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Study and Evaluation of Certain Chemical Properties of Well Water in Some Villages North of Al-Dur District

Iqbal Ali Hassani, Abid Ahmed Erdeni

Department of Biology, College of Education for Women, University of Tikrit, Iraq.
Email: iqbal.Hasani27@st.tu.ed

The current study was conducted at the University of Tikrit, College of Education for Women, Department of Life Sciences. It involved a field study of the physical and chemical properties of groundwater in the north of Al-Dur district (Na'ima area), aiming to determine the quality of this water. The study began in September 2023 and concluded in February 2024. Seven wells in the study area were selected. Part of the tests was conducted at the Salah Al-Din Water Directorate, Quality Control Division, and the other part in the laboratories of the College of Chemical Engineering and the College of Environmental Engineering at the University of Tikrit. The study included the analysis of some chemical properties (pH, total dissolved solids, suspended solids, total alkalinity, total hardness, biochemical oxygen demand, chloride ion, sulfate ion, sodium ion, potassium ion, calcium ion, magnesium hardness, and nitrates). The results were compared based on international and Iraqi standards. The pH values ranged from a minimum of 6.37 to a maximum of 8.4, with averages between 7.190 and 7.62, indicating slightly acidic to slightly basic conditions within the Iraqi water standards. Salinity ranged from 0.12 to 0.25 g/L, meeting the Iraqi drinking water standard of 0.5 mg/L. Total dissolved solids ranged between 1380.2 and 1903.0 mg/L. Suspended solids had a maximum value of 2.04 mg/L and a minimum value of 0.63 mg/L. Total alkalinity ranged between 60 and 120 mg/L, while total hardness ranged from 1843.3 to 2357.5 mg/L, classifying the well water as very hard. Biochemical oxygen demand ranged between 0.6833 and 1.3833 mg/L. Chloride ranged from 29.974 to 132.342 mg/L, and sulfate levels were high, ranging from 1891 to 2477 mg/L.

Keywords: water quality, well water.

1. Introduction

Since ancient times, humans have recognized the importance of water as an essential element for the life of all living organisms, making water the lifeblood necessary for economic and social development. Without water, such development becomes impossible. Due to increasing water demand, water resources have been continuously decreasing (Al-Janabi, 2008). It is crucial to continuously monitor water resources and conduct qualitative studies on different water sources (Ismail et al., 2020).

Water is a primary component of cells, necessary for enzymatic function, and is involved in all chemical and biological reactions within an organism's body, comprising 80% of the living mass, and up to 99% in some plants (Al-Saadi, 2002). Groundwater, the second main source of potable water, is stored underground between soil and rock pores, filtering down through the soil to lower layers. Its depth varies depending on the geological formation (Al-Kalabi, 2016). Areas lacking surface water may rely heavily on groundwater, making its study essential for providing an important water source for agricultural, industrial, economic, and domestic uses (Al-Sahaf et al., 1983; Abbas, 2010). Studying groundwater is crucial for understanding its physical and chemical properties, which determine water quality and suitability, including dissolved elements and ions (Yuping et al., 2016).

2. Study Objectives:

1. To study the physical and chemical properties of well water in some villages north of Al-Dur district.

2. To determine the suitability of well water for human and animal consumption and irrigation.

3. Materials and Method

Description of the Studied Wells

Seven wells were selected and are described as follows. The ages of the wells ranged from 1 to 30 years, the diameters of the casing pipes were 8 inches, and the diameters of the extraction pipes ranged from 3 to 4 inches. The study area is located 16.736 kilometers away from the Tigris River, measured from the farthest well in the study area. The wells are distributed at varying distances, with the distance between each well being no less than 500 meters and exceeding 100 meters. The depths of the wells ranged between 80 to 100 meters, classified as deep wells, drilled mechanically and of the closed type (Al-Sayegh and Al-Omari, 1999).

Well No. 1

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 85 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 8 inches and an extraction pipe diameter of 4 inches. The well is 1 years old and 15,876 kilometers away from the Tigris River, used for irrigation and livestock.

Well No. 2

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 93 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 10 inches and an extraction pipe diameter of 4 inches. The well is 3 years old and 15,919 kilometers away from the Tigris River, used for irrigating crops such as wheat, barley, and alfalfa, as well as for livestock.

