table 8: Todd classification (1959) for agricultural crops and compared with water samples

Crop Divisions	**Low TDS Endurance**	**Medium TDS Endurance**	**High TDS Endurance**	Groundwater Samples	
				1st Period	2nd Period
Fruit	< 3.0 dms/cm Avocado, lemon, Orange, Apple Strawberry, Picot Prune, Plum	3.0-4.0 dms/cm Olive, Date, Fig Cantaloupe, Pomegranate.	4.0-10.0 dms/cm Palm.		
Vegetable	3.0-4.0 dms/cm Green Bean, Celery Radish,	4.0-10.0 dms /cm Cucumber, Onion, Peas Carrot, Potato, Cauliflower Lettuce, Squash.	10.0-120.0 dms/cm Spinach, Kale Asparagus.	0.280-0.520 dms/cm	0.350-0.740 dms/cm
Field Crops	4.0-6.0 dms/cm Field Bean	6.0-10.0 dms/cm Sunflower, corn, rice Flax, Castor Bean, Corn Wheat.	10.0-100.0 dms/cm Cotton, Sugar Beet, Barley.		

5-Irrigation Purposes

Total Dissolved Solid (TDS): Water quality is frequently determined using TDS. High TDS levels may indicate the presence of dissolved salts and minerals, but it does not provide information about the specific types of ions present. Water samples from the research area are compared with the Train classification (1979) to determine whether the water is suitable for irrigation; the results indicate that all of the water samples are suitable and have no negative impacts on crops (Table 9).

Table 9: Irrigation water based on TDS according to Train classification (1979) and compared with water samples in both periods

TDS (mg/l)	**Specifications**	**Groundwater Samples**	
		1st Period	**2nd Period**
< 500	When used for irrigation, no negative effects occur.	**179.2-332.8**	**224-473.6**
500 – 1000	Used for irrigation had a negative impact on crops that were susceptible to salinity.		
1000 – 2000	Causing adverse influence on crops therefore for usage need experience.		
2000 – 5000	Used for applications requiring experience and for high tolerance agricultural irrigation.		

(B) Sodium Percent (Na%): Increased sodium concentration in irrigation water degrades well-structured soils, which reduces soil permeability to water and aeration, which in turn reduces crop development (Lak, 2007). All groundwater samples from both periods are safe and do not contain any harmful levels of sodium because its concentration is less than 60% (where greater than 60% is deemed toxic to plants) (Appendix C).

Sodium Adsorption Ratio (SAR): SAR provides information about the potential risk of soil degradation due to the presence of sodium in irrigation water. It is particularly relevant in arid and semi-arid regions where irrigation is essential for agriculture. According to Bauder and Davis (2004), the general classification of water sodium dangers based on SAR value indicates that the groundwater samples are suitable for irrigation and of low hazard due to high concentration of calcium and magnesium in comparison with sodium (Table 10 and Appendix C).

Table 10: General classification of water sodium hazard based on SAR values and compared with the groundwater samples according to (Bauder and Davis, 2004).

SAR values	Sodium hazard of water	Description	SAR value of the water samples 1st Period	2nd Period
1 - 9	Low	Uses with caution on crops that are sensitive to salt.	**0.06 - 0.8**	**0.04 - 1.1**
10 - 17	Medium	Leaching and amendments (like gypsum) are required.		
18 - 25	High	Generally unsuitable for continual use.		
> 26	Very high	Generally, not suitable for purpose.		

(D) Residual sodium carbonate (RSC): Residual sodium carbonate typically refers to the remaining amount of sodium carbonate (Na_2CO_3) in a solution or substance after a chemical reaction or process. It's important to control and monitor the levels of residual sodium carbonate, especially in applications where precise concentrations are crucial or where excessive amounts could be undesirable. Groundwater samples in the study area compared with the Eaton (1995) classification demonstrate that all water samples are appropriate for irrigation (Table 11 and Appendix C). RSC has negative values in most of the groundwater in Iraq due to high concentration of Ca and Mg and zero concentration of CO_3.

Table 11: Classification of water based on RSC values and compared with groundwater samples according to Eaton (1995).

