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Physicochemical Assessment and Magnetic Treatment of Groundwater in Al-Dhibaei Area, Tikrit City, Iraq: Implications for Potable and Aquatic Ecosystems

Hala Mahmood Esmaeel[1*], Shahd Tariq Khalaf[2], Noor Qutiba Saleh[3]
[1]Department of Biology, College of Education for Pure Sciences, Tikrit University, Tikrit, Iraq
Corresponding Author: hala.m.ismail@tu.edu.iq

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ABSTRACT

Water is vital to life on Earth, making it one of the most precious elements. The current study was conducted in Tikrit City/Al-Dhibaei area, where three wells were addressed during the study period, from January 2025 to March 2025. All samples were conveyed to the laboratory for prompt physical and chemical analysis. Several physical properties were measured, including water temperature, electrical conductivity, and dissolved solids in addition to several chemical properties, for example pH, total hardness, calcium hardness, magnesium hardness, and salinity. After that, some properties of these waters were treated using magnetic technology. The results showed that the water temperature ranged from 21.2 to 24.1°C, and the electrical conductivity ranged from 2450 to 3000μS/ cm, while the pH ranged from 6.4 to 7.9, and the salinity ranged from 1.5 to 1.8ppt. The wells were classified as difficult based on the cumulative rates of dissolved ions and total hardness, which ranged between 1558 and 1680. Meanwhile, the levels of calcium hardness ranged from 1330 to 1336, and the levels of magnesium hardness ranged from 277 to 360, respectively. The magnetic treatment unit demonstrated high efficiency in removing salinity, as the salinity present in the water of these wells was removed and reduced.

INTRODUCTION

Water is a fundamental component of all living organisms and ecosystems. Cells, whole species, and ecosystems are essentially reliant on the availability of water. Water constitutes the predominant material on Earth, comprising around 70% of the planet's surface and 65–90% of the mass of living species **(Dargaville & Hutmacher, 2022)**. As a result, the scientific community has focused on the importance of water in biological processes for over a century **(Novick *et al*., 2022; Pantsar *et al*., 2022)**. Water is essential for all key activities in living organisms. The morphology and functionality of cells and the extracellular matrix (ECM) are profoundly influenced by the physical and chemical properties of water. Water has several broad biological activities, including acting as a transport channel for nutrients and waste materials, facilitating chemical reactions, regulating cellular osmosis and maintaining cell turgidity, regulating body temperature, providing lubrication, regulating pH, and forming pH buffers **(Dargaville & Hutmacher, 2022)**.

Rivers, seas, oceans, groundwater, and rainfall are the primary categories into which water sources may be divided **(Abdullah *et al.*, 2024)**. Since river water is the primary source for supplying human needs, it is the most important of them **(Kuehne *et al.*, 2023)**. Water conservation, pollution, and future water shortages are challenges that many nations throughout the world have started to address **(Varol *et al.*, 2012)**.

Groundwater is defined as water found deep within the Earth, stored in the pores or cracks of rocks, and formed through percolation of water through the soil and rocks to the lower layers of the Earth. It is the most significant proportion of fresh water after frozen water **(Akhtar *et al*., 2020)**. Groundwater contains varying concentrations of salts, primarily calcium and magnesium salts. The geological makeup of the region where the water flows or settles affects the mineral composition of groundwater. In general, most groundwater has a high salt content, so it is brittle. Hardness decreases with a decrease in the concentration of salts in it **(Wen *et al*., 2024)**.

The study of groundwater is crucial for identifying water sources that can be used for development purposes, including irrigation and agriculture, as well as in urban and industrial areas, for human consumption, and to mitigate the risk of groundwater pollution **(Awad *et al*., 2022; Abanyie *et al*., 2023)**. Improving its quality and ensuring it conforms to standard specifications for drinking water has become increasingly important with the growing population and diverse needs for fresh water, which can be achieved by enhancing the physical and chemical properties of water **(Beg *et al*., 2021)**. The importance of the physicochemical properties of water lies in determining the quality and suitability of the organic and inorganic elements and compounds it contains **(Al-Magdamy *et al*., 2024)**. Higher temperatures also change water's physical properties, such as its density and viscosity, which directly affects the metabolism, reproduction, and overall survival of organisms **(Al-Fanharawi, 2017)**. Electrical conductivity (EC) is a measure of water's ability to carry an electric current **(Theyab & Erdeni, 2025)**. It depends on the concentration of dissolved ions in the water, the temperature, and the geological nature of the riverbed **(Al-Fanharawi, 2017)**. Dissolved solids measure the concentration of inorganic salts and other organic materials present in water. They occur naturally in water or are introduced by industrial and residential waste discharged into the atmosphere or via evaporation processes caused by elevated temperatures or precipitation. They are also contingent upon the Earth's geology **(Adjovu *et al*., 2023)**. pH is the most important chemical property of water and is a measure of the acidity or alkalinity of the solution. It affects drinking water and wastewater. Most organisms live within a narrow and critical pH range **(Saalidong *et al*., 2022)**. Hardness denotes the capacity of water to precipitate soap. Soap precipitates in mineral-rich water due to the presence of divalent calcium and magnesium ions, along with other multivalent metal ions such as iron, aluminum, and zinc **(Dey *et al*., 2024; Ingin *et al*., 2024)**.

Additionally, the hydroxide ion contributes to the formation of hardness salts in water, which exist as carbonates, bicarbonates, chlorides, and sulphates. Calcium and magnesium ions are the primary contributors to hardness in most waters, despite the presence of other metallic elements. The concentration of calcium in natural water depends on the type of soil and the areas through which the rivers flow **(Souiad *et al*., 2021; Perera *et al*., 2023)**. The current research aimed to study some of the most important physicochemical properties of water from three wells in the city of Tikrit in the Al-Dhibaei area, with an attempt to remove or reduce the high concentrations of some elements by using magnetic technology for safe use for drinking and domestic purposes, compared to the standard specifications for drinking water. The Al-Dhibaei area was selected due to its increasing reliance on groundwater and growing concerns about water quality in nearby villages.

MATERIALS AND METHODS

Description of study site

The city of Tikrit, the administrative center of Salah al-Din Governorate in northern Iraq, was selected as the study area. It is located approximately 180km north of the capital, Baghdad, on the banks of the Tigris River. Geographically, Tikrit lies at approximately 34°36′00″ N latitude and 43°41′00″ E longitude. Fig. (1) shows the geographical location of Salah al-Din Governorate **(Najam *et al*., 2022)**.

