Groundwater Quality Evaluation for the Limestone Aquifer Utilizing Hydrochemical Characteristics and Imitative Techniques, Eastern Nile Valley, Egypt

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Abstract

The construction of new towns and land reclamation initiatives are now being given a lot of attention by the Egyptian government in an effort to solve the country's overpopulation issue. Groundwater quality in the Limestone aquifer was evaluated using integrated physico-chemical criteria under sustainable development guidelines. Forty groundwater samples were taken from the research area's fractured limestone aquifer during the summer of 2021. The results showed that according to their physico-chemical characteristics, the primary ion contents were derived in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > HCO_3^- > CO_3^{2-}$. Chemical analysis findings showed that the bulk of the groundwater points from the Eocene had calcium levels that varied from 3.9 ppm to 19.5 ppm. The methods by which highly soluble carbonate minerals like calcite, dolomite, and sulphate are leached may be responsible for the high concentration of calcium ions in the groundwater of the studied region. The quantity of magnesium ions in groundwater wells ranged from 6 ppm to 24.32 ppm. Sodium is the predominant cation, with concentrations between 440 and 1020 ppm. Chloride concentrations varied between 335 to 674 ppm. Sulphate concentrations varied between 323 to 1478 ppm. The bulk of groundwater samples from the Eocene had bicarbonate concentrations from 62 to 124 ppm. Landowners in newly reclaimed lands should be urged to employ contemporary irrigation techniques including sprinkler and drip irrigation technologies for the integrated management and efficient use of water resources.

Keywords: Groundwater quality, Limestone aquifer, Physico-chemical parameters.

Introduction Introduction

In many parts of Egypt particularly in the desert areas, groundwater is regarded as one of the primary sources of both rural and agricultural water supply (**Abd-Elmabod et al., 2019**). Concerns about the sustainability of the groundwater resource and the lives it supports have been raised in recent years due to escalating abstraction to fulfil domestic supply demand and development of reclamation on desert fringes (**Elnashar, 2014**). The topic of employing unconventional water sources, such as agricultural drainage water, brackish groundwater desalination, and urban wastewater, is brought up by Egypt's lack of irrigation water supplies

(**El Arabi, 2012**). The source of the water and the kind of the rocks that hold the water are the two key elements that affect the quality of groundwater. Additionally, the flow and movement of water between different points are significant considerations (**Elnashar, 2014**). Human excrement and agricultural wastes rich in fertilizers including nitrogen, phosphorous, and potassium are the main sources of minerals entering waterways. Phosphorus is a vital element in limiting algal development and water pollution (**Gad et al., 2016**). Fundamental details on water quality, a variety of geochemistry procedures and water characterization for agriculture may all be found in the chemical composition of the water in relation to geochemical factors. According to **Gad *et al.,* 2016**, the imitative approach is a useful and widely used way for illustrating the significant geochemical activities that regulate the chemical composition of water. The imitation methods, such as the Piper diagram (**Piper, 1944**) and the Schoeller diagram (**Schoeller, 1962**), are commonly used to better understand the hydrogeochemical properties of water. These approaches are based on the geochemical categorization of natural fluids and the study of chemical data. These methods can also be used to specify the geochemical laws that determine the chemical composition of water (**Elsayed *et al.,* 2020**). Total dissolved salts (TDS), hydrogen ion concentration (pH), temperature (T ^{o}C), sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), sulphate (SO_4^{2-}), chloride (Cl^-), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) are some of the physico-chemical parameters that are thought to be important indicators as well as a crucial factor water quality assessment (**Al-Mashreki, *et al.,* 2023**). Therefore, the goals of this work were to: (i) assess the source of groundwater and (ii) assess the geochemical characteristics of the Limestone groundwater aquifer.

Materials and Methods

Study area

The investigated region is around 100 kilometers (km) south of Cairo and 10 kilometers (km) east of Beni Suef City. The research region spans the boundaries of the governorates of El Minya and Beni Suef (Fig. 1). According to Figure 1, the research region is situated between Latitudes 28° 30′, 29° 06′ N and Longitudes 30° 48′, 31° 12′ E. It takes up around 1200 sq. km. of space (Fig. 1). The high plateau of the Eastern Desert and the Nile River form the east and west borders of the region, respectively. The research area's ground elevation varies from a positive 45 meters (m) along the Nile River to a positive 250 meters (m) towards the Eastern Plateau.

