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Groundwater QualityAssessment for Irrigation Using Indexing Approach for The Limestone Aquifer in Eastern Nile Valley, Egypt

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Abstract

In arid regions, groundwater is regarded as the primary supply of freshwater and is a valuable natural resource. Groundwater quality in the Limestone aquifer was evaluated using integrated physicochemical criteria under sustainable development guidelines. Forty ground water points were sampled from the fractured limestone aquifer in the investigated region during the summer of 2021. According to their physicochemical qualities, the main ion concentrations were derived in the following order: Cl-> SO42->HCO3->CO32- and Na+> Ca2+> Mg2+> K+.The Na-SO4 and Na-Cl water types were the two kinds of groundwater present in the Eocene aquifer.The irrigation water quality index (IWQI) found that about 82.5% of groundwater samples had high restrictions (HR), which should be utilized for irrigation of plants with moderate to high salt tolerance with specific salinity management procedures. In addition, approximately 2.5% of samples were moderate restriction (MR), approximately 7.5% of samples were low restriction, and about 7.5% of samples had no restrictions (NR) on irrigation and most plants may be used for irrigation without running the risk of toxicity.The IWQI results should be utilized for irrigation of plants with moderate to high tolerance to salts with special salinity control practice.

Keywords: Groundwater quality,Irrigation index,Limestone aquifer.

Introduction

The majority of Egypt's agricultural operations depend on the availability of agricultural water viasurface water. Farmers in the Delta area of the northern Nile are making heavy use of surface water networks for irrigation **(Gad *et al.*, 2023)**. Because these canals are thought to be the only source of irrigation in that area, the impact on their crops is significant. Water is a necessary component of life and one of the most plentiful resources on the surface and inside the Earth. Around 4% of Egypt's total land area is used for agriculture, most of which is located in the Nile

Delta and the confined valley that runs parallel to the Nile. The area is one of the most heavily irrigated in the world, and it produces a wide variety of crops. Since the efficiency of agricultural water use is currently generally low, recovering deep percolation losses through groundwater pumping and reusing return flows collected by agricultural drainage networks have become crucial components of Egypt's management of its water resources **(Gad *et al.*, 2022)**. This is done in order to close the gap between supply and demand **(Abd-Elmabod *et al.*, 2019)**.

Human excrement and agricultural wastes rich in fertilizers including nitrogen, phosphorous, and potassium, with phosphorous being the important element limiting the growth of algae and water pollution, are the main sources of the minerals entering the water. The fundamental goal of irrigation water quality indicators (IWQIs) is to transform a huge amount of complex data into numerical information, which contributes to better comprehension of water quality. Each index's main goal is to assess a drainage system's suitability for irrigation applications **(Masoud *et al.*, 2022)**.

The individual water quality measure does not provide enough information to determine the validity of water for agriculturedue to its potential for limitation and possibility for regularly generating subpar findings in the evaluation. The irrigation water quality index (IWQI) is a simple approach for certifying water quality that may reply for modifications in the fundamental properties of water. According to **Elsayed, et al., 2020, Bora and Goswami, 2017**, the IWQI is a strategy that ranks the cumulative impact of all the water quality-related factors on the total water quality to measure the water quality at an agreed-upon location and time.

The principal cations and anion, heavy metals, temperature, and pH measurements are the key parameters of water quality and are used extensively in the IWQIs, which categorize the quality of water for consumption. The IWQI score, which sums together the effects of several water quality parameters, is regarded as an accurate measure. The WQIs offer a useful evaluation of the irrigation water quality **(Brown, 1970)**. As a result, the presence of multiple major dissolved ions in water is a common factor in defining various IWQIs including major cations and anions.The objectives of this investigation were to (i) determine the source and type of groundwater in the Limestone aquifer and (ii) assess the quality of that groundwater utilizing IWQI.

Materials with methods

Study area

The study's geographical 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 Fig. 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.