RSC Value	Description	Groundwater Samples 1st Period	2nd Period
> 2.5	Unsuitable for Irrigation		
1.5 – 2.5	Ranges between appropriate and unsuitable water for irrigation		
< 1.5	Suitable for Irrigation	**-2.67 – -0.9**	**-3.09 – -0.44**

(E) Chloride: While chloride is not adsorbed by soil, it is easily transported by soil water, where it is absorbed by roots and subsequently accumulated in leaves (Rijtima, 1981). Although chloride is extremely necessary for plants in very small amounts, excessive concentrations of it can be hazardous to crops that are sensitive. According to Bauder and Davis' (2004) classification, all the groundwater samples are safe for plants because their chloride concentration is less than 70 mg/l (Table 12 and Appendix C).

Table 12: Bauder and Davis classification (2004) and comparing with the water samples in both periods.

Chloride (mg/l)	Effect on Crops	Cl^- of the Water samples 1st Period	2nd Period
Below 70	Safe for all plants in general	15.97-63.9	13.85-35.50
70-140	Sensitive plants display damage		
141-350	Plants that are moderately tolerant exhibit damage		
Above 350	Can cause intense problems		

Conclusion

Groundwater serves various essential purposes and is a vital resource for both human activities and ecosystems. According to the hydrochemical investigation, hydrogen bicarbonate water types prevail in the examined water samples. All the water samples are suitable for drinking except one water well sample (Zanglan well) has nitrate concentration above the standard limit. All groundwater samples are suitable for all types of industry, and in very good class for livestock and excellent class for poultry purposes. Total dissolved solids indicate that all of the water samples are safe to use for irrigation and have no negative impacts on crops. Sodium percent indicates that the water is not poisonous to plants. SAR indicates that the water has low sodium hazard, which poses little risk to plants, and RSC indicates that the water is suitable for irrigation. Based on chloride concentration, all the groundwater samples are safe for all types of plants.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

References

Altoviski, M.E., 1962. Hand Book of Hydrogeology. Gosgeolitzda Moscow, USSR (in Russian), 614 P.

Ayers, R.S. and Westcottt, D.W., 1989. Water Quality for Agriculture. Irrigation and Drainage paper 29. Rev.1, FAO, Rome, Italy, 174 P.

Balachandar, D., Sundararaj, P., Rutharvel, M.K. and Kumaraswamy, K., 2010. An Investigation of Groundwater Quality and its Suitability to Irrigated Agriculture in Coimbatore District, Tamil Nadu, India – A GIS approach. International Journal of Environmental Sciences, 1(2), pp. 176-190.

Bauder, T.A., Waskom, R.M. and Davis, J.G., 2004. Irrigation Water Quality Criteria.

Dastorani, M.T., 2022. Evaluation of Water Harvesting Potential in Residential Houses of Arid Regions (Case Study: Mashhad, Northeast of Iran). Arabian Journal of Geosciences, 15(23), 1704. https://doi.org/10.1007/s12517-022-10996-5.

Davis, S.N. and Dewiest, R.J., 1966. Hydrology; John Wiley and Sons., Inc.: New York, NY, USA, 463 P.

Doneen, L.D., 1954. Salination of Soil by Salts in the Irrigation Water. Am. Geophys. Union Trans., 35, pp. 943-950.

Eaton, F.M., 1950. Significance of Carbonates in Irrigation Waters. Soil Sci., 69, pp. 123-133.

Esmael, S. and Seeyan, S., 2023. Hydrochemical Investigation and Quality of Groundwater in Erbil-Pirmam Area, Kurdistan Region, Iraq. Iraqi Geological Journal, 56 (1A), pp. 67-85, DOI: https://doi.org/10.46717/igj.56.1A.7ms-2023-1-19.

Gang, S., Jia, T., Deng, Y., Xing, L., Gao, S., 2023. Hydrochemical Characteristics and Formation Mechanism of Groundwater in Qingdao City, Shandong Province, China. Water, 15, 1348. https://doi.org/10.3390/w15071348.

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, 3rd ed.; USGS Water Supply Paper: Reston, VA, USA, 263 P.

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq (1^{st} Edition).

Karanath, K.R., 1987. Ground Water Assessment Development and Management. New Delhi. Tata McGraw Hill, pp. 217-275.

Lak, M.H., 2007. Environmental Study of Arab - Kand Waste Water Channel in Erbil Governorate / Kurdistan Region – Iraq. M. Sc. Thesis, 119 P.