Sample collection and analysis

In the research region, forty groundwater points were taken from the fractured limestone formation (Fig. 1). A portable meter called the SG78-Seven Go Duo pro was used to test pH/Ion/Conductivity in-suite. The entire sum of the dissolved main ions was used to calculate total dissolved salts (TDS). The sample containers were thoroughly rinsed with distilled water after being cleaned with acid steam stripping and permitted to sit for two days. Clean plastic bottles devoid of air bubbles were utilized for collecting water points. Each station's water collection was used to rinse the bottles, which were then labelled and hermetically sealed outside. Before being transported to the laboratory, samples were maintained in a refrigerator at 4° C and filtering via a 0.45 m filtration barrier to analyze significant ions. According to established analytical procedures, all water samples were examined for the presence of the main ions including cations and anions (**APHA, 1998**).
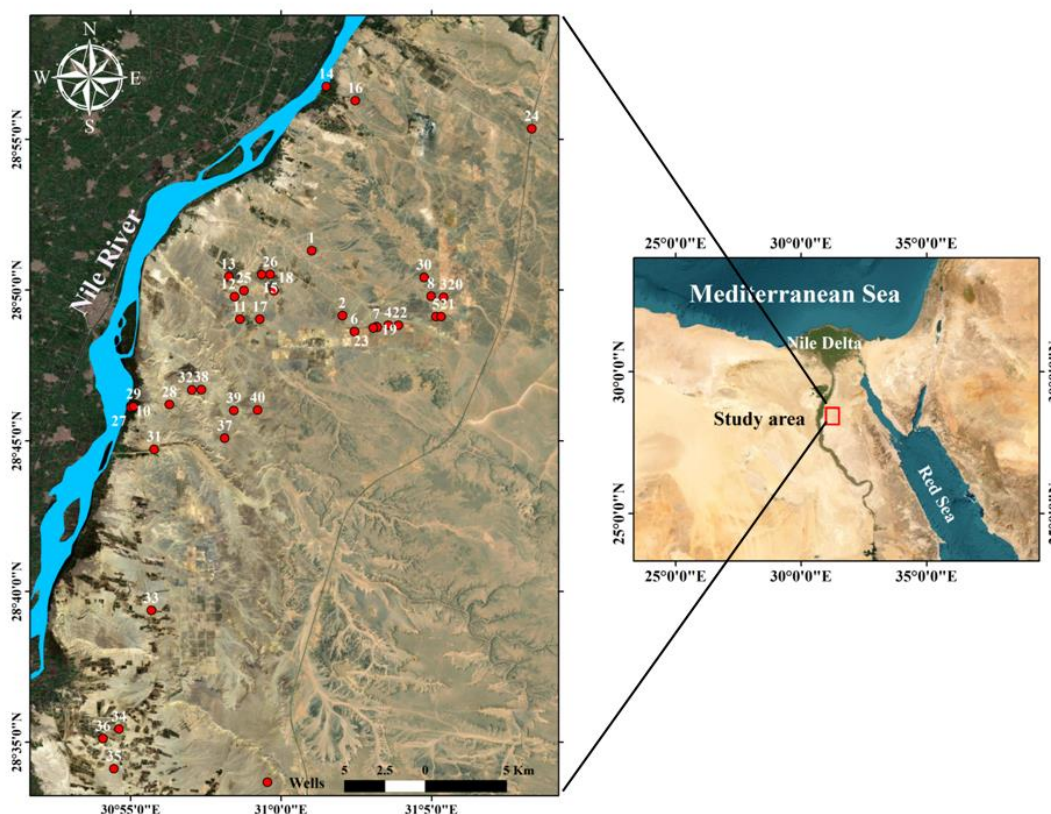
Fig. 1. Location map of groundwater samples.

Table 1. Analysis methods of physico-chemical parameters for the collected groundwater samples.

Physico-chemical parameter	Method (APHA, 1998)
SO_4^{2-}	4500-SO_4^{2-} E
Cl^-	4500-Cl^- B
HCO_3^-	Titration method
Na^+, K^+,	Flame photometer
Mg^{2+} and Ca^{2+}, Cu, Fe, Mn, Zn	Atomic absorption spectrometer

Imitative techniques

The Piper diagram (**Piper, 1944**) and Schoeller diagram (**Schoeller, 1962**) are two imitative methodologies that were utilized to ascertain the composition of water and its hydrochemical characteristics using the Geochemist's Workbench Student Edition 12.0 software. The geochemical properties of water and the kind of water were studied using the analytical values of the collected water samples, including anions and cations.

Results and Discussion
Physico-chemical parameter

Depending on the location, the lithologic facies of the water-bearing formation, the geologic environment, notably the structural framework, and the current hydrologic conditions,

either on the surface or below, the groundwater east of the Nile Valley exhibits unique geochemical features. Discussions of the geochemical composition and distribution as well as the hydrochemical categorization of groundwater are used to examine the hydrogeochemical properties (Table 2). Physico-chemical characteristics were derived in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > HCO_3^- > CO_3^{2-}$.

Table 2. Statistical description of the physicochemical parameters.

Parameter	Min	Max	Mean
pH	7.11	7.80	7.45
EC	300.00	5500.00	2789.62
TDS	192.00	3520.00	1785.35
K^+	3.11	37.80	8.26
Na^+	27.60	1122.40	602.41
Mg^{2+}	6.00	24.32	12.21
Ca^{2+}	20.00	80.00	42.50
Cl^-	35.50	674.50	425.21
SO_4^{2-}	38.40	1680.00	739.27
HCO_3^-	62.00	124.00	74.40
CO_3^{2-}	0.00	0.00	0.00

Geochemical Facies and Controlling Mechanisms

Different methods have been devised to characterize the pattern variability and concentration or relative abundance of main or minor elements in various water samples. The trilinear diagram and Schoeller diagram are the most pictorial techniques of describing the presence or relative abundance of ions in individual water samples. The Piper's diagram and Schoeller diagram are the two most often used graphical ways to represent the quantity or relative abundance of ions in specific water samples (**Piper, 1944; Schoeller, 1962**).

The trilinear diagram is the most often utilized in the geochemical categorization of groundwater. This type of categorization is depended on the proportional equivalent of cations and anion. The major anions (Bicarbonate + carbonate, sulphate, and chloride) are displayed in the lower right triangle, whereas the major cations (calcium, magnesium, sodium, and potassium) are plotted in the bottom left triangle. Three points are used to represent the sample: one for the cations, one for the anion, and one for the projection of the first two points onto the diamond-shaped field.