Well No. 3

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is

100 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 10 inches and an extraction pipe diameter of 4 inches. The well is 2 years old and 15,316 kilometers away from the Tigris River, used for irrigation and livestock.

Well No. 4

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 100 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 10 inches and an extraction pipe diameter of 4 inches. The well is 23 years old and 14,985 kilometers away from the Tigris River, used for irrigation, livestock, and domestic purposes.

Well No. 5

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 93 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 8 inches and an extraction pipe diameter of 4 inches. The well is 3 years old and 15,766 kilometers away from the Tigris River, used for irrigation, livestock, and domestic purposes.

Well No. 6

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 100 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 8 inches and an extraction pipe diameter of 4 inches. The well is 3 years old and 16,488 kilometers away from the Tigris River, used for irrigation, livestock, and domestic purposes.

Well No. 7

Located north of Al-Dour district (Al-Naama subdistrict) within the study area, this well is 100 meters deep, drilled mechanically, closed type, with a casing pipe diameter of 8 inches and an extraction pipe diameter of 4 inches. The well is 7 years old and 16,216 kilometers away from the Tigris River, used for irrigation and livestock.

Sample Collection

Samples were collected from the studied wells during the study period from September 2023 to February 2024, at a rate of once a month. Water was pumped from the well for 10 minutes to eliminate stagnant and polluted water, then the samples were collected in 5-liter polyethylene bottles after washing them three times with the sample water at each well. Air and water temperatures were measured on-site, and 250 ml dark bottles were filled for each well to measure Biological Oxygen Demand (BOD). Other tests were conducted in the laboratory, including the following physical and chemical tests:

Chemical Properties

pH Measurement

The pH was measured using a PH/CON 510 series Okton, Cole Parmer, USA, after calibration with buffer solutions of pH 4, 7, and 9 at the start of each measurement.

Salinity

Salinity was measured based on the electrical conductivity values of the samples according to the method of Goltermant et al. (1978). The results were expressed in g/L using the formula:

Salinity (g/L) = (14.78 - Conductivity (μS/cm)) / 1589.08

Total Dissolved Solids (TDS)

TDS was measured in the laboratory using a HANNA TDS meter by immersing the electrode in the sample water in a special container for two minutes until the reading stabilized, then recording the result in mg/L.

Total Suspended Solids (TSS)

TSS was measured according to the method of the American Public Health Association (APHA, 2003) by filtering 100 ml of the sample through a 0.45 μm filter paper after pre-weighing (B). The paper was dried in an oven at 103-105°C for three hours, then weighed again (A). The results were expressed in mg/L.

Total Alkalinity

Total alkalinity was measured using the method described by APHA (2003) and expressed in mg/L by taking 50 ml of the sample, adding three drops of methyl orange indicator, and titrating with 0.02N sulfuric acid until the color changed to reddish-orange. The results were averaged over two readings and calculated as calcium carbonate (CaCO3) using the formula: Total Alkalinity (mg/L) = (V_{H2SO4} * N_{H2SO4} * 1000 * Mole-wt as CaCO3) / V_sample

Total Hardness

Total hardness was measured using the method of Lind (1979) by taking 5 ml of the sample, diluting to 25 ml with distilled water, and titrating with 0.02N Na2EDTA after raising the pH to 10 with 1 ml of ammonia buffer solution and adding a spoonful of Erichrom Black-T. The results were expressed in mg/L using the formula: Total Hardness (mg/L) = (V_{Na2EDTA} * N_{Na2EDTA} * 1000 * M.W as CaCO3) / V_sample

Biological Oxygen Demand (BOD)

BOD was measured by incubating dark Winkler bottles for five days at 25°C in a water bath, then determining the dissolved oxygen (DO5). The difference between the initial dissolved oxygen (DO0) and DO5 represented the BOD5 in mg/L (APHA, 2005): BOD5 = DO0 - DO5

Chloride Ion (Cl-)

Chloride ion was measured according to the American Society for Testing and Materials (ASTM, 1984) by taking 50 ml of the sample, adding two drops of potassium chromate, and titrating with 0.0141N silver nitrate solution until the color changed to cloudy yellow. Chloride concentration was calculated using the formula: Chlorinity (mg/L) = (V_{AgNO3} * N_{AgNO3} * 1000 * Mole-wt as CaCO3) / V_sample

Sulphate Ion (SO_4)

