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Groundwater suitability for irrigation and domestic use applying CCME WQI model and GIS in East El-Owainat, Egypt

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GROUNDWATER is the major source of irrigation and domestic water use in the East El-Owainat region since it is accessible and pollutant-free. The measured qualitative groundwater variables (salinity, alkalinity, total dissolved salts, total hardness and soluble ions), irrigation indexes and Canadian water quality index (CCME-WQI) were calculated to estimate water quality. Piper's trilinear diagram showed that over 85% of the total samples exhibit Na-Cl facies, indicating that the mineral structure of the water reservoir has a substantial effect on the chemical characteristics of aquifers. The tested groundwater samples revealed that 59.68% of the salt assemblage consisted of NaCl, Na_2SO_4, $MgSO_4$, and Ca $(HCO_3)_2$, illustrating the leaching effects and dissolving evaporating deposits as well as the intermediate stages of chemical evolution. About 39% of the total samples had Fe concentrations higher than what is acceptable for human consumption. The US Salinity Diagram revealed that the bulk of the tested samples belong to the C3S1 group, which defines a high salinity with a low Na type. According to CCME-WQI, 80 and 97% of groundwater samples are acceptable for drinking and excellent for irrigation, respectively. A factor analysis suggests that ion exchange and groundwater-rock exchanges, all of which are connected to the natural water source, have a favorable impact on the water quality. Groundwater quality based on the CCME-WQI index remains suitable for human and cultivation purposes. For ecosystem safety, groundwater quality must be monitored regularly.

Keywords: Nubian sandstone, aquifer, East El-Owainat, US Salinity Diagram, Canadian water quality index.

1. Introduction

East El-Owainat area ranks as the second largest agricultural project located in southern Egypt ≈ 365 km south of El-Dakhla Oasis, New Valley Governorate and about 500 km far away from Lake Nasser. The area has fertile soil and pollutants pollution-free so it has high potential for agriculture. The cultivated area is ≈ 214 thousand hectares, almost half of its distributed among agricultural companies that produce many crops totaling 3 million tonnes each year. Also, complete settlements were established, and they relied on accessible water sources (El Nahry et al. 2010). Masoud et al. (2013) revealed that the Nubian sandstone reservoir in the southern part of Egypt serves as the main recharge source for the East-Oweinat region. Sayed et al. (2004) reported that the groundwater in the East Oweinat region matches the natural water category, indicating a meteoric water source. They also highlighted that the structural arrangement of the region influences groundwater flowing system. The accessible groundwater in the East El-Owainat region might be applied to sustainable development over approximately 174 years if the current situation is managed well (Ibrahem 2019). In the East El-Owainat region, groundwater is the only source for irrigation and domestic use. Natural filtering may result in great groundwater quality in numerous localities. On the other hand, groundwater properties are susceptible to ecosystem changes (Makki *et al.*, 2021; Nofal *et al.*, 2024). Many researchers have observed high iron (Fe) concentrations in the Nubian sandstone aquifer, which is the principal geogenic trouble of drinking and irrigation water supply (Yehia et al. 2017; Gad et al. 2016; Embaby and Ali 2021; El-Rawy et al. 2019). Iron complexes might be a greater risk to health compared to the fairly innocuous mineral itself. The highest Fe concentration in irrigation water should be < 5 mgl^{-1} (Ayers and Westcot 1994), whereas it is limited to 0.3 mgl^{-1} in drinking water (WHO 2011). Hemochromatosis patients may experience adverse