The specific study area is located at coordinates 34.5369591° N latitude and 43.6058697° E longitude, as shown in Fig. (1). It is worth noting that Tikrit is situated in a semi-hilly region with an elevation of approximately 100 meters above sea level, which primarily consists of agricultural land. The Tikrit district of Salah al-Din Governorate distributes several wells with varying uses, ranging in depth from 90 to 120 meters. These wells are classified as deep wells and are of the casing type, which is dug using hammers. Three wells were selected within the study area, ranging in age from 15 to 30 years, with casing pipe diameters ranging from 8 inches and suction pipe diameters ranging from 3 to 4 inches.

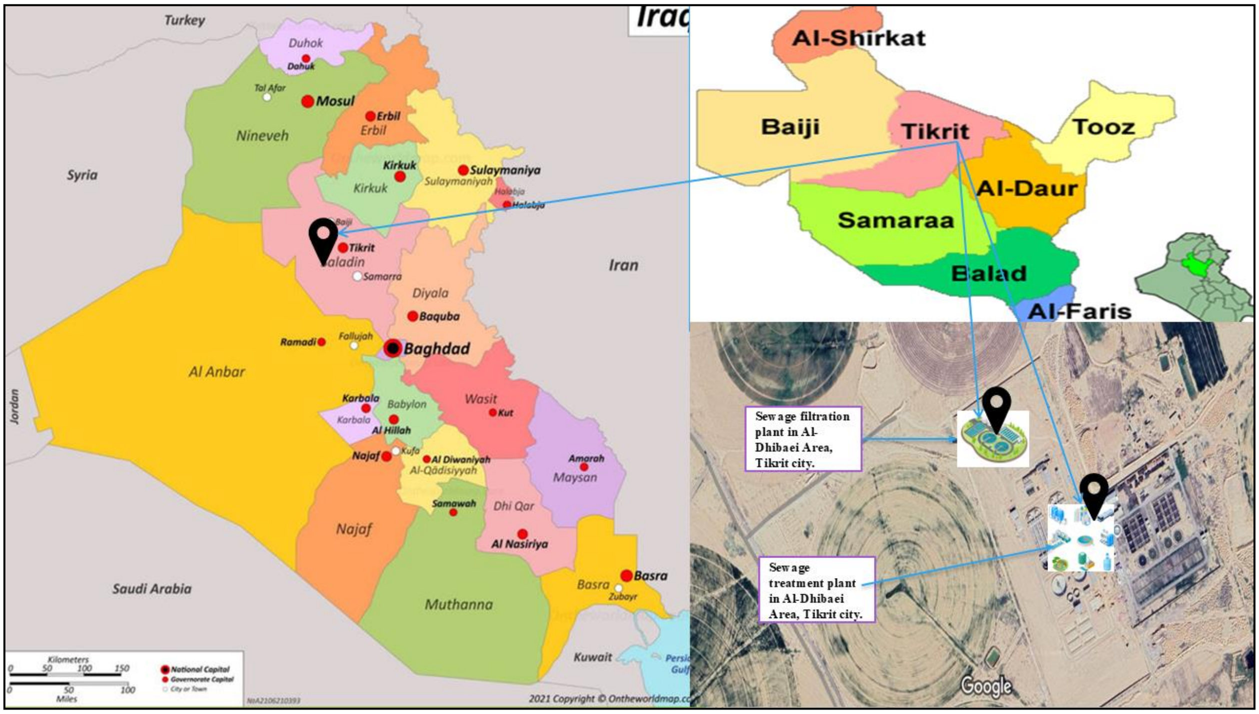

Fig. 1. Location map of the sewage treatment and filtration plant in Al-Dhibaei area, Tikrit City, Salah Al-Din Governorate, Iraq

Sample collection

Water samples were collected from the selected wells on a monthly basis during the study period, from January 2025 to March 2025. Samples were obtained during ten minutes of running water to eliminate stagnant, polluted water. The bottles were filled with minimal air space to preserve their physical and chemical qualities throughout transport, employing 2.25-liter polyethene bottles that were washed with sample water three times before collection. All samples were transported to the laboratory for immediate physical, chemical, and microbiological investigation. All glassware employed was first purified with distilled water and then dried in an electric oven. Analyses were conducted in the laboratories of “Tikrit University and the Quality Control and Chemical Engineering departments of the Salah al-Din Water Directorate”.

Physical and chemical tests

Physical tests

Measurement air and water temperature

Air and water temperatures were recorded in the field with a mercury thermometer with a range of 0- 100°C and a graduation of 0.1°C. The thermometer was positioned one meter above the ground surface in the shade while monitoring the air temperature. The water temperature was recorded after immersing the thermometer bulb at the designated sampling site and calibrating it to the Celsius scale. The procedure was executed thrice to validate the measurement.

Measurement of total dissolved solids (TDS)

Total dissolved solids (TDS) in water samples were measured according to the standard method **(APHA, 2017; Chambers, 2019)**. A volume of 50ml of filtered water samples was evaporated and then dried in an electric oven at 105°C. The TDS concentration was calculated using the following equation, and the results were expressed in milligrams per liter (mg/L).

Sample volume (ml -B) ×1000/ A) Total dissolved solids mg\L /L

A = weight of the plate with the remainder. B = weight of the empty plate.

Measurement of electrical conductivity(EC).

The electrical conductivity of water was measured using a field-made Lovibond E.C. meter from Germany after calibration, and the results were expressed in µS/cm.

Chemical tests

Measurement of pH

The pH of the samples was measured using a pH meter manufactured by HANNA (Microprocessor HI 9321) after calibrating the device with buffer solutions with a pH of 4, 7, and 10.

Measurement of salinity

Salinity was measured based on the electrical conductivity values of the samples, and the results were expressed in g/L as in the following equation:

Salinity (km/L) = (ECV µS/cm-(14.78) (1589.08)

Measurement of total alkalinity

The basicity was assessed using the methodology outlined by **APHA (2017)** and **Chambers (2019)**, with findings reported in units of L/mg. Fifty millilitres of the sample were extracted, and three drops of methyl orange indicator were included. A yellow hue was produced and subsequently filtered with 0.02 N sulphuric acid until the color transitioned to a reddish-orange. The average of two readings was taken. The basicity of calcium carbonate ($CaCO_3$) was determined using the equation below.

$$\text{Total Alkalinity } mg/L = \frac{V_{H2So4} \times N_{H2SO4} \times 1000 \times \text{ Mole} - \text{wt as CaCo3}}{V_{sample}}$$

Measurement of total hardness

Total hardness was measured according to the standard method of **APHA (2017)** and **Chambers (2019)** by taking 50mL of sample water and adding 1mL of ammonia buffer solution to adjust the pH to 10. Then, 0.5g of the Eri chromic Black T indicator was added, and the color changed to wine red. It was sieved with a 0.02N sodium EDTA solution until the color turned blue, and the average of three readings was taken. The total hardness was calculated according to the following law.