The water in the upper triangle of the diamond-shaped field shows secondary salinity characteristics, where sulphate and chloride > sodium and potassium. So, calcium, magnesium, and sulphate are the hypothetical salts. In the Piper trilinear diagram, two triangles are shown, one representing cations and the other indicating anions and a diamond-shaped area to signify a cation and anion position combined. The integrated single diamond-shaped field position helps one to make inferences and to differentiate water based on hydrogeochemical characteristics. The diamond-shaped area is broken into four main parts in the Piper diagram, each part representing and defining a certain kind of variation or dominance of cations and anions. The data from the groundwater's chemical analysis are represented on the diagram in relation to the research region (Fig. 2).
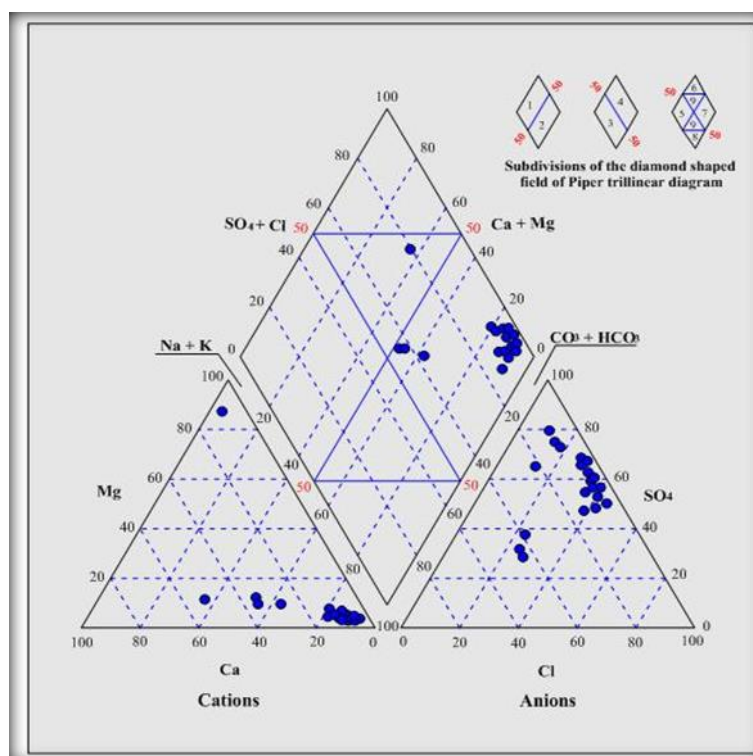
Fig. 2. Piper trilinear diagram.

The semilogarithmic Schoeller graph used in the chemical analysis of the collected groundwater points revealed that sodium was the most prevalent cation, followed by calcium, magnesium, and potassium, in that order. Sulphate, bicarbonate, and carbonate were the next most prevalent anions, followed by chloride.

It was suggested to use a semi-logarithmic graph to quickly compare various water chemical analyses visually. This graph enables the representation of the cations and composition of several samples on a single plot, allowing for the easy identification of important trends. The slopes of the straight lines connecting two components (in milliequivalents per liter) of two separate samples, when compared, reflect the connection between these two constituents. On the Schoeller diagram, parallel lines represent the same associations between the charged chemical species. According to Scholler's graph, two different water types in the Eocene groundwater aquifer were distinguished, such as Na-SO$_4$ and Na-Cl (Fig.3).

Physical and chemical characteristics
pH values
The Eocene aquifer's groundwater samples' pH ranged from 7.11 in well No. 3 to 7.80 in well No. 26, indicating neutral to extremely alkaline water conditions (Fig. 4).

Total dissolved solids (TDS)
It has been noted that the electrical conductivity of the groundwater in the Eocene aquifer varied from 1.2 mohs/cm in well number 34 to 5.5 mohs/cm in well number 39. According to the salinity classification of **Cheboratev, 1955**, the groundwater of the Eocene aquifer consists mostly of relatively fresh water with salt values ranged from 700 to 1500 ppm.
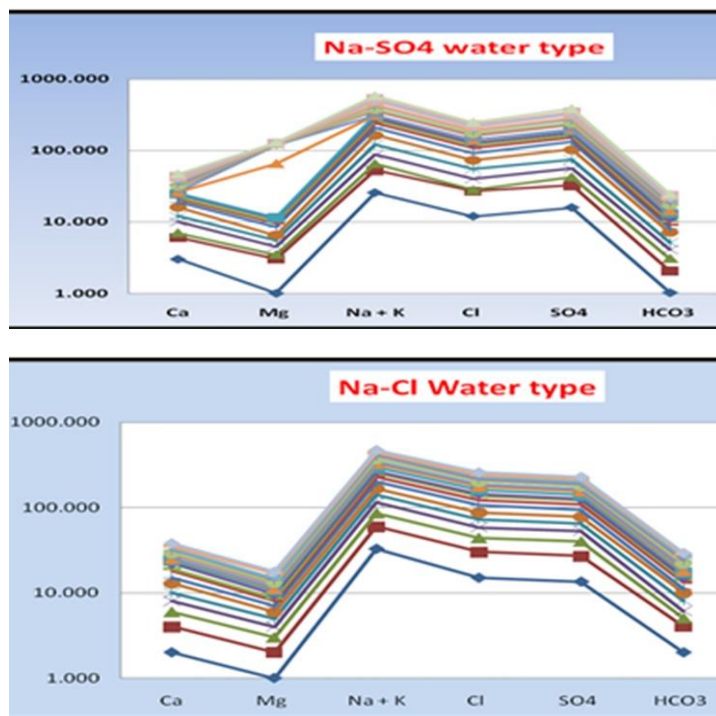
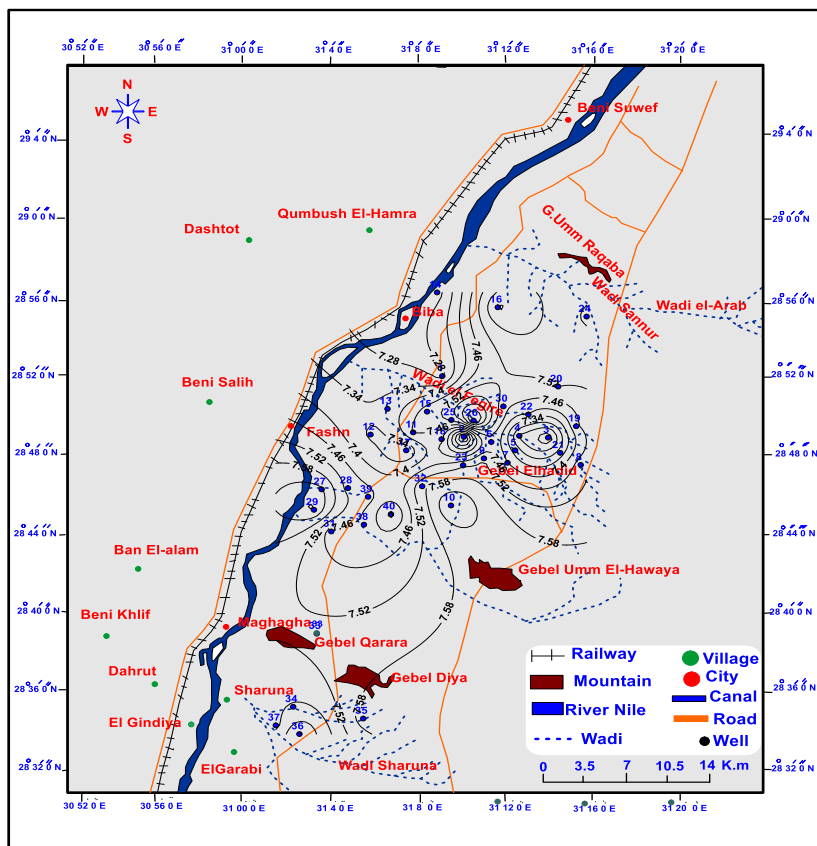Fig. 3. Schoeller semilogarithmic graph showing water type.