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effects on their liver, spleen, and heart when consuming large levels of iron in humans (Abdelhafez et al. 2021). Groundwater quality is an important challenge in many arid environments due to increased evaporation and little rainfall resulting in many constraints on its usage and management, as well as a hindrance to the growth of local economies (Abdelhafez *et al.*, 2021; Abdelaty *et al.*, 2022; Saleh *et al.*, 2023). Groundwater geochemical parameters are affected by the nature of recharging water, water-rock interaction, groundwater patterns, and hydrogeological assembly as well as earth material types (M. Gad et al. 2016; Saleh et al. 2023). The variations in groundwater quality are commonly caused by overuse, recharge water type, and human activity (Elnazer et al. 2021; Abdelshafy et al. 2019; Ismail et al. 2021). So, it is essential to examine the chemical properties of any aquifer to be permitted for irrigation or domestic purposes (Mester *et al.*, 2018). It may be helpful to apply a ranking according to the content and concentration of soluble ions in water to assess if it is suitable for human consumption and agricultural uses. The water quality index (WQI) and irrigation water quality index (IWQI) are important in measuring the appropriateness of water sources for cultivation and human consumption (Asadi et al. 2020). The Canadian Council and Environment Minister established a Water quality index in 2001 to simplify water quality data (CCME 2007; Alexakis 2022). This index provides the capacity to combine numerous assessments with diverse measuring units into a single measure and to express multiple aspects in a single number. The index may produce a comprehensive assessment of water quality which may be presented to consumers in a simple manner. Both engineering and non-technical users can benefit from this technology, which makes reporting information about water quality. As a result, establishing a water quality index is one of the primary issues in groundwater investigations. The objective of the current study is to establish and categorize groundwater quality for drinking and irrigation according to the CCME WQI model as well as the environmental impact of its use on agricultural and drinking purposes. The FAO (Ayers and Westcot 1994) and WHO, (2011) guidelines were used as indicators for various sets of variables.

2. Materials and Methods

2.1. Location

The East-Owainat area is a part of the Western Desert of Egypt and it is located close to the Egypt-Sudan border. The study area is governed by longitudes 28° 32′ 00" E and 28° 56′ 00" E and latitudes 22° 7′ 00" N and 22° 40′ 00" N (Figure 1).

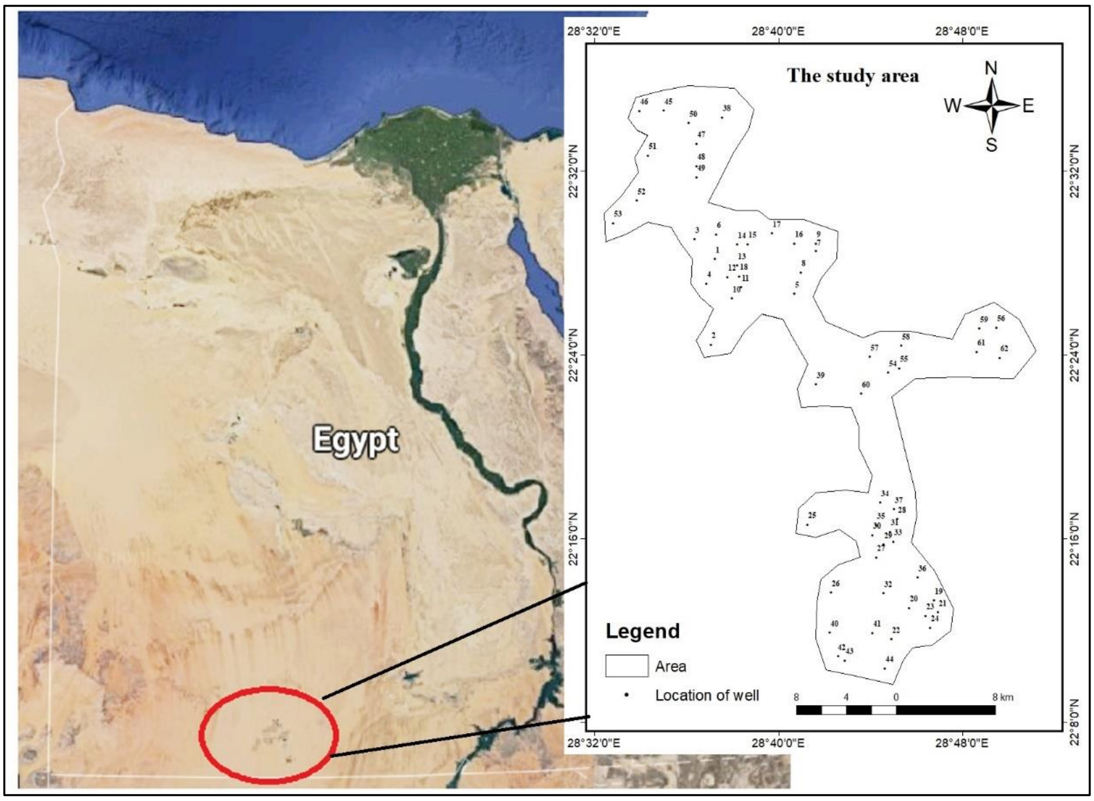

Fig. 1. Map of the study location displaying the exact positions of groundwater samples.