$$\text{T.H mg/L as } CaCO_3 = \frac{\text{V x N x wt- as x 1000}}{\text{ml of Sample}}$$

Measurement of calcium hardness

The calcium hardness of the samples was determined according to the **ASTM (2004)** method for water testing, using the following steps: 50ml of sample water was taken, 2ml of 2.5 N sodium hydroxide solution was added, and drops of calcium indicator (Murixide) were added. The mixture was then sieved with a standard 0.05 M Na_2 EDTA solution until the color changed from pinkish-red to aquamarine. Calcium hardness was calculated using the following formula, which represents the calcium hardness of the sample water in milligrams of calcium carbonate per liter.

$$calicium\ Hardness\ \ mg/L = \frac{\mathrm{V_{EDTA}} \times \mathrm{N_{EDTA}} \times 1000 \times\ \mathrm{Mole-wt\ as\ CaCO3}}{2 \times V_{sample}}$$

Measurement of magnesium hardness

Based on the standard method of the **ASTM (2004)** for water testing, the magnesium hardness of the samples was determined in terms of milligrams of magnesium carbonate per liter by applying the following equation:

$$\text{Magnesium Hardness } mg/L = \ Total\ Hardnes\ \ -\ Calicium\ Hardness$$

Water hardness treatment

A treatment unit was designed and implemented to treat hardness in healthy water as follows:

Processing unit description

The saltwater magnetization device was constructed, consisting of a 16 mm diameter, 30cm long plastic tube through which the water to be treated passes. Magnetic bars (15cm long) are installed longitudinally along the tube. The fundamental component of the water magnetization device is the magnetic bars, whose function is to generate magnetic lines in a radial direction. These bars are a set of opposite magnetic bars arranged so that their like poles are opposite. The strength of the magnetic field generated by the magnet is measured using a Gauss meter, with a magnetic strength of 3,000 Gauss chosen for the experiment. The magnet is then coated with an insulating material to concentrate the magnetic field strength inward, in the direction of water flow through the tube. The outer casing is covered with a reinforced polyethene tube, resistant to rust, weather conditions, and shocks, to protect the magnetic component from damage.

Fig. 2. Processing unit

Statistical analysis

The significance of differences, whether location differences or monthly differences in physical and chemical factors, was determined using the analysis of variance method and the Statistical Package for the Social Sciences (SPSS) program. Correlation Coefficient values were also calculated at the probability level $P \leq 0.05$.

Duncan test

It is a complementary test to the variance test, as it shows which of the variables differs from the other in causing significant changes in the studied variables at a significant level of $P \leq 0.05$.

RESULTS AND DISCUSSION

Groundwater temperature measurements are conducted on-site to prevent changes due to time and weather conditions. Groundwater has a narrow range of temperature variation, an important physical indicator of its quality **(Riedel, 2019)**. A disparity exists between surface and groundwater temperatures; the sites and, in certain instances, exchange rates may be deduced from temperature data **(Boano *et al*., 2014; Saphores *et al*., 2024)**. Seasonal or daily fluctuations in surface water temperature influence elements of the heat budget, including the interaction between groundwater and surface water, as seen in Fig. (3) **(Webb *et al*., 2008)**. Parameters for the heat budget of a surface water body are accessible; groundwater flow may be approximated by either resolving the unknown in the heat balance equation or by simulating the balance and calibrating the groundwater exchange limit to attain equilibrium. **Glos (2017)** illustrated this methodology with HFLUX software. **Schmidt *et al.* (2007)** similarly delineated the application of longitudinal stream temperature variations to assess groundwater flow along a river trajectory.

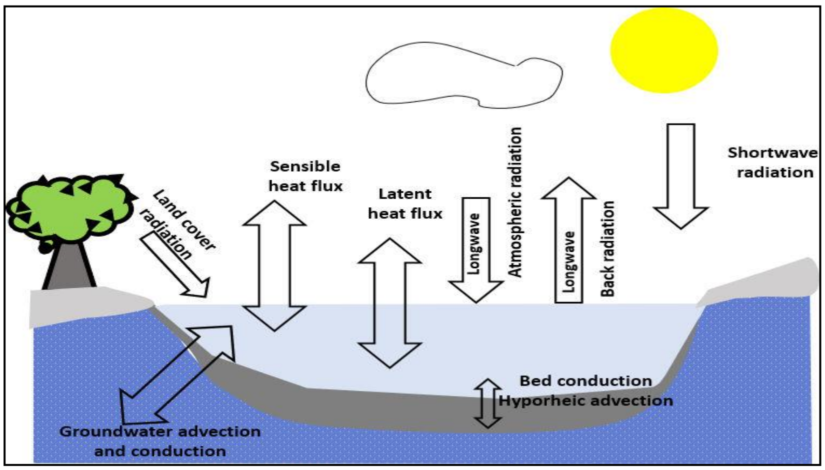

Fig. 3. Elements of a heat budget for a surface-water feature include interactions with the substrate, hyporheic water, and groundwater systems **(Woessner, 2023)**

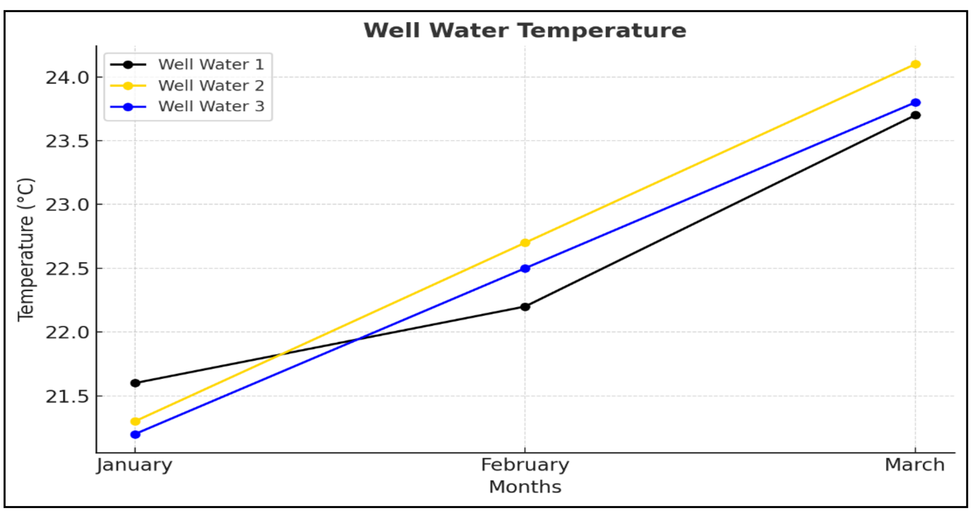

Chart 1. Well water temperature measurement during the study period (degrees Celsius)

Temperature is an important environmental factor that significantly influences various biological and chemical processes in aquatic ecosystems. It plays a key role in regulating metabolic rates in aquatic organisms, enzyme activity, and the solubility of gases such as oxygen. Temperature also affects water's physical properties, like density, which influences layering (stratification) and circulation, and impacts the rate of nutrient cycling and decomposition **(Woessner, 2023; Khaliq *et al*., 2024)**.