Fig. 4. The pH distribution map.

The low salinity levels indicate that the water came from meteors. The lower aquifer's low salinity (the Nubian sandstone aquifer) upward leaking through faults and fracture also reduces salinity. The salinity pattern for the samples taken from the Eocene groundwater aquifer was shown in Fig. 5. The primary source of groundwater rising during fractures, fissures, and faults from the deep aquifer known as the Nubian sandstone aquifer (**Abdel-Aziz et al., 2023**). The southern region (caves), where there are many of these structures, has higher production than the northern and central parts (Fig. 5).
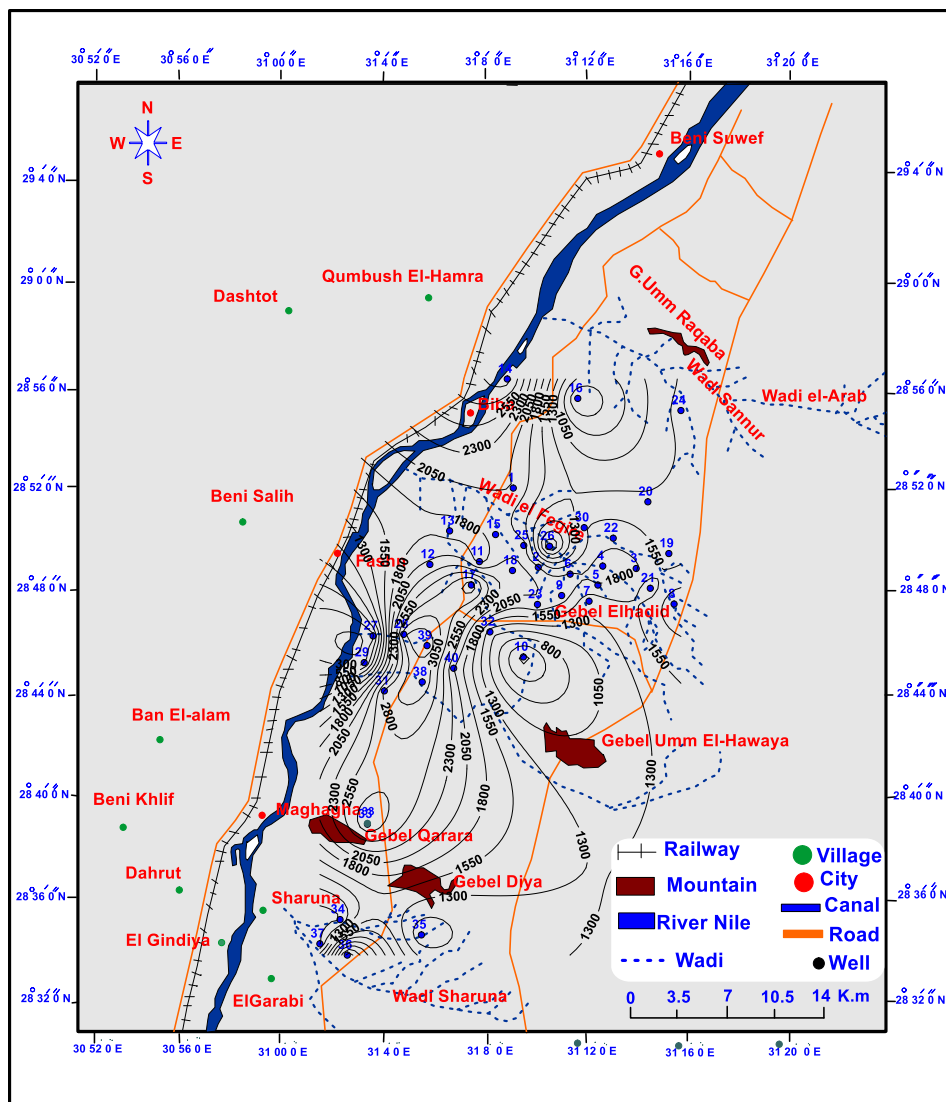

Fig. 5. Total dissolved salts distribution map.