Large daily changes with dry weather and extremely high temperatures distinguish the region. It is in a hyper-arid meteorological category with a drought grade of 0.05 (Ibrahem 2019; El Nahry et al. 2010).

The highest temperatures (40 °C) have been reported in summer, whereas the lowest temperatures (5.2 °C) are reported in winter. The evaporation is high (32.8 mm day^{-1}) in June and low (5.4 mm day^{-1}) in January (Araffa and Bedair 2021). As reported by a digital elevation model, the land topographic altitudes range from 209 m (ASL) towards the northeast to 344 m (ASL) towards the southwest, having a northeastern surface slope of 0.8 mkm^{-1} (Ibrahem 2019).

2.2 Geomorphologic, geologic and hydrologic setting

According to Youssef (Youssef 1996), there are six main geomorphological types in the East El-Owainat region, which are high sand sheets, moderate sand sheets, low sand sheets, high gravelly sand plains, low gravelly sand plains and depression. Geologically, the East-Oweinat region recognizes sedimentary succession (Figure 2) extends from the Cretaceous to the Quaternary and includes exposed igneous and metamorphic rocks categorized as Precambrian basement rocks (Al Temamy and Barseem 2010). The six hills formation, which composes almost all region topography and represents the Upper Jurassic and Lower Cretaceous, was composed of Nubian Sandstone that rests straight on Precambrian basement rocks (El-Osta 2006; Ibrahem 2019). Sand sheets, drift sands, gravelly sheets, and sand dunes are the many types of Quaternary deposits found in the region (Al Temamy and Barseem 2010). A few vertical and sloped laminas filled the main fissures just due to the dry conditions (which persisted for lengthy geological periods), fracturing, disintegration, and percolation occurring in a few of the ironstone beds. The northern part is covered by the Lower-Upper Cretaceous Sabeya Formation and the northeast part are covered by the Lower Cretaceous Kissiba Formation. In the study area, the Quaternary deposits are divided into gravelly sheets, sands, sand sheets, and sand dunes (Nabawy et al. 2019).

The Nubian Sandstone is the most accessible water-bearing formation in the East El-Oweinat region, so it is economicly utilized for cultivation manegements (Ibrahem 2019). The Nubian aquifer provesexceptional hydrogeological conditions and hydraulic characteristics (Nabawy et al. 2019). Its transmissivity ranges from roughly 1020 m^2day^{-1} to 3231 m^2day^{-1}, via a mean of 2060 m^2day^{-1}(Ghoubachi 2019). In accordance with Gheorghe et al. (1978), the transmissivity data show that the water reservoir has a high potential (>500 m^2day^{-1}). Also, it has a decent reservoir thickness up to 336 m and a thin aquitard layer and its calculated groundwater volume is 350 billion cubic meters (bcm) of natural water. It is composed of identical shale strata interspersed between middle to coarse-texture sandstones. The Nubia aquifer's hydraulic parameter was improved, and its storage capacity increased over a lengthy period of time when a dry diagenetic history was prominent in the reservoir sequence.