In this study, water temperature values ranged from the lowest recorded value of 21.2°C in January 19, 2025, in well 3, to the highest recorded value of 24.1°C in March 12, 2025, in well 2. The results showed apparent spatial variation, with the highest water temperatures consistently recorded in well 2 and the lowest in well 3. This variability is attributed to the geographic location of each well, its depth, and its exposure to solar radiation, as well as the seasonal climatic conditions of the study area and the time of sample collection. Generally, the low temperatures recorded in January indicate the onset of winter, while the relatively high temperatures in March reflect the transition to early spring, when ambient temperatures begin to rise. Understanding these temporal and spatial variations in water temperature is essential for interpreting the environmental dynamics and water quality parameters in groundwater systems **(Yanes *et al*., 2025)**.

The results of this study are consistent with the results of several studies conducted in Iraq on groundwater. **Mohammed and Ahmed (2025)** showed temperatures ranging from 16.16 to 18.3°C. On the other hand, **Ali and Jabbar (2014)** recorded temperatures ranging from 19.8 to 24.6°C during their assessment of water quality in Kirkuk Governorate. These similarities support the reliability of the current results and indicate the consistency of thermal conditions across similar groundwater sources in the region.

EC is a numerical expression of the positive and negative ions in water, indicating its ability to carry an electric current. The EC of water depends on its temperature, as ions facilitate this process. There is a clear correlation between the concentration of dissolved salts in water and its electrical conductivity; the EC of water increases by 2% with every degree Celsius **(APHA, 2017)**.

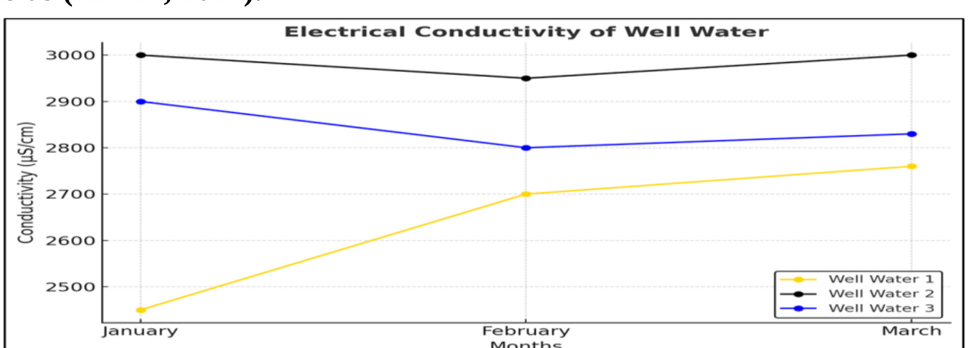

Chart 2. Measurement of EC wells (µS/cm)

EC is directly proportional to the concentration of dissolved compounds and their ionic strength, acting as an indicator of the quantity and quality of dissolved ions in water **(Corwin & Yemoto, 2020)**. The conductivity of electric charges in water is also contingent upon the temperature of the water since ions facilitate this process. **Hsu *et al*. (2024)** stated that there is a direct relationship between the number of dissolved salts in water and electrical conductivity. EC is an effective measure for determining the number of dissolved solids and identifying salts and mineral compounds in groundwater, thereby facilitating the detection of waterborne contaminants **(Gökçekuş *et al*., 2025)**. According to the Food and Agriculture Organisation (FAO) standards, 31% of groundwater samples exhibit moderate salinity (700-3000 $\mu S/cm^3$), while the remaining percentage is classified as highly salinized (exceeding 3000 $\mu S/cm^3$).

The results of the current study indicate that the average EC values ranged between 2450 and 3000 µS/cm, with the lowest value (2450 µS/cm) recorded in January for the water of well no. (1), while the highest value (3000 µS/cm) was recorded in March for the water of well no. (2), as shown in chart (2). These results are close to the those reached by **Dalas *et al*. (2022)** to assess the water quality of some groundwater wells and indicate its suitability for irrigation and drinking in the light of international and Iraqi standards Balad district, Salah Al-Din Governorate, Iraq, as they ranged between 590 and 3482 µs/cm in wells 4, respectively. Moreover, it is higher than what **Qader and Ghazal (2008)** detected in their study evaluating the quality of groundwater in the Sheikhan-Bartella area in northern Iraq, as the EC values ranged between 1602 and 463 microsem/cm in wells 8 and 5, respectively, and lower than the results of **Awad *et al*. (2022)** in their study entitled "Groundwater Hydrogeochemical and Quality Appraisal for Agriculture Irrigation in Greenbelt Area, Iraq, in which the EC values ranged between 4680-5960 microsem/cm.

Conductivity predominantly arises from the geological composition of the source region. These results imply a high concentration of dissolved chemical ions in these three wells, since the inflowing water traverses more soluble rocks. This also suggested elevated total dissolved solids (TDS), as conductivity correlates with TDS **(Al-Tayyar & Al-Shwany, 2024)**.

The pH is crucial for identifying the qualitative characteristics of natural water, as it plays a significant role in the chemical and biological balance within water. The concentration of hydrogen ions is of great importance because it affects many chemical reactions, and many living systems are strongly linked to the pH value, even within narrow ranges **(Saalidong *et al*., 2022)**. It is considered an indicator of the balance between alkalinity and acidity in water and controls most chemical reactions and transformations in aquatic environments.

Al-Shanona *et al.* (2018) indicated that the pH value is controlled by the relationship between the concentration of hydrogen ions (H+) released from carbonic acid and the hydroxyl radical (OH-) produced by the decomposition of bicarbonates, which is a regulating property of water and makes natural waters slightly alkaline, as confirmed by scientific publications **(APHA, 2017)**. The pH is affected by dissolved gases such as carbon dioxide, hydrogen sulphide, and ammonia, as well as bicarbonate and carbonate ions present in water **(Kumar & Jain, 2022)**.