Nagaraju, A., Sunil Kumar, K., Thejaswi, A., 2014. Assessment of Groundwater Quality for Irrigation: A Case Study from Bandalamottu Lead Mining Area, Guntur District, Andhra Pradesh, South India. Appl. Water Sci., 4, pp. 385-396.

Pradhan, B. and Pirasteh, S., 2011. Hydro-Chemical Analysis of the Ground Water of the Basaltic Catchments: Upper Bhatsai Region, Maharastra, Hydrology Journal, 5, pp. 51-57.

Rengasamy, P., Marchuk, A., 2011. Cation ratio of soil structural stability (CROSS). Soil Res., 49, pp. 280-285.

Richard, L.A., 1954. Diagnosis and Improvement of Saline and Alkali Soils. Agricultural Hand Book 69, US Dept. Agric., Washington, D. C., 160 P.

Rijtima, P.E., 1981. Quality Standards for Irrigation Waters. Acta Hort. 119, pp. 25-35.

Sarwade, D.V., Nandakumar, M.V., Kesari, M.P., Mondal, N.C., Singh, V.S. and Singh, B., 2007. Evaluation of Seawater Ingress into an Indian Attoll. Environmental Geology., 52(2), pp. 1475-1483.

Saxena, V.K., Singh, V.S., Mondal, N.C. and Jain, S.C., 2003. Use of Chemical Parameters to Delineation Fresh Groundwater Resources in Potharlanka Island, India. Environmental Geology, 44(5), pp. 516-521.

Seeyan, S., Adham, A., Mahdi, K., Ritsema, C., 2021. Water Quality, Availability, and Uses in Rural Communities in the Kurdistan Region, Iraq. Water, 13, 2927. https://doi.org/10.3390/w13202927

Seeyan, S., Akrawi, H., Alobaidi, M., Mahdi, K., Riksen, M., Ritsema, C., 2022. Groundwater Quality Evaluation and the Validity for Agriculture Exploitation in the Erbil Plain in the Kurdistan Region of Iraq. Water, 14, 2783. DOI: https://doi.org/10.3390/w14182783

Smiles, D.E., Smith, C.J., 2004. A Survey of the Cation Content of Piggery Effluents and some Consequences of Their Use to Irrigate Soils. Aust. J. Soil Res., 42, pp. 231-246.

Sridhar, S.G.D., Kanagaraj, G., Sharma, K.K.S.M., and Priyalakshmi, R., 2013. Hydrochemical Analysis and Evaluation of Quality of Groundwater in Kancheepuram District, Tamilnadu, India. Asian Journal of Science and Technology, 9, pp. 19-27.

Stevanovic, Z. and Markovic, M., 2003. Hydrogeology of Northern Iraq, Climate, Hydrology, Geomorphology and Geology.

Szabolcs, I., Darab, C., 1964. Influence of Irrigation Water of High Sodium Carbonate Content of Soils. In Proceedings of the 8th International Congress of ISSS, Tsukuba, Japan, pp. 803-812.

Todd, D.K., 1959. Groundwater Hydrology. John Wiley and sons, Inc, New York and London, 240 P.

Todd, D.K., 1980. Groundwater Hydrology. 2nd Edition, John Wiley and Sons, Inc, New York, 535 P.

Train, R.E., 1979. Quality Criteria for Water. Castle House Publication, Ltd., 256 P.

USEPA, 2006. United State Environmental Protection Agency, National Primary Drinking Water Standard.www.usepa.gov/safe water salinity of groundwater in SA/Fact sheet 32. www.dWLbe.sa.gov.au.

WHO 2004. Guide lines for Drinking Water Quality. 3rd edition. 1, 540 P.

WHO, 2011. Guide Lines for Drinking Water Quality. 170 P.

Wilcox, L.V., 1955. The Quality of Water for Irrigation USE. US Dept. Agricultural Tech. Bull., No. 962, 40 P.

Zhang, Y., Chen, Z., Huang, G., Yang, M., 2023. Origins of Groundwater Nitrate in a Typical Alluvial-Pluvial Plain of North China Plain: New Insights from Groundwater Age-Dating and Isotopic Fingerprinting. Environ. Pollut., 316, 120592.

Appendixes

Appendix A: Physical and chemical analysis of the studied samples in the first period.