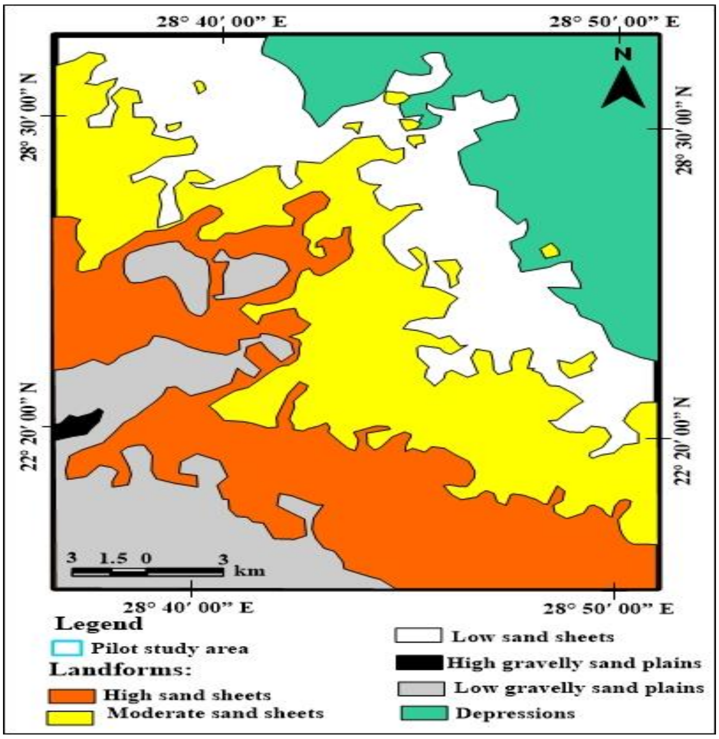

Fig. 2. The geomorphological map of the study region.

2.3. Groundwater sampling and analysis

During the summer season (September 2022), groundwater samples were collected from 62 wells spread throughout the study area (Figure 1). The global positioning system (GPS) was used to locate the groundwater well sites. The groundwater samples were taken after 3 hours of pumping water for every well in 500 ml sterile polyethylene bottles filled to their maximum and locked well to ensure air evicted. A JENWAY Model 430 meter was used to determine the electrical conductivity (EC), soil reaction (pH), and total dissolved solids (TDS) of groundwater at 25° C. Sodium (Na) and potassium (K) concentrations were measured by a flame photometer (JENWAY PFP7), while calcium (Ca), magnesium (Mg), chloride (Cl), and HCO_3 concentrations were measured by volumetric titration methods, and the SO4 concentration was measured by a UV spectrophotometer. In addition, iron (Fe) and manganese (Mn) concentrations were determined by inductively coupled plasma mass spectrometry. Landsat-8 satellite image (Path, 177 and Row, 44; 2022) was utilized and geometrically corrected using ENVI 5.1 software (ITT, 2017). Furthermore, ArcGIS 10.2.2 software (ESRI 2014) was utilized to create maps illustrating the location and spatial distribution of groundwater samples. The research's entire approach is shown in Figure 3.

2.4. Groundwater assessment for irrigation purposes

Several irrigation quality indices, including total hardness (TH), sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), magnesium hazard (MH), permeability index (PI), salinity potential (SP), Kelley's ratio (KR), and Langelier saturation index (LSI), were evaluated and calculated to assess the groundwater suitability for irrigation.

$$TH = (Ca^{+2} + Mg^{2+}) \times 50 \quad (1)$$

$$SAR = \frac{Na^{+}}{\frac{\sqrt{Ca^{2+}+Mg^{2+}}}{2}} \quad (2)$$

$$Na^{+}\% = \frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \quad (3)$$

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (4)$$

$$MH = \frac{Mg^{2+}}{Mg^{2+}+Ca^{2+}} \times 100 \quad (5)$$

$$PI = \frac{(Na^{+}+\sqrt{HCO_3^{-}})}{(Ca^{2+}+Mg^{2+}+Na^{+})} \times 100 \quad (6)$$

$$SP = Cl^{-} + \frac{SO_4^{2-}}{2} \quad (7)$$

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \quad (8)$$

$$LSI = pH - pH_S \quad (9)$$

2.5. Drinking and irrigation groundwater quality index

The water quality was assessed as suitable for drinking or irrigation by using the Canadian Water Quality Index model for the groundwater samples (CCME 2007). The following list of CCME-WQI equations, which rely on CCME (CCME 2007), is: (10)-(16): F1 (scope) displays the proportion of failed features to the total number of attributes evaluated.

$$F1 = \left(\frac{\text{Number o f failed attributes}}{\text{Total number of attributes}}\right) \times 100 \quad (10)$$

The percentage of failed evaluations is shown in F2 (Frequency). A test contrasted a parameter's value from a sample operation to its reference value.

$$F2 = \left(\frac{\text{Number o f failed measures}}{\text{Total number of measures}}\right) \times 100 \quad (11)$$

Amplitude (F3) indicates the degree to which failed test values fail to fulfill their goals (guidelines). An excursion is the number of times a sample's level exceeds (or falls below, if the guideline is a minimum).