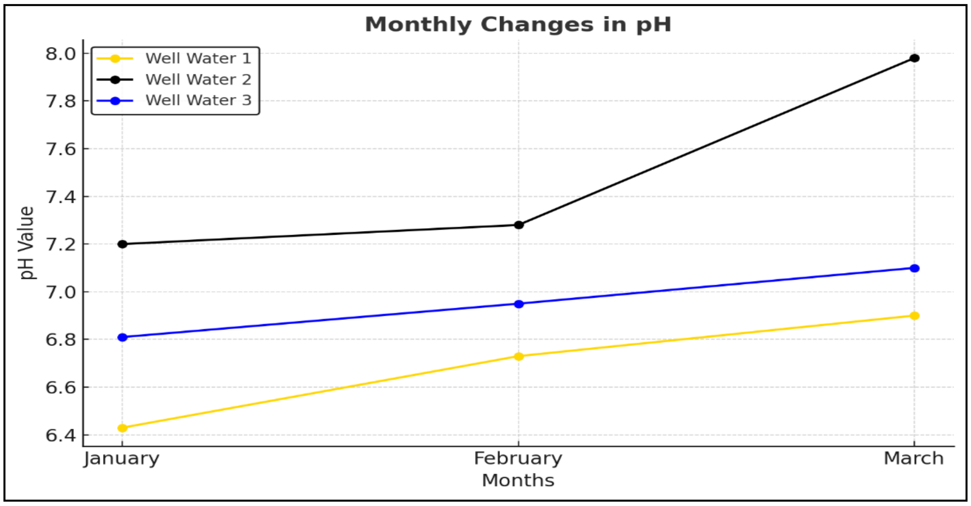

Chart 3. Monthly changes in pH of wells during the study period

As shown in Chart (3), the pH values of groundwater samples in the study area ranged from 6.43 to 7.98. The lowest pH value (6.43) was recorded in December in well 1, indicating slightly acidic conditions, while the highest value (7.98) occurred in March in well 2, reflecting mildly alkaline water. The observed values align closely with findings from previous studies on groundwater quality by **Al-Shanona *et al.* (2018)**, when studying the water quality assessment in the village of Abu Maria in Mosul Governorate, where values ranged between 7.76 and 6.29, and **Salih *et al*. (2023)** in their study to assess the suitability of well water in the Kirkuk Governorate, which ranged between 7 and 8.4. These values are lower than the results of the study by **Alsahan *et al*. (2023)**, in which pH values ranged between 8.4 and 7.3. Most of the results varied over the months of the study. This variation suggests that seasonal fluctuations, as well as geological and anthropogenic factors, influence groundwater pH levels. Most of the well waters studied were close to neutral. They did not experience significant fluctuations due to their high ability to neutralise the acidity of water and soil, both of which are rich in large amounts of carbonate and bicarbonate salts. The high pH values are attributed to the high levels of sulphur and chlorine, which led to an increase in the salinity concentration in the water, making the pH close to neutral **(Nguyen & Huynh, 2023)**. The presence of acidic ions in the water, including sulphates, nitrates, and chlorides, causes the low pH values. Additionally, the decomposition and biological oxidation of organic matter decrease the concentration of dissolved oxygen in the water and lead to the formation of carboxylic compounds and acids. Furthermore, under anaerobic conditions, sulphur ions undergo oxidation and reduction processes that result in the formation of oxidised H_2S when exposed to oxygen, which then forms sulphuric acid. **(Sharma & Kumar, 2020)**.

Salinity is typically determined indirectly by measuring EC, the most common method for assessing salinity **(APHA, 2017)**. It is related to the concentration of total dissolved solids more than to the specific components of these salts. Salinity has a direct relationship with the osmotic regulation of the organism's cells, and organisms differ in their tolerance to salinity **(Corwin & Yemoto, 2020)**.

Salinity quantifies the concentration of salt in water. Dissolved ions elevate both salinity and conductivity, establishing a correlation between the two metrics. Saline waters derive their elevated composition from dissolved ions, such as sodium, chloride, carbonate, and sulphate. Salts and other elements influence the quality of water utilized for irrigation or consumption. Aquatic creatures are significantly affected, with each species possessing a specific salinity tolerance range. Elevated salt concentrations may render water inappropriate for household, agricultural, or industrial applications. Moreover, the ionic content of water may be crucial **(Pooja, 2017)**.

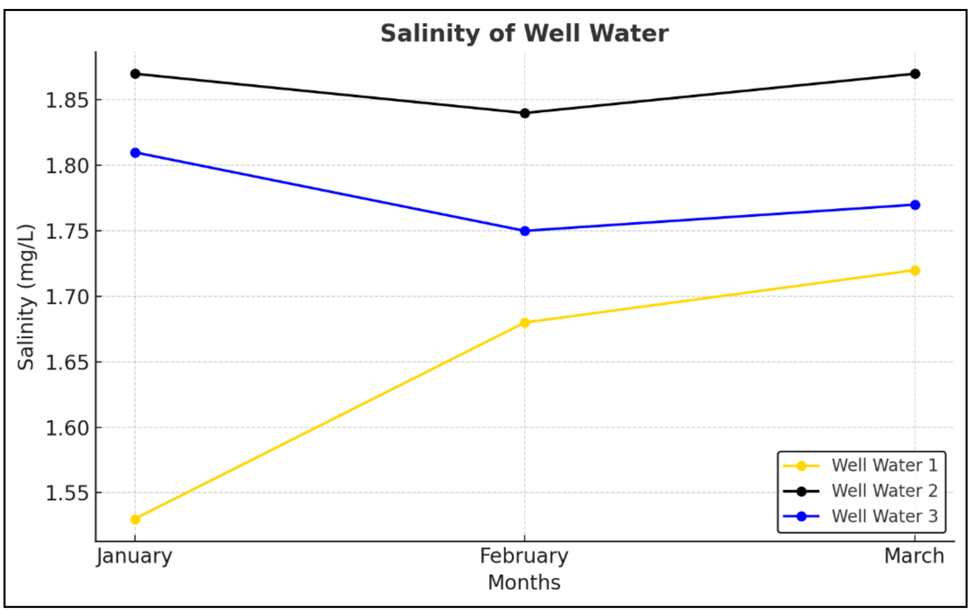

Chart 4. Salinity of well water during the study period (g/liter)

The salinity, as shown in Chart (4), reached its lowest value of 1.53g/ L in January in the water of well (1) and its highest value of 1.87g/ L in January and March in the water of well (2). The degree of salt formation in terrestrial ecosystems fluctuated mainly owing to variations in precipitation, temperature, and soil drainage capacity. Nonetheless, the circumstances alter in regions where irrigated agriculture is practised, necessitating that irrigation needs be fulfilled using salty or brackish water. The ineffective use of these borderline quality fluids can lead to the accumulation of salt and sodicity in the root zone, hindering plant development to a degree that renders economically sustainable agriculture unfeasible, resulting in farm abandonment. Consequently, it is imperative to delineate soil salinity in these regions and either advance agricultural practices by establishing crop zones according to salt levels or execute a comprehensive salinity management program to enhance farm output **(Choukr-Allah *et al*., 2023)**.