Distribution of calcium (Ca^{2+})

The most important cation in the majority of naturally occurring fresh water is calcium. It contributes to the development of the most prevalent calcium minerals in sedimentary rocks. The most prevalent calcium-containing minerals in sedimentary rocks are fluorite (CaF$_2$), carbonate, and sulphate. Gypsum (CaSO$_4$2H$_2$O) and anhydrite (CaSO$_4$) are sulphate minerals. Calcite (CaCO$_3$) and aragonite (Ca Mg (CO$_3$)$_2$) are carbonate minerals. Calcium concentrations in the bulk of Eocene groundwater samples ranged from 3.9 ppm to 19.5 ppm. High calcium concentration levels are mostly caused by the dissolution of calcium-rich sediments (**Abdel-Aziz et al., 2023**). Fig. 6 demonstrated that the eastern side of the Nile River had higher Ca^{2+} distributions.

The leaching of highly soluble carbonate minerals like calcite, dolomite, and gypsum from the water-bearing formation, which has a significant impact on water quality, which may be the cause of the high concentration of calcium ions in the investigated region.
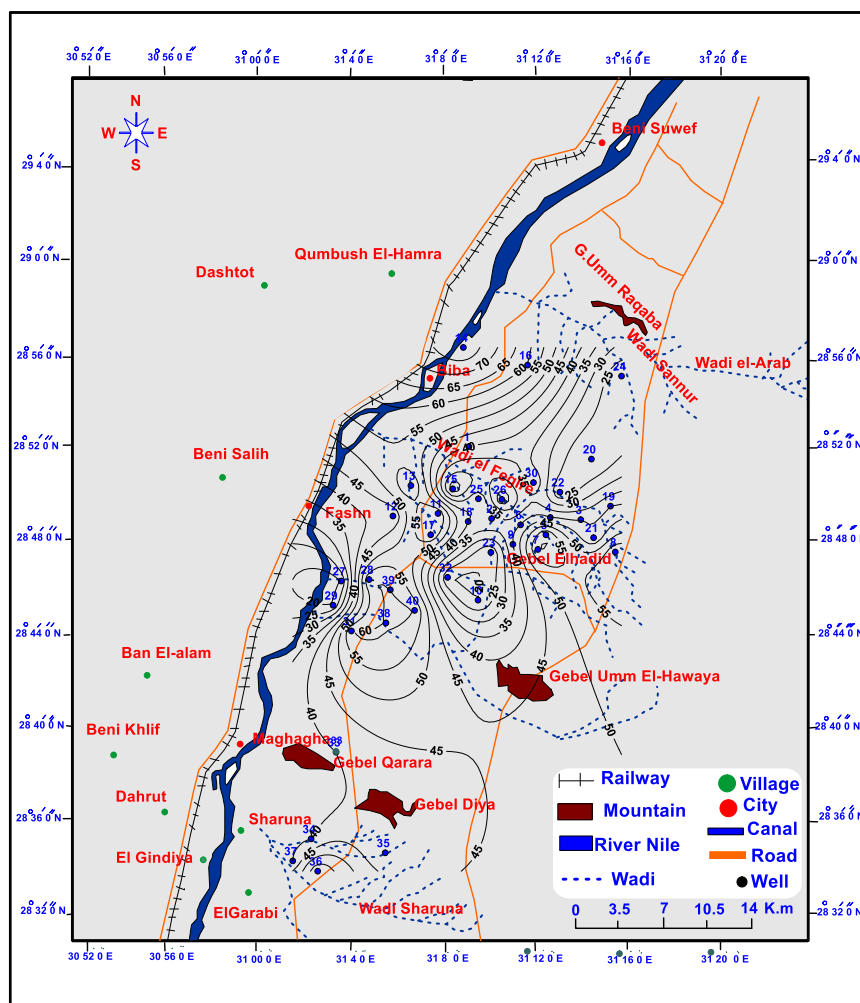

Fig. 6. Calcium distribution map.

Distribution of Magnesium (Mg^{2+})

Magnesium chloride salts, which represent the impact and leaching of marine deposits, may be responsible for the high magnesium concentrations. Magnesium ion concentrations in groundwater wells ranged from 6 ppm in well number 10 to 24.32 ppm in well number 37, which was located in the central and northwestern part of the research region. Fig. 7 demonstrated that magnesium levels were low on the research area's eastern side and increased on the middle and western sides, which corresponded to the leaching and dissolving of deposits containing magnesium (**Abdel-Aziz et al., 2023**).

Distribution of Sodium (Na$^+$)