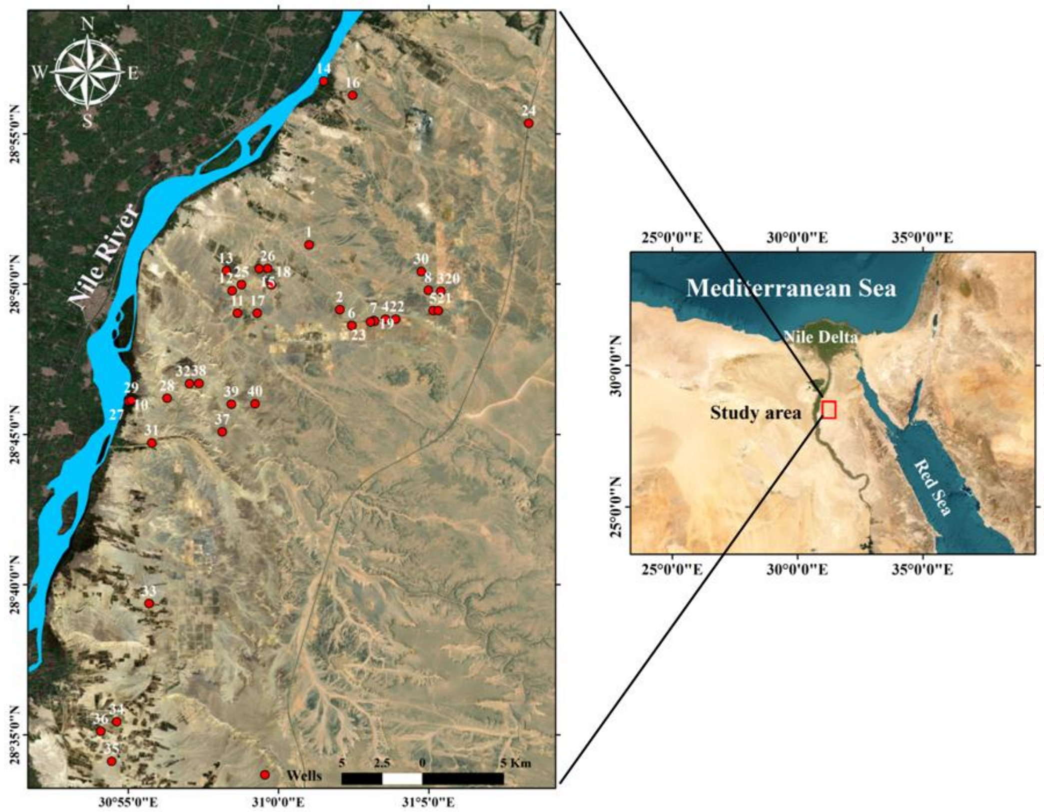

Fig. 1. The map of investigated area and water samples.

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 the 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. Within an hour of collection, the samples were taken to the lab for analysis. Before being transported to the laboratory, samples were maintained in a refrigerator at 4° C and filteringvia 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 (Table 1) **(APHA, 1998)**.

Indexing approach

An easy-to-use approach that may respond to adjustments in the fundamental features of water is the Irrigation Water Quality Index (IWQI). For the purpose of helping to evaluate the total quality of the water at a certain place and time, it is described as an approach that offers a rating (0-100) of the cumulative influence of various criteria of water quality on the total water quality. The recommended IWQI simplifies the evaluation of the quality of agricultural water by reducing huge amounts of data into one metric that represents the state of the irrigation water availability. The suggested sub-indices functions also aid each parameter's understanding of its pollution state. The recommended sub-indices and the whole irrigated water quality index are expected to be extremely helpful to irrigation water conservation, site individuals, and those in responsibility for observing, evaluating, and regulating agriculture waters.In order for the general public to comprehend and apply complicated water quality data, the water quality index calculation aims to convert such numbers. As a result, the irrigation water quality index (IWQI), which is based on a number of crucial characteristics and offers a basic assessment of water quality, is a highly useful and practical tool.

Table 1. Analysis methods of physicochemical parameters for the collected groundwater samples.