The average total alkalinity values during the current study period ranged from 120 to 180mg/ L in the water of wells 1 and 3, respectively. The lowest total alkalinity value was recorded at 120mg/ L in February in the water of well (2), and the highest value was 180mg/ L in March in the water of well (3), as shown in Chart (5). Regarding total alkalinity, the results of the current study are consistent with those of **Abdullah *et al*. (2024)**, who reported values ranging from 180 to 100mg /L. Compared to the ranges of 230–146, 221–120, 240–145, and 140–300mg/ L reported by **Fratham (2018)**, **Sultan (2019)**, **Mahmoud (2021)** and **Alawi and Khamis (2022)**, these values are lower. The results of the current study increased in the fall and peaked in winter due to rainfall and lower temperatures, which make carbon dioxide more soluble in water. Since high alkalinity values can increase soil acidity and limit nutrient availability, it is essential to maintain moderate alkalinity levels to prevent adverse effects on soil **(Al-Mukhtar *et al*., 2020)**.

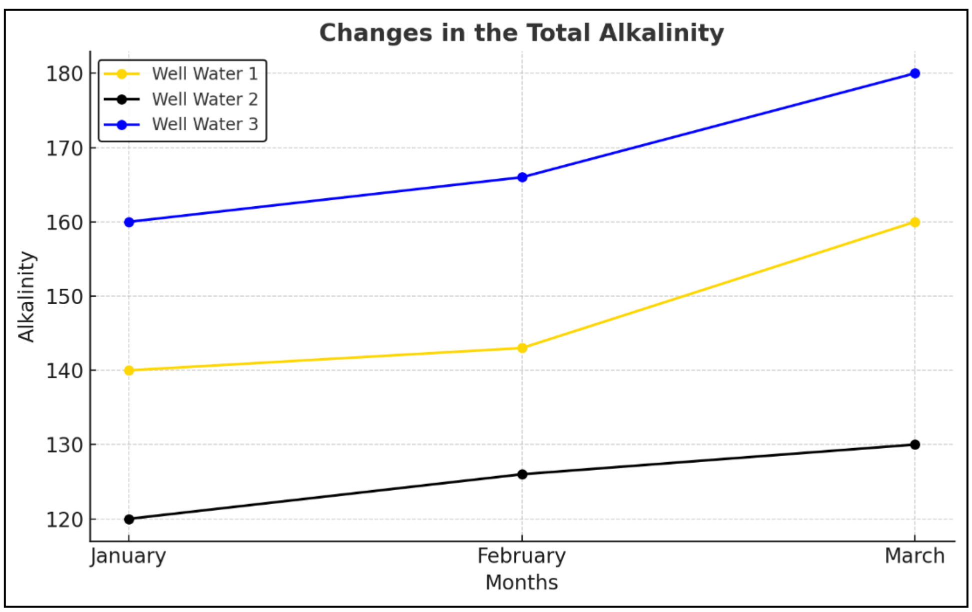

Chart 5. Monthly variations in the total alkalinity of well water over the study duration

Alkalinity is essential for controlling the pH and buffering capacity of natural aquatic systems. Consequently, precise measurement is crucial for comprehending diverse aquatic settings that influence water quality and ecosystem vitality **(Boyd, 2015)**. Total alkalinity values may be attributed to the nature of the geological formations in the study area. This variation depends on the source of carbonates (CO_3) and bicarbonates (HCO_3) in the well water. Their sources of groundwater include limestone rocks in contact with groundwater, as well as rainwater containing carbon dioxide, and the groundwater the situation **(Pareta *et al*., 2024)**.

Total hardness levels ranged between 1558 and 1630mg/ L in the water of wells 1 and 2, respectively. The lowest total hardness concentration recorded was 1558 mg/L in January at well (2), while the highest concentration was 1630mg/ L in March at well (1). The results of this study are consistent with those of **Darwish (2011)**, who showed total hardness values ranging between 1420 and 1990mg/ L. Their values also exceed those shown by **Al-Dulaimi (2013)**, where total hardness ranged between 150 and 382mg/ L. as shown in Chart (6).

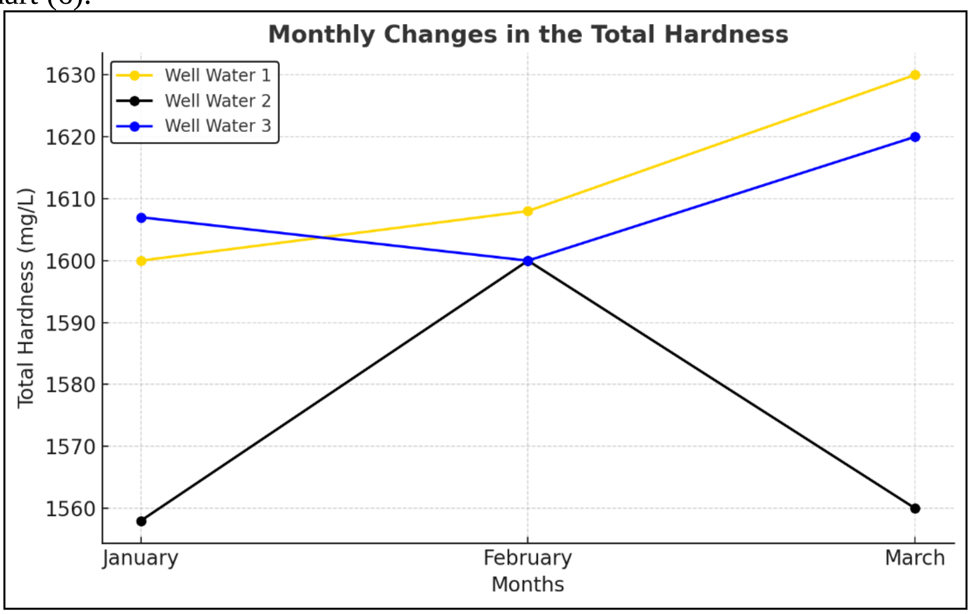

Chart 6. Monthly variations in the total hardness of well water during the research period (mg/L)

The geographical distribution of groundwater hardness in the research region is primarily determined by hydrogeochemical processes and environmental conditions, with cation exchange and evaporation concentration processes as the principal factors. Calcium and magnesium are the predominant ions responsible for hardness in natural water **(Gudzenko, 2023)**. Hardness fluctuates based on the water source, with surface water being less complex than groundwater. This is contingent upon the soil composition through which the water traverses **(Davraz & Aksever, 2025)**. Elevated levels of total dissolved solids and alkalinity in water augment hardness readings. The total hardness of water mostly depends on the concentration of calcium and magnesium ions. The hardness of well water increases significantly when it interacts with dolomite or limestone, perhaps owing to the incorporation of magnesium and calcium salts **(Al-Barwary, 2021)**. The source of calcium ions is mainly due to the geological nature of the areas through which the water passes, as calcium constitutes 30.23% of sedimentary rocks. The phenomenon of calcium dominance over other positive ions in waters and various areas of Iraq **(Hussain & Al-Kubaisi, 2022)**.