The most dominating cation in the region under study is sodium, which is found in the majority of samples in concentrations ranged from 440 ppm in well No. (22) to 1020 ppm in well No. (14). Typically, it appears as sodium salts that are easily soluble (Fig. 8). The ion exchange and leaching processes of clays and salts found in aquifer matrix are to blame for the high sodium ion concentrations seen across the research region (**Abdel-Aziz et al., 2023**).
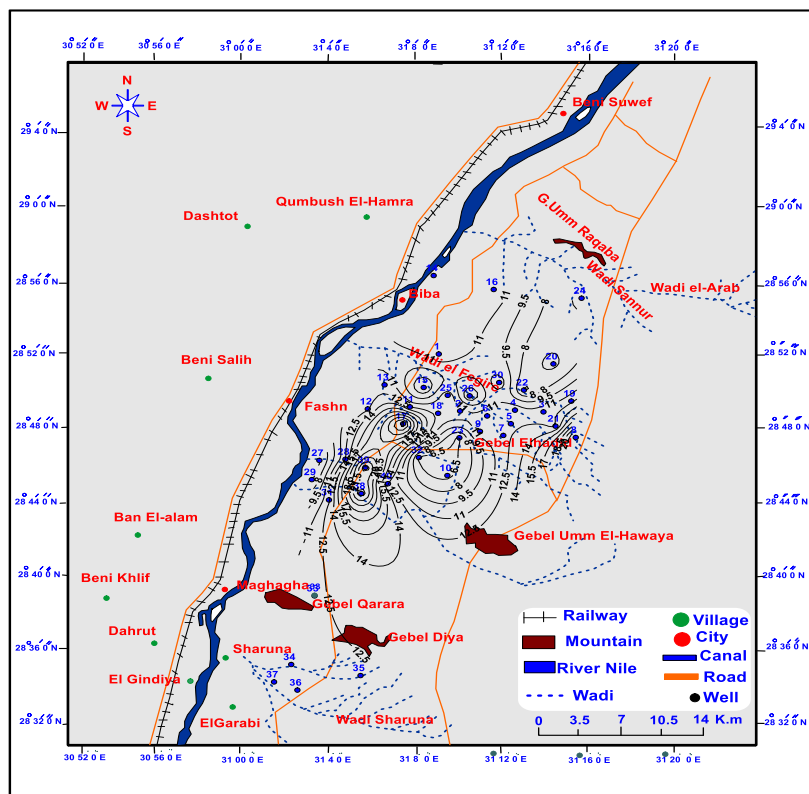
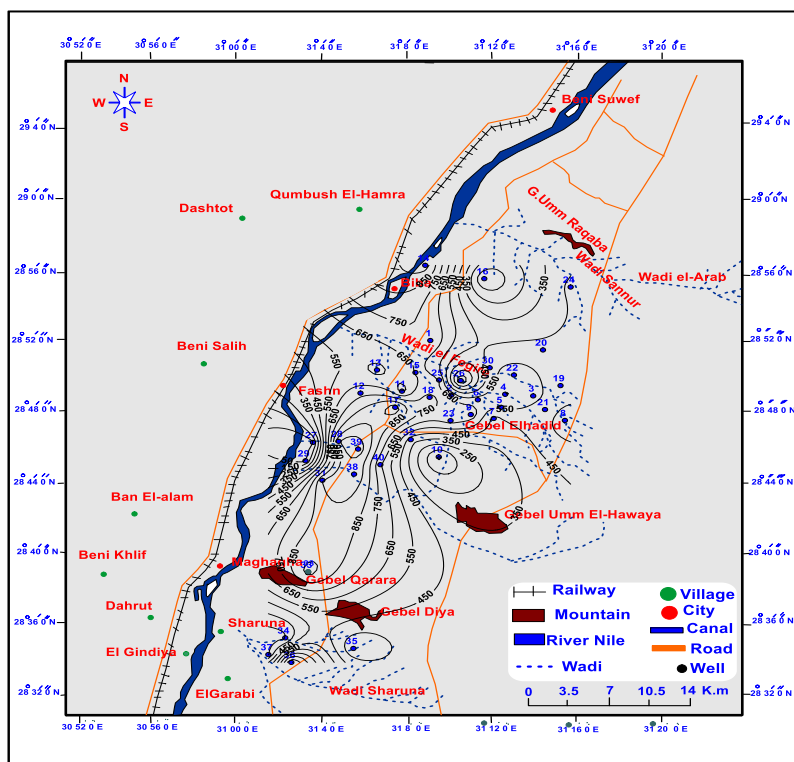Fig. 7. Magnesium distribution map.

Fig. 8. Sodium distribution map.

Distribution of Potassium (K+)

The least prominent cation in the area under study is potassium. According to Fig. 9 its content varies from 3.9 ppm in well No. 7 to 37.8 ppm in well No. 9. According to Wedepohl, 1953, the presence of potassium ions in large concentrations indicates the presence of clay minerals, particularly illite, as well as the weathering of K-minerals (**Abdel-Aziz et al., 2023**).
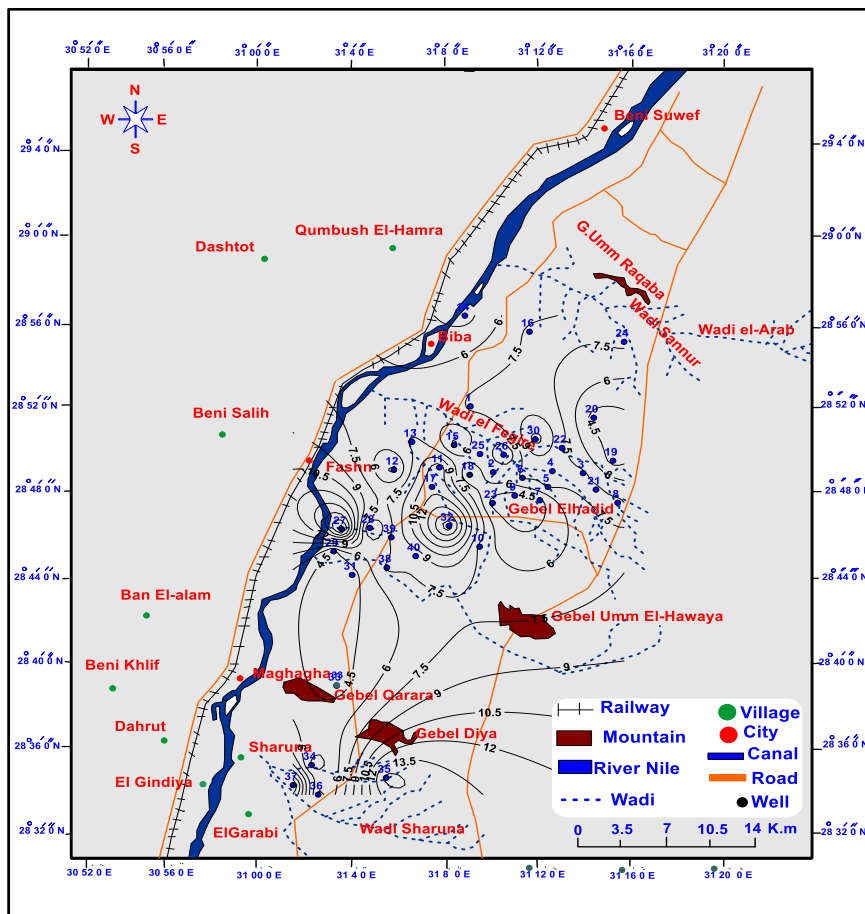

Fig. 9. Potassium distribution map.