Physicochemical 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

The following equation **(Brown, 1970)** was used to construct the IWQI as the total of each variable's specific values (Q_i) weighed by the importance of that variable in determining the total quality of the water (W_i).

$$\mathbf{IWQI = \sum_{i=1}^{n} Q_i W_i} \qquad \textbf{(1)}$$

In this equation, i stands for the number of variables, which in this case includes EC, Na^+, Cl-, HCO_3^-, and SAR (Table 2). Q_i and W_i stand for the relative value and weight of each variable, accordingly. The weight of the various water quality parameters, such as the value of the water quality measurement parameter (Q_i) and the weight of the ith value (W_i), is determined by standardizing the ith value's weight and then taking into consideration the criteria put out by Ayers and Wescot, 1999. The following equation was used to get the value of Q_i **(Meireles *et al.*, 2010)**:

$$\mathbf{Q_i = Q_{imax} - [(X_{ij} - X_{inf}) \times Q_{iamp} / X_{amp}]} \qquad \textbf{(2)}$$

Where, X_{ij} denotes the observed value of each variable.
Q_{imax} denotes the max. value of Q_i for each class to which the variable belongs.
X_{inf} denotes the lower limit value of the class.
Q_{imap} denotes the class amplitude.
X_{amp} denotes the class amplitude.
The W_i values were normalized (Table 3), and their final total was set to one using the equation below:

$$\mathbf{W_i = \frac{\sum_{j=1}^{k} F_j A_{ij}}{\sum_{j=1}^{k} \sum_{i=1}^{n} F_j A_{ij}}} \qquad \textbf{(3)}$$

where i represents the number of IWQI ranging from 1 to n.
j represents the number of IWQI factors ranging from 1 to k.
A_{ij} is the parameter i's capacity to be explained by factor j.
F is the component 1 constant value.

Table 2. Limitation values for water quality calculation (Q_i).

Q_i	EC (µs/cm)	SAR (mmol/L)	Na^+ (mmol/L)	Cl^- (mmol/L)	HCO_3 (mmol/L)
85-100	200≤EC<750	2 ≤SAR< 3	2 ≤ Na < 3	1 ≤ Cl < 4	1≤ HCO_3 <1.5
60-85	750≤EC<1500	3 ≤SAR< 6	3 ≤ Na < 6	4 ≤ Cl < 7	1.5≤ HCO_3 <4.5
35-60	1500≤EC<3000	6≤SAR<12	6 ≤ Na < 9	7 ≤ Cl < 10	4.5≤ HCO_3 <8.5
0-35	EC<200 or EC≥3000	SAR<2 or SAR≥12	Na < 2 or Na ≥ 9	Cl< 1 or Cl≥ 10	HCO_3<1 or HCO_3 ≥ 8.5

Table 3.The IWQI parameters weights.

Parameters	W_i
Electrical conductivity (EC)	0.211
Sodium (Na^+)	0.204
Chloride (Cl^-)	0.194
Bicarbonate (HCO_3^-)	0.202
Sodium Absorption ratio (SAR)	0.189
Total	1.00

Results and Discussion

Physico-chemical parameters

The geologic background, particularly the structural framework, the position, the lithologic facies of the water-bearing formation, and the prevalent hydrologic conditions, either on the surface or below, all affect the groundwater east of the Nile Valley. Through consideration of both the geochemical composition and distribution and the hydrochemical categorization of groundwater, the hydrogeochemical features are examined (Table 4). According to the physicochemical results, the main ion concentrations were derived in the following order: Cl^-> SO_4^{2-}> HCO_3^-> CO_3^{2-} and Na^+> Ca^{2+}> Mg^{2+}> K^+. The Na-SO_4 and Na-Cl water types were the two kinds of groundwater present in the Eocene aquifer.