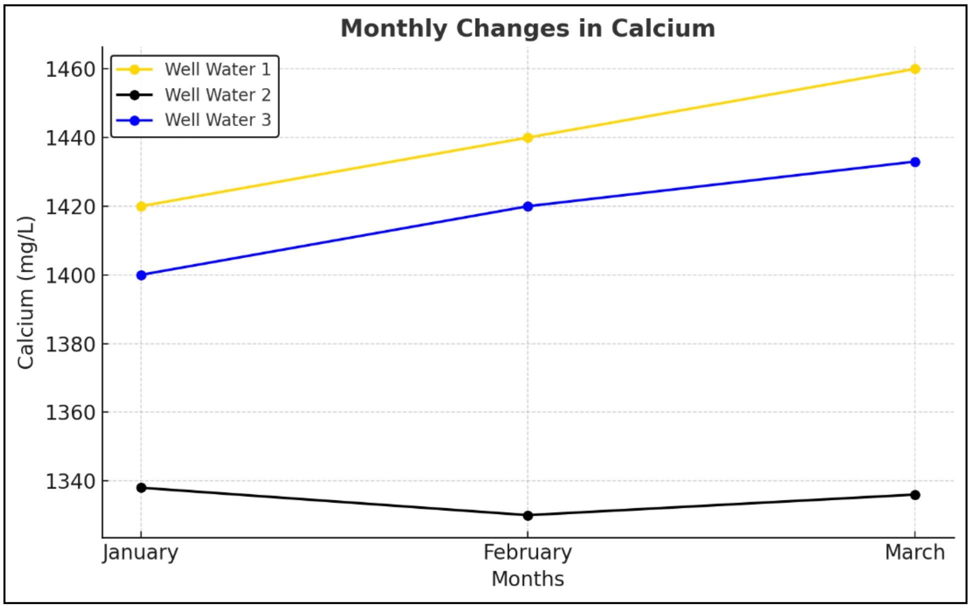

Chart 7. Monthly changes in calcium hardness of well water during the study period (mg/L)

The results, as presented in Chart (7), indicate that the average calcium hardness values in the groundwater samples ranged from 1330mg/ L in well 2 (recorded in February) to 1460mg/ L in well 1 (recorded in March). These findings suggest a notable variation in calcium hardness between wells and sampling periods.

The results of the current study are consistent with those reported by **Darwish (2011)**, who found calcium hardness values ranging from 1089 to 1542mg/ L. However, the recorded values are significantly higher than those reported in previous studies. For instance, **Abed and Abdul Jabar (2023)** documented calcium hardness values between 300 and 2000mg/ L. In their study, **Al-Malki and Al-Shwany (2023)** assessed the suitability of well water in Kirkuk Governorate, finding values ranging from 115 to 750mg/ L. **Hassan (2021)** found a range between 132 and 768mg/ L in their assessment of the well water quality index in Kirkuk City. Furthermore, **Mansour (2021)** recorded values ranging from 34 to 122mg/ L in their study of the physical, chemical, and biological properties of groundwater in Kirkuk Governorate. This variation in calcium concentrations among well water samples is attributed to the geological composition of the study area, which consists of sedimentary rocks such as limestone and dolomite. These rocks either directly contain groundwater or influence it by flowing through it through its natural movement or by recharging it with filtered rainwater. According to **Bouderbala (2017)**, calcium can constitute up to 30% of these rocks. In addition, the marked increase in calcium hardness values is associated with higher temperatures, which raise the concentration of carbon dioxide in the water. This CO_2 reacts to form bicarbonate, a significant factor in water hardness **(Hamid *et al*., 2020)**.

Magnesium ions are one of the ions that inherently contribute to water hardness. The source is predominantly geological, specifically from carbonate rocks (such as dolomite and high-magnesium calcite) that facilitate the passage of water **(Ingin *et al*., 2024)**.

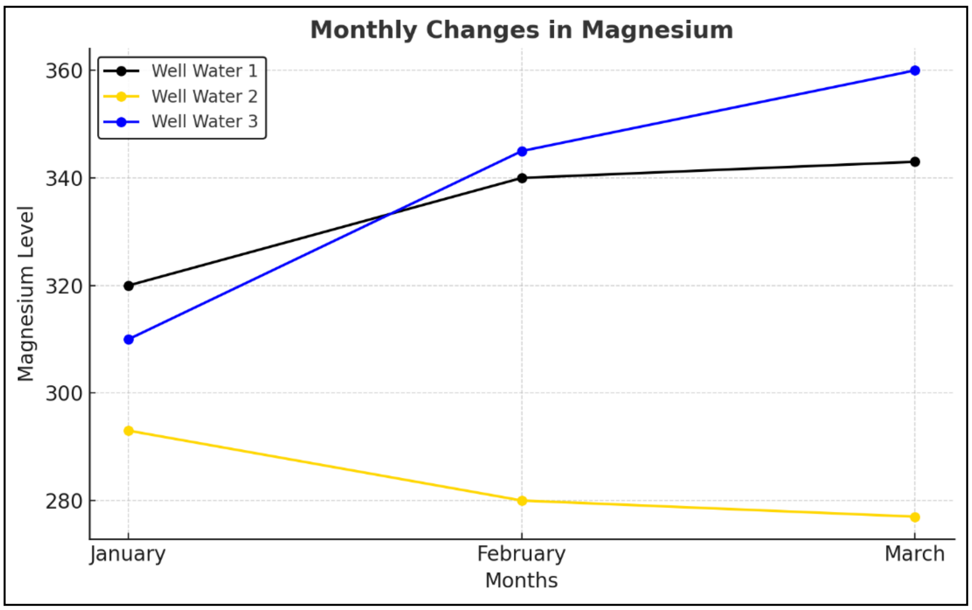

Chart 8. Monthly variations in magnesium hardness of well water during the research period (mg/L)

The results of the current study, presented in Chart (8), show that the magnesium hardness concentrations ranged between 277 and 360mg/ L in the water of wells 2 and 3, respectively. The current study recorded the lowest value of 277mg/ L magnesium hardness concentration in March for water of well no. 2, while the highest value of 360mg/ L was recorded in March for water of well no 3. The results of the current study are less than those recorded in the study of **Hamad (2017)**, with values 482- 679.023, and close to the results of **Ibrahim (2010)** and **Al-Hadithi and Al-Falahi (2024)**, who recorded 376, 427 and 394mg/ L, respectively.