Distribution of Chloride (Cl⁻)

In naturally occurring fluids, chloride ions may be found in contents ranging from 3 ppm in rainwater to 19000 ppm in seawater. Chloride is often mainly found in coastal sediments, and saltwater is thought to be the major source of the chlorides. As shown in Fig. 10. The bulk of the groundwater samples obtained revealed that the chloride content varied from 335 ppm in well No. (22) to 674 ppm in well No. (17). The leaching activities of highly soluble chloride minerals like halite and sylvite from the water-bearing formations may be responsible for the high content of Cl⁻ in the groundwater of the Eocene aquifer in the studied region (**Abdel-Aziz et al., 2023**).

Distribution of Sulphate (SO₄²⁻)

Gypsum and anhydrite are the two main sources of sulphates in natural water. In the presence of sodium chloride, calcium sulphate is much more soluble. According to Fig. 11, sulphate levels in groundwater samples range from 323 ppm in

well No. (19) to 1478 ppm in well No. (38). The highly soluble sulphate minerals gypsum and anhydrite, which have a significant impact on the geochemistry of the groundwater passing via contact with them, may be the cause of the high content of SO_4^{2-} for the groundwater in the investigated area.
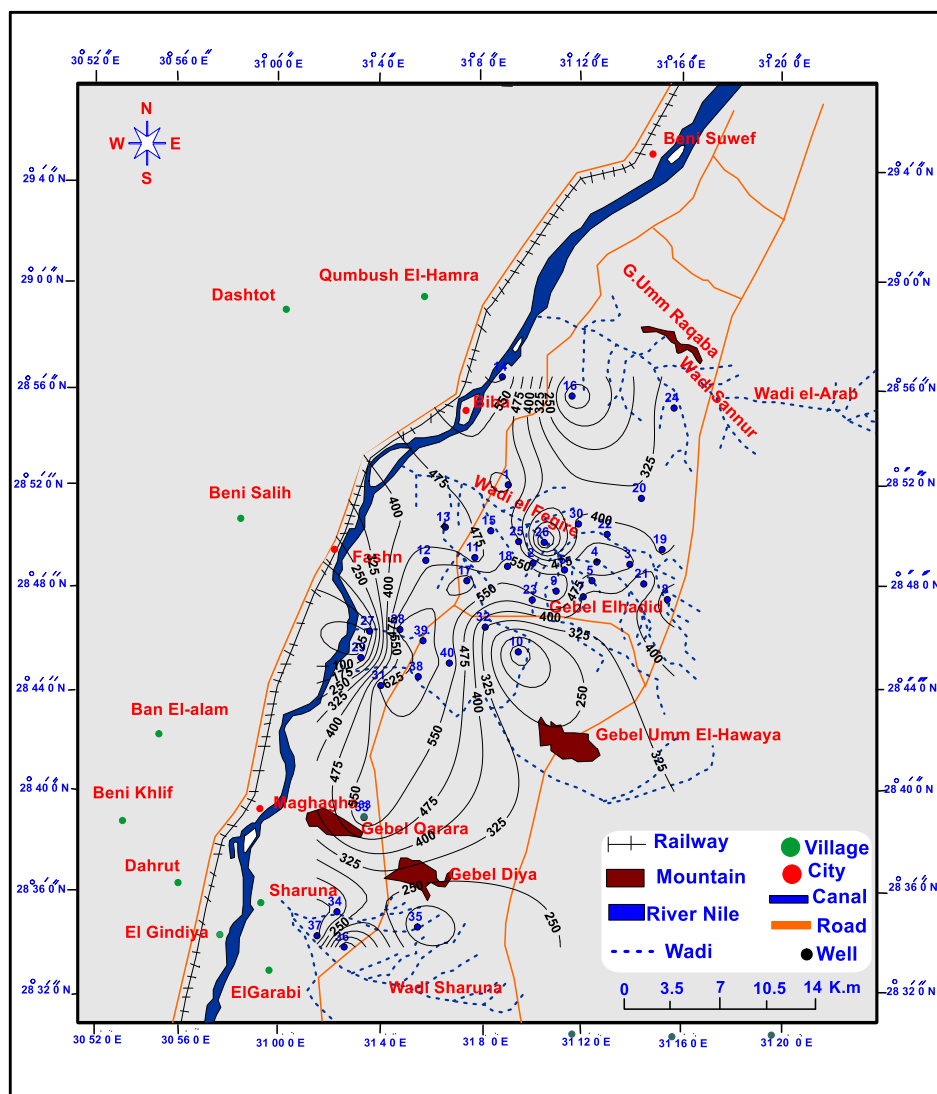

Fig. 10. Chloride distribution map.