Hydrogeochemical Facies

Based on ion interactions, the trilinear diagram of Piper, 1953 is the most often used for classifying groundwater's geochemistry. This categorization system uses cation and anion percentage equivalents per million. Two triangle-shaped diagrams are shown; the left one is for plotting the cations, while the right one is for plotting the anions with a diamond-shaped field for projection. The bottom left triangle represents the primary cations (calcium, magnesium, sodium, and potassium), whereas the lower right triangle represents the key anions (bicarbonate + carbonate, sulphate, and chloride). The sample is represented by three points, two of which are projections of the other two on the diamond-shaped field. One point each represents the cations and anions in the sample.

Table 4. Statistical description of the physico-chemical parameters.

Parameter	Min	Max	Mean
pH	7.11	7.80	7.45
EC	300	5500	2789.62
TDS	192	3520	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	739.27
HCO_3^-	62.00	124	74.40
CO_3^{2-}	0.00	0.00	0.00

The water in the upper triangle of the diamond-shaped field shows secondary salinity characteristics, where SO_4 + Cl > Na + K. So, Ca, Mg, and sulphate are the hypothetical salts. The water that appears in the bottom triangle, on the other hand, is thought to have primary alkaline characteristics, where CO_3 + HCO_3> Ca + Mg, and the typical salts are Na and K carbonate and bicarbonate. The data from the groundwater's chemical analysis are represented on the diagram (Fig. 2) in relation to the research region **(Abdel-Aziz *et al.*, 2023)**.

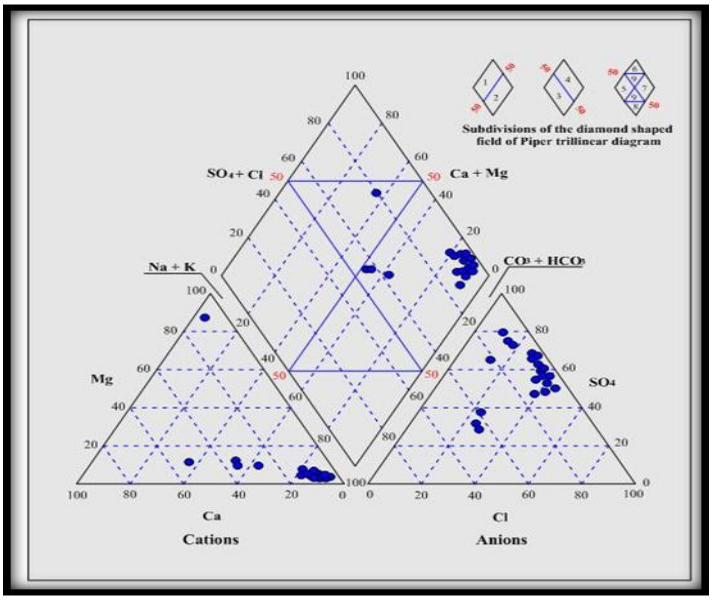

Fig. 2. Trilinear Diagram for Groundwater samples of the Eocene aquifer.

Irrigation water quality index (IWQI)

The IWQI is a calculated indicator with no dimensions that captures the composite factors affecting overall water quality. It creates a single value from a number of factors and their concentrations, providing a quantitative and detailed evaluation of the total quality of the water as well as its appropriateness for different uses **(Meireles *et al.*, 2010, Sener *et al.*, 2017, Kachroud*et al.*, 2019)**. The IWQI findings showed a range of values between 40.05 and 100.00, with a mean value of 52.98 (Table 5).

Table 5. Summary of the descriptive statistics of the determined IWQI.

Parameter	Min.	Max.	Mean
IWQI	40.05	100.00	52.98

The IWQI categorization developed by **Meireles et al. (2010)** determined that 82.5% of groundwater samples were high restriction (HR) and should be utilized for irrigation of plants with moderate to high tolerance to salts with particular salinity management practices, while approximately 2.5% of samples were moderate restriction (MR). Moreover,approximately 7.5% of samples were low restriction (LR), and approximately 7.5% of samples were no restriction (NR) for irrigation with no toxicity risk (Fig. 3).