Sulphate ions were measured using a Turbidity meter by taking 1 ml of the sample, diluting to 100 ml with distilled water, adding 5 ml of conditioning reagent, stirring with a magnetic stirrer for one minute, then adding 0.26 grams of barium chloride and stirring for another minute. The sample was placed in a turbidity meter, and the result was recorded and calculated using the formula: Sulphate concentration (mg/L) = (second reading * 100 * 0.20) + 11.66

Sodium Ion (Na^+)

Sodium ions were measured using a SHIMADZU AA-6200 Atomic Absorption Spectrophotometer in the Department of Chemical Engineering Laboratory at Tikrit University after calibration with a standard sodium solution provided by the manufacturer. Results were expressed in mg/L.

Potassium Ion (K^+)

Potassium ions were measured using a SHIMADZU AA-6200 Atomic Absorption Spectrophotometer in the Department of Chemical Engineering Laboratory at Tikrit University after calibration with a standard potassium solution provided by the manufacturer. Results were expressed in mg/L.

Calcium Hardness

Calcium hardness was measured using the method of APHA (200) by taking 5 ml of the sample, diluting to 50 ml with distilled water, titrating with 2 ml of sodium hydroxide and adding a spoonful of Murexide indicator. The results were expressed in mg/L using the formula: Calcium Hardness (mg/L) = $(V_{Na2EDTA} * N_{Na2EDTA} * 1000 * M.W \text{ as } CaCO_3) / V_{sample}$

Magnesium Hardness

Magnesium hardness was calculated as the difference between total hardness and calcium hardness according to APHA (2005) and expressed in mg/L using the formula: Magnesium Hardness (mg/L) = [Total Hardness - (Calcium Hardness * 2.5)] * 0.244

4. Results and Discussion

Chemical Properties

pH Level

Table 4-5 shows the spatial and temporal variability of pH values, with the lowest value (6.37) recorded in well 2 in November and the highest value (8.4) recorded in September. The average pH values did not differ significantly spatially but showed significant temporal differences, particularly in September and February, according to Duncan's test at the $p \leq 0.05$ level. Generally, pH values ranged from slightly acidic to slightly basic, falling within the Iraqi water standards of 6.5-8.5, as shown in the appendix.

Table 4-1: pH Levels

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	8.4	7.7	7.7	8.0	8.0	8.0	7.8	7.943 A
Oct. 2023	7.1	7.2	7.35	7.29	6.5	7.3	7.11	7.121 C
Nov. 2023	7.05	6.37	6.55	7.15	7.76	7.8	7.4	7.154 C
Dec. 2023	7.8	7.76	7.15	6.55	6.37	7.05	7.1	7.111 C
Jan. 2024	7.97	7.25	7.44	7.52	7.21	7.1	7.31	7.400 BC
Feb. 2024	7.45	7.91	7.95	7.86	7.3	7.37	7.32	7.594 B
Well Avg.	7.628 a	7.365 a	7.357 a	7.395 a	7.190 a	7.437 a	7.340 a	

These findings are consistent with Al-Tarshan (2017), Ibrahim (2015), and Al-Jamili (2021), who reported pH ranges between 7.31-7.55, 7.52-7.78, and 7.41-7.48, respectively. The pH values can be attributed to the geological composition of the area, where the well water is slightly basic due to limited direct atmospheric influence, causing CO2 dissolution in the water and high regulatory capacity of hard water (Al-Jamili, 2011).

Salinity

Water salinity is due to various ions like sodium, magnesium, carbonates, sulfates, chlorides, and potassium, which are crucial for the osmotic regulation of cells (Al-Saadi, 2002). As shown in Table 4-6, salinity values ranged between 0.1400-0.1717 g/L, with the highest value (0.25 g/L) recorded in October in well 2 and the lowest value (0.12 g/L) recorded in January in wells 4 and 5 and February in well 3. Statistical analysis using Duncan's test showed no significant spatial differences but significant temporal differences at the $p \leq 0.05$ level. The results are similar to Darwish (2011) and Hamed (2021), who reported ranges of 0.205-0.913 g/L and 0.59-0.22 g/L, respectively, but lower than Ahmed (2018) and Al-Tarshan (2017), who found ranges of 2.86-3.34 g/L and 1.37-1.87 g/L, respectively. The well water conformed to the Iraqi drinking water standards of 0.5-1 g/L, not exceeding 2 g/L for industrial and animal irrigation purposes (Montgomery, 2003).