Distribution of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-})

It is well known that the creation of the more soluble bicarbonate causes the solubility of $CaCO_3$ to significantly increase in the presence of CO_2. The atmosphere and certain organic detritus in the recent aquifer sediments, which are the primary source of carbon dioxide. The majority of Eocene groundwater samples include bicarbonate, with concentrations ranged from 62 ppm to 124 pm (Fig. 12). The excessive amount of HCO_3 in the groundwater of the study area may be caused by the leaching activities of highly solubility of carbonate elements such calcite and dolomite from the aquifer materials.
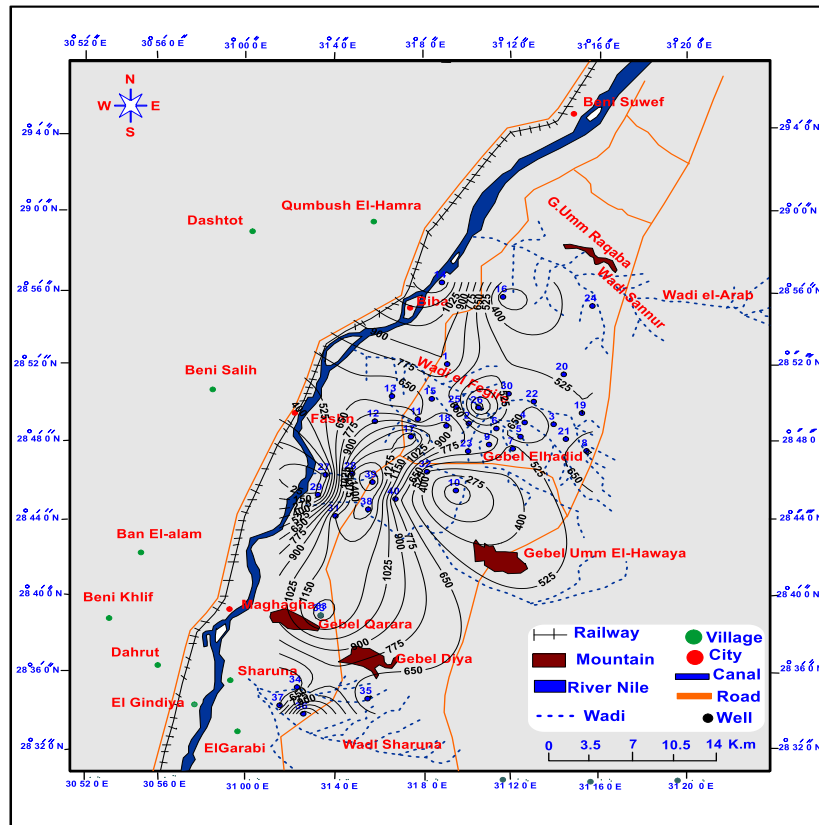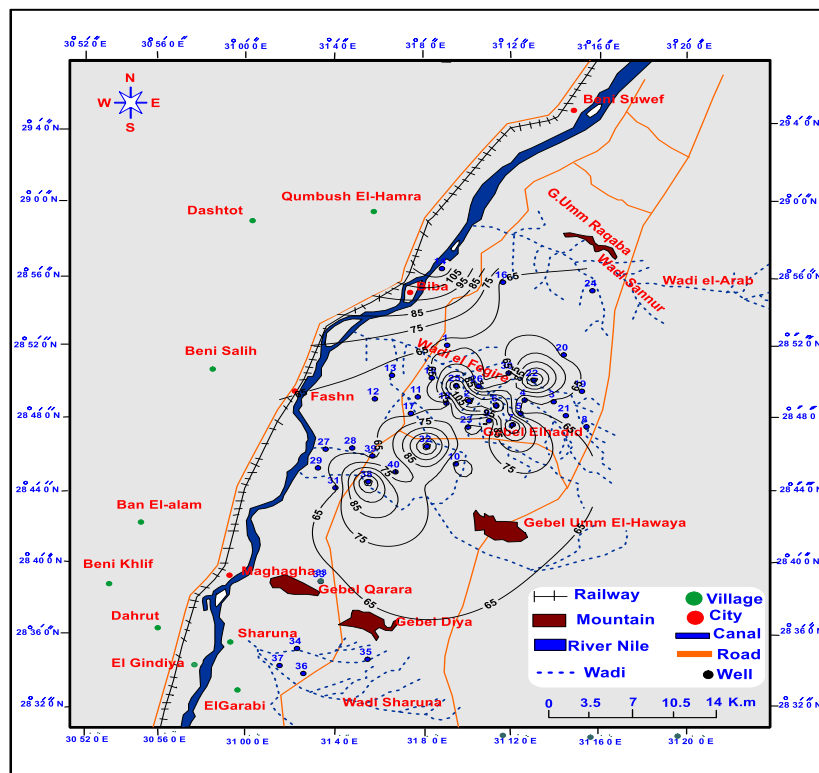
Fig. 11. Sulphate distribution map.

Fig. 12. Bicarbonate distribution map.

Conclusion

Under conditions of sustainable development, an integrated method was utilized to assess the water quality in the Limestone aquifer using physico-chemical parameters and geochemical properties of the water-bearing formation. The analytic groundwater quality indicated that $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$ and $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. The geochemical properties of the water samples that were taken also indicated the types of water that were Na-SO_4 and Na-Cl. The hypothetical salt mixture showed the existence of several salts, such as Na_2SO_4, NaCl, Ca $(HCO_3)_2$, $MgSO_4$, $CaSO_4$, and KCl with their average equivalent percentages being 43%, 40%, 7%, 5%, 4%, and 1%, respectively. the investigated groundwater chemical composition. Most of the groundwater from the studied area can be used with some limitations to avoid salinity and alkalinity issues in the long term. Landowners in newly reclaimed lands should be urged to employ contemporary irrigation techniques including sprinkler and drip irrigation technologies for the integrated management and efficient use of water resources. To enhance their reliability for preserving water quality under various conditions and to encourage decision-makers to adopt different technologies for water quality planning and management, the methodologies presented in this study should also be further investigated. The study also focused on a specific set of physicochemical elements related to water quality. Incorporating additional relevant factors, such as heavy metals, pesticides, and microbiological markers, would be advantageous in order to provide a full evaluation of the water quality and any potential impacts on agricultural productivity and public health. Examining the possible integration of socioeconomic factors, such as water demand, land use, and sociocultural practices, would help raise knowledge of the entire management of water quality and decision-making processes.

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