Whenever the ith test value is unable to exceed the goal of the jth variable (CCME 2007):

$$excursion_i = \left(\frac{\text{Failed Test Value}_i}{\text{Guideline}_i}\right) - 1 \quad (12)$$

Whenever the test value cannot fall below the goal (CCME 2007):

$$excursion_i = \left(\frac{\text{Guideline}_i}{\text{Failed Test Value}_i}\right) - 1 \quad (13)$$

The overall amount by which single tests were not in conformance is computed by adding the deviations of single tests from its goal and dividing it by the entire number of tests (both those that succeed and those that fail to do so). This parameter, known as nse, is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ o\ f\ measures} \quad (14)$$

To calculate F3, an asymptotic formula scales the normalized sum of variations from guidelines (nse).

$$F3 = \left(\frac{nse}{0.01nse+0.01}\right) \quad (15)$$

After getting the variables, the CCME-WQI is calculated by adding the F1, F2, and F3 values, as shown below (CCME 2007):

$$CCME\ WQI = 100 - \frac{\sqrt{F1+F2+F3}}{1.732} \quad (16)$$

A divide of 1.732 normalizes the obtained values to a score of 0 to 100, where 0 indicates "worst" water quality and 100 represents "excellent" water quality (CCME 2007). The WHO, (2011) and FAO (1994) suggested limits were utilized to evaluate drinking and irrigation water use (Table 2). Water quality is divided into four main groups based on WQI values: excellent (100-95), good (94-80), fair (79-65), marginal (64-45), and poor (<45).