Table 4-2: Salinity

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	0.22	0.23	0.2	0.21	0.16	0.16	0.14	0.1886 AB
Oct. 2023	0.21	0.25	0.21	0.21	0.2	0.16	0.13	0.1957 A
Nov. 2023	0.19	0.13	0.21	0.14	0.17	0.16	0.13	0.1614 B
Dec. 2023	0.14	0.13	0.13	0.13	0.13	0.14	0.14	0.1343 D
Jan. 2024	0.13	0.13	0.13	0.12	0.12	0.16	0.14	0.1329 D
Feb. 2024	0.14	0.14	0.12	0.14	0.14	0.16	0.16	0.1429 CD
Well Avg.	0.1717 a	0.1683 a	0.1667 a	0.1583 a	0.1533 a	0.1567 a	0.1400 a	

Total Dissolved Solids (TDS)

The concentration of total dissolved solids (TDS) in water indicates water quality, with lower values being preferable for various uses (Ahmed, 2018). Table 4-7 shows that TDS values ranged between 1384.2-1903.0 mg/L, with the highest value (2080 mg/L) recorded in November in well 1 and the lowest value (1260 mg/L) recorded in January in well 7. Statistical analysis using Duncan's test revealed significant spatial differences for each well but no significant temporal differences during the study period. These results are consistent with Al-Tarshan (2017), who reported a range of 2149.27 mg/L in December in well 2 to 1290.71 mg/L in March in well 9. However, the results were higher than those found by Hamed (2021), who reported TDS values between 184-466 mg/L, but lower than Ahmed (2018) and Al-Abeidi (2010), who reported 4900 mg/L and 5416 mg/L, respectively. The study's results did not meet the Iraqi drinking water standards of 430-1000 mg/L.

Table 4-3: Monthly Variations in TDS of Well Water (mg/L)

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	1950	1980	1880	1960	2010	1570	1420	1824.3 A
Oct. 2023	1970	1760	1850	1950	2020	1680	1440	1810.0 A
Nov. 2023	2080	1780	1970	2020	2100	1630	1450	1861.4 A
Dec. 2023	1860	1730	1890	1970	2040	1660	1460	1801.4 A
Jan. 2024	1420	1630	1290	1531	1590	1410	1260	1447.3 B
Feb. 2024	1514	1699	1304	1422	1658	1439	1275	1473.0 B
Well Avg.	1799.0 b	1763.2 c	1697.3 d	1808.8 b	1903.0 a	1564.8 e	1384.2 f	

Total Suspended Solids (TSS)

Table 4-4 shows the spatial variability of TSS values, with the highest value recorded as 2.04 mg/L in well 7 in November and the lowest value of 0.63 mg/L in well 2 in September. The average TSS values for the wells ranged between 0.9117 to 1.765 mg/L. Statistical analysis revealed no significant temporal differences in TSS values during the study period but did show significant spatial differences. These results are lower than those found by Al-Jamili (2021), who recorded a maximum value of 20.57 mg/L and a minimum value of 14.90 mg/L.

Table 4-5: Total Suspended Solids

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	1.06	0.63	0.84	0.97	0.97	1.12	1.57	1.0229 A
Oct. 2023	1.19	0.68	0.87	0.96	1.36	1.19	1.67	1.1314 A
Nov. 2023	1.13	0.77	0.84	1.84	1.14	1.08	2.04	1.2629 A
Dec. 2023	1.19	0.81	0.86	1.08	1.26	1.19	1.77	1.1657 A
Jan. 2024	1.36	1.59	1.13	1.25	1.5	1.22	1.51	1.3657 A
Feb. 2024	1.36	0.99	1.09	1.24	1.44	1.3	2.03	1.3500 A
Well Avg.	1.215 b	0.9117 c	0.9383 c	1.2233 b	1.2783 b	1.1833 b	1.765 a	