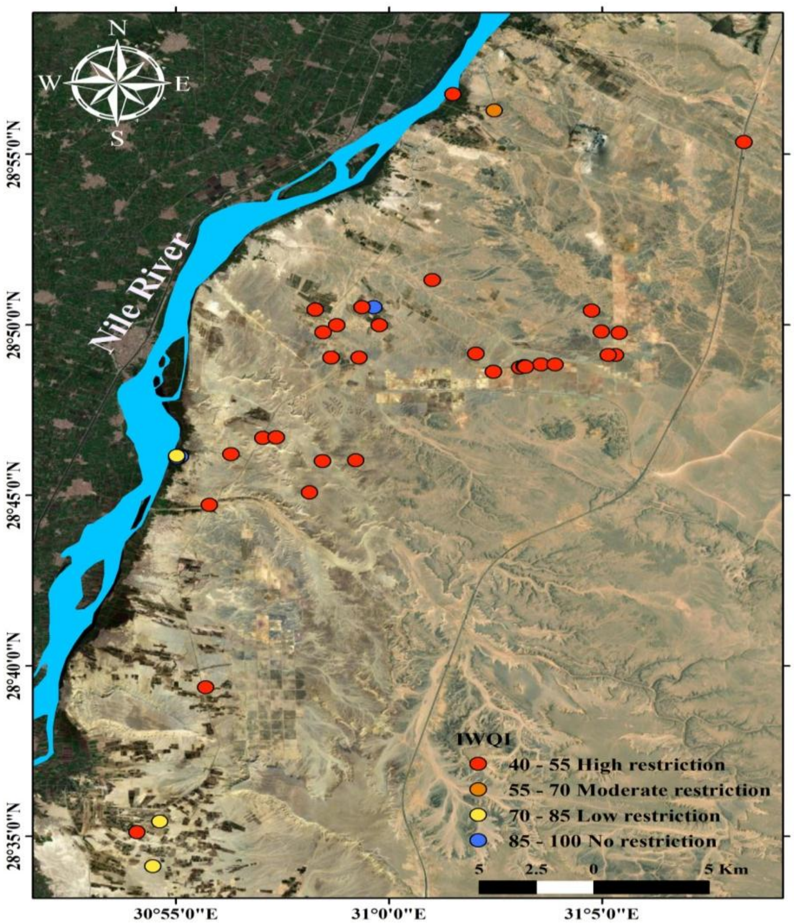

Fig.3. Spatial distribution map of IWQI.

Conclusion

In order to assess the irrigation water quality index and physicochemical characteristics of groundwater utilized for agricultural in the investigated region under sustainable development conditions, an integrated method was adopted. Cl^{-}> SO_4^{2-}> HCO_3^{-}> CO_3^{2-} and Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} were found in the groundwater samples that were collected. 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 calculated IWQI showed that approximately 82.5% of the groundwater samples were HR, which should be utilized for irrigation of plants with moderate to high tolerance to salts with special salinity control practice, approximately 2.5% of samples were MR, while approximately 7.5% of samples fall in LR and approximately 7.5% of samples fall in NR for agricultural purposes with no toxicity risk for most plants on their use for irrigation.Due to the limitations of traditional approaches for managing groundwater quality, it is essential to use dependable, efficient, and quick methods that can be utilized and assist decision-makers in comprehensively assessing important metrics appropriate for water quality. This study provides useful methods for making educated judgments on groundwater to guarantee proper leadership managementand describe in detail how sampling practices may be adjusted.In order to make the approaches recommended in this study more dependable for sustaining water quality in a range of situations and to encourage decision-makers to employ a variety of technologies for water quality planning and management, further research should be done on them. The study also focused on a particular set of physicochemical aspects of water quality.To get a more evaluation of the water quality and its potential implications on agricultural and human health, it would be advantageous to integrate additional important features, such as heavy metals, pesticides, and microbiological markers. Examining the possible incorporation of socioeconomic variables, such as water demand, land use, and sociocultural practices, would help raise understanding of the entire management of water-quality and decision-making processes.

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