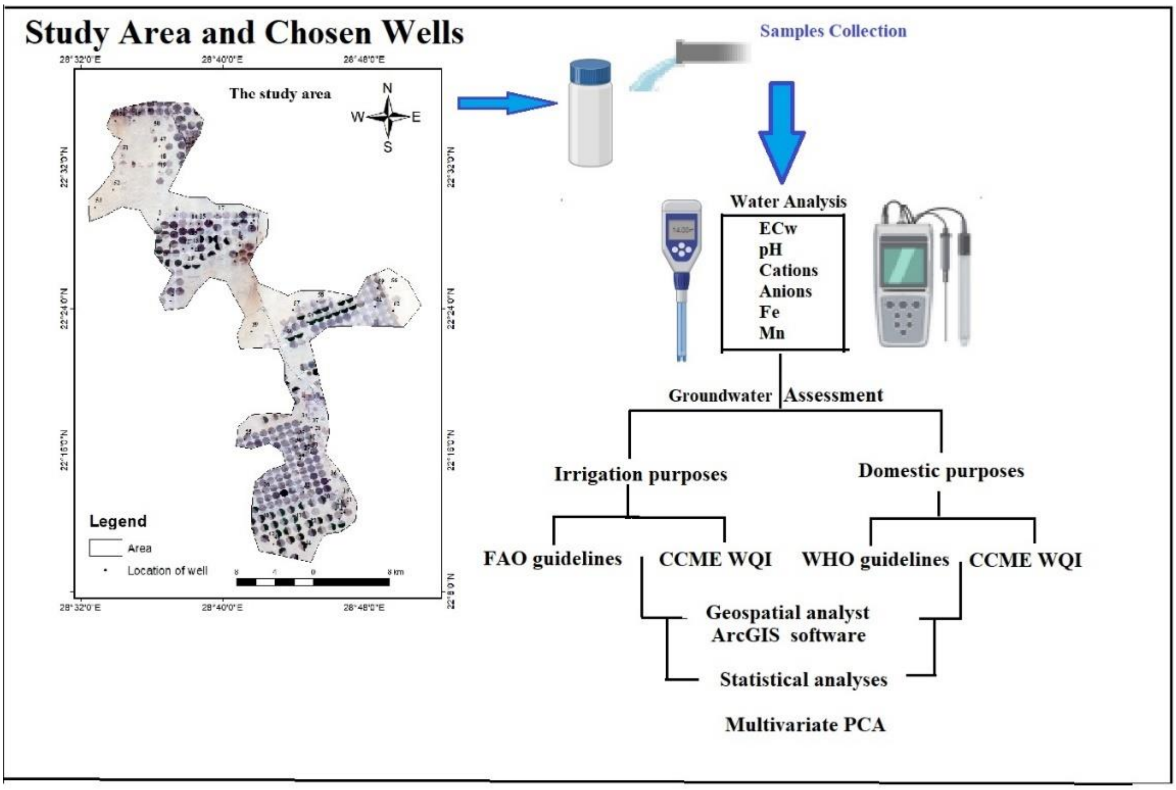

Fig. 3. An overview of the research roadmap.

2.6. Statistical analysis

Descriptive data was provided by Origin Lab (version OriginPro 2018). To clarify the relationship between key ions and their impact on groundwater chemistry. Origin Lab was also utilized to perform and display multivariate statistical analyses in the form of principal component analysis (PCA). OriginLab is used to present Piper diagrams and Gibbs plots.

3. Results

The chemical properties of groundwater can be controlled by geochemical processes that occur as fluid flows into geologic formations. So, it is essential to evaluate groundwater quality utilized for drinking or irrigation. Table 1 displays a statistical summary of the chemical parameters of the groundwater samples.

3.1. Chemical properties

The pH values of groundwater in the East El-Owainat area were approximately neutral to slightly alkaline and they varied from 7.02 to 7.90, with an average value of 7.30 (Figure 4a). Table 1 shows that the ECw values varied from 587.27 to 1585.45 µscm^{-1}, with an average value of 1045.33 µscm^{-1}. The spatial distribution of ECw (Figure 4b) demonstrates that the ECw values were low in the south and increased toward the north. The total dissolved solids (TDS) value in the studied groundwater samples ranged from 323 to 872 mgl^{-1}, with an average value of 616.35 mgl^{-1} (Table 1). The TDS spatial distribution map (Figure 4c) displays that there are general rises towards the northern area of the study region, while there are declines near the middle and southern areas.

The cation contents in the groundwater samples rise in the following order: Na^+> Ca^{2+}> Mg^{2+}> K^+, while anions increase in the following order: Cl^-> HCO_3^- >SO_4^{2-}. Calcium (Ca^{2+}) concentrations ranged from 41.98 to 87.12 mgl^{-1}, with an average value of 65.13 mgl^{-1} (Table 1). The spatial distribution map of the Ca^{2+} concentrations illustrates that they decreased in the middle and extreme southern regions (Figure 5a). Magnesium (Mg^{2+}) contents varied between 13.47 to 40.42 mgl^{-1}, with a mean value of 23.02 mgl^{-1} (Table 1). Magnesium (Mg^{2+}) concentrations increased in the north of the study area, according to the spatial distribution map (Figure 5b). Sodium (Na^+) concentrations ranged from 48 to 170 mgl^{-1}, with an average value of 103.33 mgl^{-1}. Figure 5c depicts the spatial distribution of Na+ since it increased in the north of the study area. The concentrations of potassium (K^+) in the groundwater samples ranged from 2.00 to 16.00mgl^{-1}, with a mean value of 4.60 mgl^{-1}(Table 1). The spatial distribution map of K^+ concentration in the studied groundwater samples is presented in Figure 5d.

The concentration of Cl^- ions in the groundwater samples ranged from 75.15 to 279.30 mgl^{-1}, with an average value of 153.65 mgl^{-1} (Table 1). The concentration of HCO_3^- in the groundwater samples ranged from 76.49 to 134.30 mgl^{-1}, with a mean value of 109.33 mgl^{-1}. The SO_4^{2+} ion concentration ranged from 66.90 to 324 mgl^{-1}, with an average value of 165.95 mgl^{-1} (Table 1). The spatial distribution maps of the major anions (SO_4^{2+}, Cl^-, and HCO_3^-) are shown in Figure 6a, b, and c. The concentrations of SO_4^{2+} and Cl^- anions increase in the north, although HCO_3^- concentrations are lowest in the middle and increase in the south and the north.