The high concentrations of magnesium in well water during the study months can be linked to increased water salinity resulting from the washing away of the surrounding soil by prolonged rainfall, which leads to the infiltration of salts into the well water and an increase in the presence of magnesium ions. The presence of magnesium in the study areas is linked to geological factors, including the dissolution and erosion of rock formations, in addition to the dissolution of clay minerals, which are a major source of these ions in the water **(Lerner, 2003)**.

Treatment

Magnetic technology has been used to treat groundwater due to its high efficiency in removing many contaminants, including dissolved salts and hardness. This process is carried out by magnetising water. Magnetised water is produced by passing water through a specific magnetic field using special magnetic tubes that magnetise it or by placing magnets in or near the water for some time. This results in what is known as magnetised water. This is because when water passes through a natural magnetic field, it becomes more active and energetic. Magnetisation of water changes many of its properties as a result of its influence by these magnetic fields. The magnetisation process regularly rearranges the water's charges, whereas their shape in normal water is random. The process leads to changes in (14) water properties, including EC, increased levels of dissolved oxygen, increased ability to dissolve salts and acids, crystallisation, polymerisation, surface tension, changes in the rate of chemical reactions, evaporation, wettability, softness, overall hardness, electrical insulation, and increased permeability. That is, when salt water passes through a magnetic field, the hydrogen bonds between the molecules break or dissociate. This dissociation absorbs energy, reduces the bonding level of the water molecules, increases their susceptibility to electrolysis, and affects the dissolution of crystals. Magnetic treatment improves the properties of water and is highly effective. Using magnetised water is economical, safe, and simple. The magnetisation process realigns the water's charges by reducing the bond angle between the oxygen atom and the two hydrogen atoms in the water molecule, which shrinks to 103 degrees. This, in turn, causes the water molecules to clump into groups. While the shape of these charges is random in salt water, water is chemically composed of negative and positive ions (cations and anions), meaning these charges are balanced.

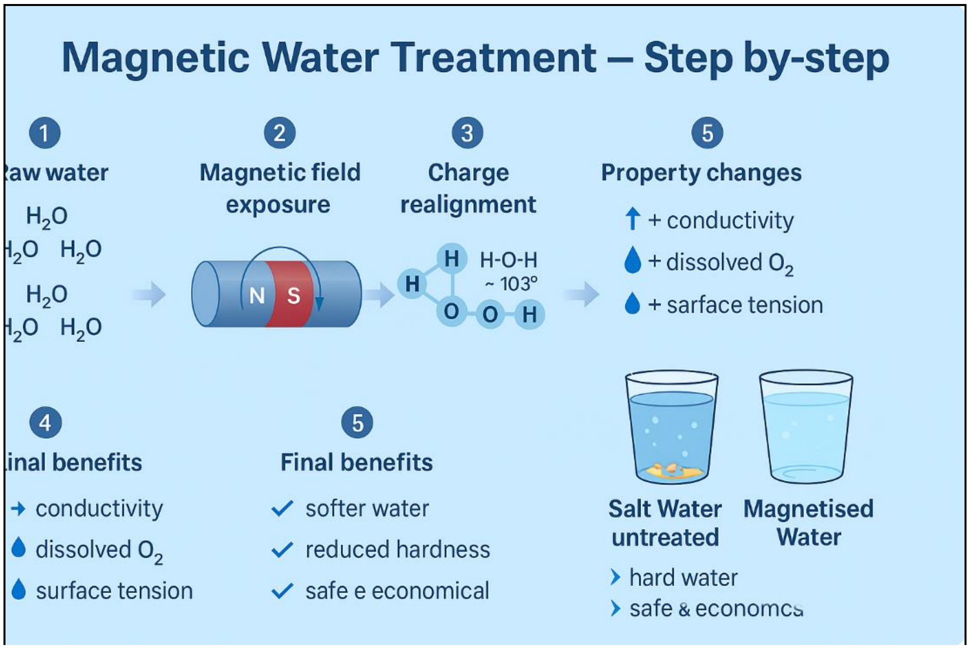

Fig. 4. Mechanism of magnetic water treatment and its effects on water properties. Raw water passes through a magnetic field, leading to charge rearrangement and modification of the water molecules' structure. This process alters physicochemical properties, such as electrical conductivity, dissolved oxygen, solubility, and surface tension. The end result is improved water quality, reduced hardness and sedimentation, and enhanced safety and efficiency in practical applications

Magnetic treatment does not reduce the total dissolved solids (TDS) and total hardness (the concentration of calcium and magnesium ions) in the treated water. That is, the measured TDS (total dissolved solids) value remains virtually constant before and after the water passes through the magnetic device, because the amount of dissolved solids in it does not change. Similarly, hardness does not decrease numerically; instead, it changes the crystal structure of the salts. Calcium carbonate transforms from calcite, the precipitated form, to aragonite, the non-precipitated form. This transformation reduces sedimentation and limescale buildup in pipes and equipment. Magnetic treatment affects the bonding pattern of salt and water molecules, improving their behaviour for use in irrigation or industrial applications. Occasionally, slight changes in the TDS reading (a slight increase or decrease) are recorded, but these changes are not considered of practical or scientific significance.

CONCLUSION

The analysis of groundwater wells in Salah Al-Din Governorate indicates a narrow temperature range among the wells, suggesting stable thermal conditions. Nonetheless, total hardness, along with calcium and magnesium hardness levels, was found to be significantly above the acceptable thresholds established by Iraqi drinking water standards, highlighting an urgent need for treatment. Magnetic water treatment technology offers a promising approach for improving groundwater quality. To improve the management and utilisation of groundwater resources, it is essential to establish a regulatory framework for well drilling based on scientific principles and supervised by specialised authorities, to reduce the risk of contamination. Moreover, conducting a comprehensive assessment of groundwater quality and developing a centralised database would be beneficial for identifying suitable drilling sites. Ultimately, there is a need to design and implement effective systems for treating water hardness and suspended solids, specifically tailored to meet the needs of domestic, agricultural, and industrial applications.

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