Wells No.	TC°	pH	EC µc/cm	TDS Mg/l	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	mg/l HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-
1	18.5	6.93	450	288	54.03	21.98	4.1	1.25	142.8	96.6	10	14.91
2	18.9	7.04	360	230.4	32.67	20.28	4.71	1.25	106.8	56.61	20	16.69
3	18.7	7	360	230.4	33.14	24.75	4.41	1	118	59.07	21	17.75
4	17.7	6.8	390	249.6	37.33	25.23	3.82	1	123.6	67.23	6.6	19.53
5	18.4	6.88	440	281.6	38.84	24.2	4.71	1	124.8	67.06	8.8	25.92
6	18.9	7.11	360	230.4	32.32	28.8	4.56	0.75	111.6	63.62	20.6	13.85
7	18.1	6.91	450	288	39.65	30.43	4.12	1	130	67.63	11.4	21.3
8	18	7.14	360	230.4	28.97	19.63	4.12	1	115.6	58.4	13.4	23.08
9	18	7.22	290	185.6	28.83	21.7	5.74	1	88.4	66.08	13.4	18.11
10	18.4	7.2	340	217.6	38.97	23.47	5.1	1	118.4	62.38	24	24.14
11	19	7.32	280	179.2	42.44	22.03	2.9	1.75	98.8	62.07	9	21.3
12	18.7	7.04	340	217.6	56.35	12.36	3.8	2	114.8	62.13	16	23.79
13	18.6	7.02	360	230.4	39.3	12.33	3.82	1	110.4	59.78	9.4	18.46
14	18.6	6.94	340	217.6	37.67	18.42	5.44	1.25	113.2	61.65	6.7	17.04
15	18.9	6.98	300	192	32.32	16.71	7.35	1.25	109.2	52.3	4.7	18.46
16	17.8	7.03	310	198.4	34.65	22.83	5.15	1.75	114	59.08	4.6	18.5
17	19.5	7.29	360	230.4	37.32	17.75	5	1.75	114	58.07	8.7	16.69
18	19.9	6.98	460	294.4	46.34	18.65	10.3	1	146.4	64.4	21	30.88
19	21.8	6.78	520	332.8	56.3	8.46	24.5	2.25	154	68.15	16	25.9
20	18.5	6.9	400	256	48.2	15.52	5.8	1	126.8	65.85	10	21.66
21	19.1	6.94	410	262.4	49.39	14.89	5.1	1	115.2	83.64	15	23.43
22	19	6.85	370	236.8	33.83	24.15	5.44	1	118.8	61.27	20	24.14
23	19	6.94	420	268.8	36.51	32.6	6.32	1.5	112	69.91	21.1	35.5
24	18.6	6.85	430	275.2	35.62	30.24	7.94	1.75	112	75.55	5.3	31.9
25	18.4	6.82	460	294.4	42.67	24.86	9.56	1.5	120	69.91	9.6	28.4
26	20.5	7.27	390	249.6	40.46	23.43	9.26	1.5	120	65.58	14.4	31.9
27	20.1	7.03	380	243.2	48.2	19.74	1.9	0.75	146	69.65	11	22.72
28	21.4	7.05	360	230.4	55.19	19.91	2.6	2	131.2	93.85	14	20.59
29	20.5	7.11	370	236.8	54	15.99	2.3	1	130	74.72	10	24.14
30	19.8	6.99	450	288	46.03	32.88	4.3	2	169.6	111.5	3	19.88
31	20.7	6.94	400	256	52.87	25.84	2.6	0.75	127.6	70.17	18.5	23.43
32	18.2	7.16	360	230.4	49.39	17.09	4.8	1.75	120	89.5	8	15.62
33	19.5	7.08	350	224	51.48	15.71	5.3	1.25	116.8	62.78	23	22.37
34	19.4	7.05	340	217.6	48.35	18.96	5.1	1.25	121.2	77.89	23	21.66
35	18.8	7.14	300	192	40.12	18.79	6	1.5	127.6	58.55	8.2	22.72
36	18.7	7.05	360	230.4	40.5	25.12	4.8	1.25	132.8	77.44	19	18.5

Appendix B: Physical and chemical analysis of the studied samples in the second period.