Total Alkalinity

Limestone and dolomite rocks are natural sources of alkalinity (Negwa et al., 2016). Statistical analysis using Duncan's test revealed significant temporal and spatial differences at the $p \leq 0.05$ level. Table 4-9 shows alkalinity values ranging from 76.3 to 90.3 mg/L in wells 1 and 5, with the highest value of 120 mg/L recorded in January in well 2 and the lowest value of 60 mg/L recorded in October in wells 4, 6, and 7, and in November in wells 3, 4, and 7, and in January in well 3. These results are lower than those found by Darwish (2011), Ibrahim (2015), and Hamed (2021), who reported alkalinity ranges of 208-540 mg/L, 111.1-151.6 mg/L, and 160.2-187.2 mg/L, respectively. The lower alkalinity values may be due to the geological nature and rocks the groundwater passes through, varying based on the source of carbonates and bicarbonates contributing to water alkalinity (Al-Safawi, 2018). The current study's alkalinity values fall within the Iraqi drinking water standards of 250 mg/L (Central Organization for Standardization and Quality Control, 6199).

Table 4-6: Total Alkalinity

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	90	70	110	100	110	90	90	94.3 A
Oct. 2023	68	70	64	60	80	60	60	66.0 C
Nov. 2023	70	75	60	60	74	70	60	67.0 C
Dec. 2023	80	90	100	82	88	90	100	90.0 B
Jan. 2024	70	120	60	100	90	80	110	90.0 B
Feb. 2024	80	100	90	70	100	84	90	87.7 B
Well Avg.	76.3 b	87.5 a	80.7 b	78.7 b	90.3 a	79.0 b	85.0 a	

Total Hardness

Table 4-10 shows that total hardness values ranged between 1843.3-2357.5 mg/L in wells 4 and 6, respectively. The highest total hardness value recorded was 3335 mg/L in well 6 in February, and the lowest value was 1150 mg/L in well 4 in September. Statistical analysis indicated significant temporal differences between September and February and significant spatial differences between wells 6 and 4 at the $p \leq 0.05$ level. The current study's results are higher than those found by Hamed (2021) and Dawood (2022), who reported total hardness ranges of 165.8-345.1 mg/L and 200.0-654.0 mg/L, respectively, but consistent with Majid and Fadel (2009), who reported groundwater hardness values between 1300-3500 mg/L in a study on groundwater usability in parts of Fallujah city. Total hardness is an indicator of calcium, magnesium, and bicarbonate ions, with hardness values varying based on the water source, being lower in surface water than groundwater, and depending on the geological nature of the area (Ibrahim, 2015). The well water studied was classified as very hard according to Todd (1980), attributed to the calcareous nature of Iraqi soil. The well water hardness values did not meet the proposed drinking water standards and the Iraqi and international drinking water standards of 250-500 mg/L (Central Organization for Standardization and Quality Control, 1996; CEOH, 2003; US-EPA, WHO, 1996).

Table 4-7: Total Hardness

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	1610	1725	1610	1150	1380	1610	1380	1495.0 E
Oct. 2023	2070	2350	2070	1285	1610	2300	1840	1932.1 D
Nov. 2023	1840	1955	2070	2185	2300	2530	2070	2135.7 C
Dec. 2023	2070	2530	2185	2300	2530	1840	2070	2217.9 B
Jan. 2024	2530	2300	2070	1955	1840	2530	2645	2267.1 B
Feb. 2024	1840	2530	2645	2185	2300	3335	3174	2572.7 A
Well Avg.	1993.3 e	2231.7 b	2108.3 d	1843.3 f	1993.3 e	2357.5 a	2196.5 c	

Biological Oxygen Demand (BOD)

Biological Oxygen Demand (BOD) is one of the most important indicators of organic pollution when assessing water quality. It indicates the amount of oxygen required by living organisms to perform organic decomposition over a specific period under aerobic conditions (Gupta et al., 2017).

Table 4-8 shows that BOD levels ranged between 0.6833-1.3833 mg/L, with the highest BOD value recorded in the studied wells being 3.9 mg/L and the lowest being 0.0 mg/L. The current results are consistent with Hamed (2021), who reported BOD values ranging between 0.43-

1.25 mg/L, and higher than those found by Al-Jubouri (2017), who reported values between 0.43-0.62 mg/L. Statistical analysis using Duncan's test indicated no significant spatial differences but significant temporal differences at the $p \leq 0.05$ level. The low BOD values are attributed to the filtration processes the water undergoes as it percolates through rock layers, the wells' distance from pollution sources like factories and sewage, and the continuous renewal of water used for irrigating crops and livestock. The results meet the World Health Organization (WHO) standards of less than 5 mg/L (Appendix).