Wells No.	TC°	pH	EC µc/cm	TDS mg/l	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	mg/l HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-
1	19.3	7.19	530	339.2	54	39.96	6	7.5	286.4	80	14	35.5
2	20.3	7.41	510	326.4	26.24	24	6.6	19.7	161	66	19	21.33
3	20	7.57	430	275.2	33	29.98	7.4	5.7	144	71.5	23	28.4
4	19.6	7.51	520	332.8	42	34.46	4.12	10.7	180	95.5	12	26.98
5	20.6	7.38	560	358.4	34	46.38	6	17.5	178	98	18	42.6
6	19.8	7.38	550	352	32	38.16	6	10.7	182	79	16	28.4
7	19.1	7.38	610	390.4	36	32.08	6.03	13.5	195.6	83	18	31.95
8	20.3	7.88	430	275.2	42	38.25	4.4	14	212.4	90	11	39.05
9	19.6	7.54	380	243.2	37	33.31	5.1	8	200	89	14	26.62
10	19.5	7.52	470	300.8	35	31.28	6.3	9	141.6	77	23	31.95
11	22	7.9	350	224	39	32.2	3.5	14	160	84	12	21.3
12	19.6	7.5	440	281.6	32	28.27	5.7	18.3	150	72	18	28.4
13	20.2	7.5	470	300.8	24	31.22	5.1	10.75	202.8	81	12	21.3
14	19.2	7.32	410	262.4	36	32.68	6	8	195	89	11	21.3
15	19.7	7.71	560	358.4	35	33.26	6.6	11	162	73.6	9	24.85
16	18.6	7.58	450	288	34	30.25	6.3	11	160	75	12	28.4
17	21	7.32	490	313.6	30	33.55	3.82	13.5	152	85	5.9	29.4
18	21	7.4	740	473.6	38	34.94	12.4	24.5	220	70	20	35.5
19	22.5	7.45	550	352	36	35.01	38.5	12.5	224	120	11	31.95
20	18.5	7.48	540	345.6	35	34.39	9.9	6.75	144	82	18	46.15
21	19.4	7.36	500	320	45	41.04	6.32	10	204	96	62	31.95
22	19.8	7.42	470	300.8	30	45.4	5.4	9.5	168	98	23	24.49
23	24.3	8.16	550	352	30	34.44	7.9	17	177	79	21	21.3

24	19.5	7.35	630	403.2	38	35.95	9.9	22	201	86	14	63.9
25	19.6	7.14	660	422.4	36	34.87	13.1	20	216	75	14	35.5
26	23	7.57	630	403.2	22	32.73	17.5	36	176	82	25	18.46
27	22.7	7.7	470	300.8	42	40.53	1.62	7.5	188	104.5	16	48.28
28	26.3	7.2	560	358.4	43	41.04	2.2	22	203	87.6	17	24.85
29	23.7	7.65	500	320	42	40.82	1.62	10	144	78	62	15.97
30	23	7.8	590	377.6	34	35.39	7.9	37	204	88.5	10	31.97
31	24	7.44	510	326.4	41	36.63	1.62	11	164	79.6	26	27.33
32	20.6	8.42	580	371.2	39	36.67	3.53	15	172	89	9.9	42.6
33	20.6	7.55	480	307.2	35	29.47	3.82	13	156	76.7	26	20.52
34	20.5	7.58	470	300.8	42	36.83	5.14	14	205	80	10	35.5
35	20.3	7.63	430	275.2	29.6	34.67	5.2	18	184	81	12	22.72
36	18.7	7.54	490	313.6	33	38.04	5.15	18	202	101	25	21.3

Appendix C: Calculated parameters of water quality in the study area for both periods.