Table 4-8: Biological Oxygen Demand (BOD)

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
17/9/2023	1.4	1.3	0.0	0.5	0.9	0.0	0.0	0.5857 C
17/10/2023	1.3	0.2	0.3	0.0	1.2	0.5	0.3	0.5429 C
15/11/2023	1.1	0.5	0.2	0.6	0.0	0.2	0.9	0.5000 C
21/12/2023	0.4	0.9	0.6	0.2	0.0	0.7	0.5	0.4714 C
22/1/2024	0.6	1.5	1.6	1.9	0.8	0.9	1.2	1.2143 B
12/2/2024	2.5	3.9	2.5	2.0	1.5	1.8	1.2	2.2000 A
Well Avg.	1.2167 a	1.3833 a	0.8667 b	0.8667 b	0.7333 b	0.6833 b	0.6833 b	

Chloride Ion (Cl-)

Table 4-9 shows that chloride ion concentrations ranged from 29.974-32.345 mg/L in wells 1 and 6, respectively. The lowest chloride value was 13.536 mg/L in well 6 in October, and the highest value was 63.16 mg/L in well 2 in September. Statistical analysis using Duncan's test showed no significant spatial differences but significant temporal differences at the $p \leq 0.05$ level. The results are consistent with Al-Qaragholi (2018) and Al-Abeidi (2010), who reported chloride ranges of 36.3-79.7 mg/L and 33.9-69.6 mg/L, respectively, but higher than Hamed (2021), who reported ranges of 11.88-27.00 mg/L. The results are lower than those found by Ahmed (2018) in a study on desalination of well water in the Al-Alam area of Salahuddin, which reported ranges of 142.9-820 mg/L. The variations in chloride ion values during the study period are due to climatic differences between summer and winter and the dilution effect from rainfall (Hamed, 2021). The chloride ion values in the current study comply with the US-EPA standards of 250 mg/L and the Iraqi drinking water standards (Appendix).

Table 4-9: Chloride Ion

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	40.23	63.16	46.15	52.64	53.64	46.24	46.06	49.731 A
Oct. 2023	14.1	14.194	14.664	15.794	17.484	13.536	15.886	15.094 D
Nov. 2023	26.226	21.526	19.928	29.798	22.56	20.586	21.714	23.191 C
Dec. 2023	35.636	34.22	34.456	35.754	26.668	37.878	38.586	34.743 B
Jan. 2024	36.58	29.14	37.76	29.97	33.39	39.17	28.9	33.559 B
Feb. 2024	27.072	31.584	32.242	22.654	30.08	36.66	38.72	31.287 B
Well Avg.	29.974 a	32.304 a	30.867 a	31.102 a	30.637 a	32.345 a	31.644 a	

Sulphates (SO_4)

The study results for well water, as shown in Table 4-10, indicate that sulphate levels ranged between 1891-2447 mg/L during the study period, with wells 7 and 4 showing these respective values. The highest sulphate concentration (3111 mg/L) was recorded in well 6 in January, while the lowest value (1561 mg/L) was noted in well 7 in September. Statistical analysis using Duncan's test revealed significant spatial and temporal differences in the studied wells at a significance level of $p \leq 0.05$. The current results are higher than those found by Hamad (2017) and Dawood (2022), who reported sulphate levels ranging from 480-1350 mg/L and 7.66-29.33 mg/L, respectively. However, the results are comparable to those of Jebril (2006), who reported a maximum sulphate ion concentration of 4071 mg/L in her study on groundwater quality in Hilla. The high sulphate concentrations in the studied well water could be due to the proximity to the Hamrin Mountain range and the gypsum nature of the land, along with agricultural sources and animal waste from livestock areas. Sulphate concentrations in groundwater often increase with depth due to the dissolution of evaporite rocks in contact with groundwater (Al-Youzbeki and Youssef, 2007). The study's sulphate levels did not meet the standards set by the US Environmental Protection Agency (US-EPA) (2018) and the Iraqi Central Organization for Standardization and Quality Control (1996), which are 250 mg/L.

Table 4-10: Sulphates

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	2411	2311	2331	2491	2091	1833	1561	2147.0 C
Oct. 2023	2291	2951	2051	2851	2780	1757	2001	2383.1 B
Nov. 2023	2431	2031	2511	2071	2551	2991	1971	2365.3 B
Dec. 2023	2031	1641	1891	2151	1731	1851	1891	1883.9 D
Jan. 2024	2611	2411	2471	2211	2611	3111	2031	2493.9 A
Feb. 2024	2251	2651	2211	2911	2831	1951	1891	2385.3 B
Well Avg.	2337.7 b	2332.7 b	2244.3 c	2447.7 a	2432.5 a	2249 c	1891 d	

Sodium Ions (Na^+)

Table 4-11 shows that the highest recorded sodium ion concentration was 96.27 mg/L in November in well 4, while the lowest concentration was 59.4 mg/L in well 7. The average sodium ion concentrations during the study period ranged between 64.537-87.785 mg/L in wells 7 and 5, respectively. The study's findings are consistent with those of Awadh and Al-Kilabi (2014), who reported ranges of 28.1-74.5 mg/L, and lower than those recorded by Ibrahim (2010) and Mahdi (2008), who reported sodium concentrations of 618 and 900 mg/L, respectively. Statistical analysis revealed significant temporal and spatial differences in sodium ion concentrations between the wells and study months according to Duncan's test, with notable differences between September and February and between wells 7 and 5. The presence of sodium ions in groundwater is due to rock salt in geological formations, and water releases sodium ions when it does not reach sodium minerals and in the presence of bicarbonates (Abdullah and Hussein 2015; Khan et al., 2020). Sodium ion concentration increases in winter with rainfall, which washes soil and carries sodium ions, and in summer due to higher evaporation rates (Alexander, 2008). The study's sodium ion concentrations comply with the Iraqi drinking water standards of 200 mg/L (Central Organization for Standardization and Quality Control, 2001) and international standards (CEOH, 2003; US-EPA, 2002; WHO, 2004).

Table 4-11: Sodium Ions

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	87.54	78.81	82.98	91.18	93.36	70.32	59.4	80.513 AB
Oct. 2023	82.1	70.44	75.23	90.71	91.55	71.12	64.72	77.981 AB
Nov. 2023	93.35	74.71	92.94	96.27	94.43	71.98	65.95	84.233 A
Dec. 2023	89.34	71.63	86.9	86.25	89.52	79.18	71.81	82.090 A
Jan. 2024	70.21	72.1	70.12	65.9	75.4	60.13	61.72	67.940 C
Feb. 2024	78.35	79.15	68.47	70.9	82.45	69.44	63.62	73.197 BC
Well Avg.	83.482 ab	74.473 cd	79.440 bc	83.535 ab	87.785 a	70.362 de	64.537 e	

Potassium Ions (K^+)

Table 4-12 shows that the highest potassium ion concentration recorded during the study was 9.7 mg/L in well 4 in November, and the lowest was 5.27 mg/L in well 3 in February. The average potassium ion concentrations ranged between 6.2333-8.6717 mg/L in wells 7 and 5, respectively. Statistical analysis using Duncan's test indicated significant spatial differences between the studied wells but no significant temporal differences at the $p \leq 0.05$ level. The study's findings are consistent with those of Al-Dulaimi (2015), who reported a maximum potassium ion concentration of 12.34 mg/L and a minimum of 8.81 mg/L. The current study's results are higher than those found by Hamed (2021) and Al-Tarshan (2017), who reported potassium ion ranges of 0.85-1.61 mg/L and 2.4-5.1 mg/L, respectively. Potassium ion concentrations are generally much lower than other cations, especially sodium ions, due to potassium's high resistance to weathering and its adsorption by soil layers, which reduces its concentration (Ibrahim and Nofal, 2020).

Table 4-12: Potassium Ions

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	7.94	8.5	8.32	8.79	9.44	7.19	6.34	8.0743 A
Oct. 2023	7.53	8.26	8.75	7.9	9.53	7.25	6.28	7.9286 A
Nov. 2023	7.06	7.43	9.16	9.7	9.69	6.64	6.14	7.9743 A
Dec. 2023	6.84	7.11	8.45	8.7	9.27	7.23	5.94	7.6486 AB
Jan. 2024	7.62	8.71	6.42	6.8	6.95	6.32	6.7	7.0743 B
Feb. 2024	7.96	8.54	5.27	6.66	7.15	6.34	6.0	6.8457 B
Well Avg.	7.4917 bc	8.0917 ab	7.7283 b	8.0917 ab	8.6717 a	6.8283 cd	6.2333 d	