Well	First Period						Second Period					
No.	SAR	NA%	RSC	MR	RSBC	PI	SAR	NA%	RSC	MR	RSBC	PI
1	0.12	4.46	-2.16	0.67	-0.36	4.14	0.15	7.04	-1.29	1.22	2.00	4.53
2	0.16	6.70	-1.55	1.02	0.12	6.23	0.22	19.41	-0.64	1.51	1.33	8.49
3	0.14	5.56	-1.76	1.23	0.28	5.30	0.22	10.21	-1.75	1.50	0.71	7.60
4	0.12	4.64	-1.91	1.11	0.16	4.39	0.11	8.41	-1.98	1.35	0.85	3.84
5	0.15	5.54	-1.88	1.03	0.11	5.30	0.16	11.39	-2.59	2.25	1.22	4.82
6	0.14	5.18	-2.15	1.47	0.22	5.07	0.17	10.14	-1.75	1.97	1.39	5.57
7	0.12	4.37	-2.35	1.27	0.15	4.16	0.18	12.05	-1.23	1.47	1.41	5.96
8	0.15	6.82	-0.90	1.08	0.55	6.49	0.12	9.49	-1.76	1.50	1.39	3.87
9	0.20	7.87	-1.77	1.24	0.01	7.53	0.15	8.51	-1.31	1.48	1.43	4.99
10	0.16	6.00	-1.93	0.99	0.00	5.75	0.19	10.45	-2.00	1.47	0.57	6.30
11	0.09	4.17	-2.31	0.86	-0.50	3.42	0.10	9.99	-1.97	1.36	0.68	3.55
12	0.12	5.35	-1.95	0.36	-0.93	4.48	0.18	15.44	-1.46	1.46	0.86	6.32
13	0.14	6.18	-1.17	0.52	-0.15	5.72	0.16	37.11	-0.44	2.14	2.13	6.02
14	0.18	7.33	-1.54	0.81	-0.02	6.89	0.17	9.40	-1.29	1.50	1.40	5.88
15	0.26	10.53	-1.20	0.85	0.18	10.07	0.19	11.25	-1.83	1.57	0.91	6.36
16	0.17	6.93	-1.74	1.09	0.14	6.20	0.19	11.71	-1.56	1.47	0.93	6.51
17	0.17	7.32	-1.45	0.78	0.01	6.53	0.11	10.72	-1.77	1.84	0.99	4.11
18	0.32	10.96	-1.45	0.66	0.09	10.79	0.35	19.64	-1.16	1.52	1.71	10.51
19	0.80	24.27	-0.98	0.25	-0.29	23.66	1.10	29.90	-1.01	1.60	1.88	26.67
20	0.19	7.02	-1.60	0.53	-0.33	6.78	0.28	11.65	-2.22	1.62	0.61	8.91
21	0.16	6.28	-1.80	0.50	-0.58	6.02	0.16	8.62	-2.28	1.50	1.10	4.97
22	0.17	6.66	-1.73	1.18	0.26	6.41	0.15	8.37	-2.48	2.50	1.26	4.60
23	0.18	6.50	-2.67	1.47	0.01	6.04	0.23	15.24	-1.43	1.89	1.40	7.72
24	0.24	8.38	-2.43	1.40	0.06	7.78	0.28	16.99	-1.56	1.56	1.40	8.49
25	0.29	9.81	-2.21	0.96	-0.16	9.36	0.37	18.82	-1.12	1.60	1.74	11.24
26	0.29	10.05	-1.98	0.95	-0.05	9.58	0.55	30.73	-0.91	2.45	1.79	17.10
27	0.06	2.46	-1.64	0.68	-0.01	2.39	0.04	4.61	-2.35	1.59	0.99	1.60
28	0.08	3.60	-2.24	0.59	-0.60	2.84	0.06	10.65	-2.19	1.57	1.18	2.03
29	0.07	3.04	-1.88	0.49	-0.56	2.79	0.04	5.64	-3.09	1.60	0.26	1.55
30	0.12	4.55	-2.22	1.18	0.48	3.93	0.23	21.87	-1.26	1.72	1.65	7.31
31	0.07	2.70	-2.67	0.81	-0.55	2.62	0.04	6.50	-2.37	1.47	0.64	1.69
32	0.15	6.15	-1.90	0.57	-0.50	5.46	0.10	9.77	-2.14	1.55	0.87	3.33
33	0.17	6.37	-1.95	0.50	-0.65	5.97	0.12	10.68	-1.61	1.39	0.81	4.20
34	0.16	6.01	-1.99	0.65	-0.43	5.62	0.14	10.19	-1.77	1.45	1.26	4.52
35	0.20	7.78	-1.46	0.77	0.09	7.23	0.15	13.69	-1.31	1.93	1.54	5.35
36	0.15	5.56	-1.91	1.02	0.16	5.20	0.14	12.53	-1.47	1.90	1.66	4.84