Calcium Hardness

Table 4-13 shows that the calcium hardness rates during the study period ranged from 333.58 to 394.17 mg/L. The highest value recorded was 602 mg/L in well 4 in February, while the lowest value was 215 mg/L in wells 4, 6, and 7 in September. These results are higher than those reported by Fattah (2015) and Hamed (2021), which ranged between 165-601 and 68.25-102.37 mg/L respectively. However, the current results are lower than those found by Hamad (2017) and Ibrahim (2015), who reported ranges of 478.7-614.4 and 744.4-922.2 mg/L respectively. The statistical analysis using Duncan's test indicated a significant spatial difference between wells 1 and 2, and a significant temporal difference between September and February at a significance level of ($p \leq 0.05$). The high calcium hardness recorded during the study period can be attributed to the geological composition of the studied area, rich in limestone rocks, with calcium constituting 30.23% of sedimentary rocks (Turshan, 2017). The calcium values during the study period did not comply with the Iraqi drinking water standards (Central Organization for Standardization and Quality Control, 1996) and the global standard of 50 mg/L (Appendix Table).

Table (4-13) Calcium Hardness

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	236.5	279.5	279.5	215	258	215	215	242.64 D
Oct. 2023	387	301	236.5	322.5	344	301	215	301.00 C
Nov. 2023	473	301	332.5	430	516	387	516	422.21 B
Dec. 2023	236.5	258	344	258	279.5	301	279.5	279.50 C
Jan. 2024	516	432	473	344	387	408.5	365.5	418.00 B
Feb. 2024	516	430	473	602	516	580	559	525.14 A
Well Avg.	394.17a	333.58c	356.42b	361.92b	383.42a	365.42b	358.33b	

Magnesium Hardness

According to Table (4-14), the magnesium hardness rates ranged from 232.65 to 344.91 mg/L in wells 4 and 6 respectively. The highest value was 459 mg/L in well 2 in December, while the lowest was 134.2 mg/L in February in well 1. Statistical analysis using Duncan's test showed significant temporal and spatial differences at a significance level of ($p \leq 0.05$). The current study's results were comparable to those by Turshan (2017), which ranged between 386.33-505.92 mg/L in wells 8 and 7 respectively, but higher than those by Dawood (2022) in a study of groundwater quality in Al-Dur district, with magnesium hardness ranging from 8.00-220.00 mg/L in wells 5 and 7. It was also higher than Mansour's (2021) study on the physical, chemical, and biological properties of groundwater in Kirkuk, with magnesium hardness ranging from 18.0-113.0 mg/L.

Table (4-14) Magnesium Hardness

Date	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Monthly Average
Sep. 2023	248.5	250.4	222.3	149.4	179.3	261.6	205.5	216.71 D
Oct. 2023	269	389.7	284	139.6	169.5	377.5	317.8	278.16 C
Nov. 2023	160.4	293.4	413.2	270.8	246.4	337.3	190.3	273.11 C
Dec. 2023	360.8	459	323	403	446	265	334.5	370.19 A
Jan. 2024	302.5	298.9	216.6	267.18	212.89	368.14	422.4	298.37 C
Feb. 2024	134.2	355	356.8	165.9	246.4	459.9	433.5	336.25 B
Well Avg.	268.24c	341.07a	302.65b	232.65d	250.08cd	344.91a	317.33ab	

The high magnesium hardness levels are due to the increased dissolution and decomposition of geological formations containing gypsum and limestone in the study area (Lerner, 2015). The magnesium hardness values in this study did not meet the Central Organization for Standardization and Quality Control (1996) standards, which are 50 mg/L (Appendix).

5. Conclusions

1. The variations in air temperature in September and January are due to temperature differences, while water temperatures had a narrow range of fluctuation.
2. Based on the Biological Oxygen Demand values, the wells are classified as clean water.

3. Sulfate levels were high and did not meet the global and Iraqi standards.
4. Calcium, magnesium, and total hardness values did not comply with the Iraqi drinking water standards.
5. Sodium, potassium, and chloride levels were within the Iraqi drinking water standards.

6. Recommendations

1. Implement an organized and correct method for using groundwater and educate farmers to use this water according to their needs to prevent soil salinization.
2. Find appropriate methods for treating groundwater, especially for domestic use.
3. Conduct scientific studies and research on groundwater as it is a major water resource.

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