Trace elements: The Fe contents in the groundwater ranged from 0.01 to 7.60 mgl^{-1}, with a mean value of 0.69 mgl^{-1} (Table 1). The spatial distribution map of iron is shown in Figure 7a. The Fe concentrations increase towards the southwest. Manganese (Mn^{2+}) concentrations were less than 0.05 mgl^{-1}, with a mean value of 0.003 mgl^{-1} (Figure 7b).

Table 1. Statistical analysis of the chemical parameters of the groundwater samples and their limitation value for water quality assessments, as defined by FAO (1994) and WHO, (2011).

Index	Min.	Max.	Average	S. D.	Drinking Limit	No. of samples exceeds the acceptable level (%)	Irrigation Limit	No. of samples exceeds the acceptable level (%)
					WHO [11]		FAO [10]	
pH	7.02	7.90	7.30	0.18	6.5-8.5		– –	
ECw	587.27	1585.46	1045.33	230.91	1500	2 (3.2%)	3000	
TDS	323.00	872.00	616.35	148.48	1000			
Ca	41.98	87.12	65.13	11.99	75	14 (23%)	400	
Mg	13.47	40.42	23.02	6.85	100		61.25	
Na	48.00	170.00	103.33	28.09	200*		919	
K	2.00	16.00	4.60	2.12	12	1 (1.6%)	78	
Cl	75.15	279.30	153.65	39.74	250*	1 (1.6%)	1063	
HCO_3	76.49	134.30	109.73	14.44	120	21 (33%)	610	
SO_4	66.90	324.00	165.95	49.74	250*	3 (4.8%)	1920	
Fe	0.01	7.60	0.69	1.32	0.3	24 (38.7%)	5	2 (3.2%)
Mn	0.00	0.05	0.003	0.01	0.4		0.2	

DS and ion values are in mgl^{-1}, while EC is in μScm^{-1}. *There is no health-based recommendation; but the problem is the smell, taste, corrosion, and symptoms of digestion caused by greater SO_4^{2-} levels.

3.2. Hydrogeochemical features

The Piper plot was used to illustrate the tested groundwater classes (Figure 8). This diagram shows important traits and correlations to distinguish multiple sample groups. The hydrogeochemical facies of the tested groundwater are identified as NaCl, mixed Ca-Na-HCO_3 based on the diamond matrix component. Furthermore, Na-Cl facies covered over 85% of the samples, and total alkalis (Na and K) were more dominant than alkaline earth (Ca^{2+} and Mg^{2+}), and strong acids (Cl^- and SO_4^{2-}) exceeded weak acids (CO_3^{2-} and HCO_3^-).

Gibbs, (1970) scatter plots were used to identify the rock-water connection for groundwater. Gibbs plots describe the distribution and association of total dissolved salts with the dissolved ions ratio ($Na^+ + K^+$/ $Na^+ + K^+ + Ca^{2+}$) and Cl^- / $Cl^- + HCO_3^-$ in groundwater samples. According to Figures 9a and b, chemical weathering associated with rock-forming minerals or rock dominance is one of the major aspects governing the chemical evolution of groundwater inside the studied area. The Gibbs ratio calculations show that Gibbs ratios 1 (0.53-0.72) and Gibbs ratio 2 (0.40-0.73) belong to the rock dominance.

The combined concentrations of cations and anions in the groundwater of the research area indicate a sequence of salt assemblages. The percentages of dissolved cations and anions are given in this way of calculating. In terms of potential salt combinations of groundwater samples evaluated in the study area, groundwater samples contain the following assemblage:

Group I: NaCl, Na_2SO_4, $MgSO_4$, Ca $(HCO_3)_2$
(59.68% of all studied samples)

Group II: NaCl, Na_2SO_4, $MgSO^4$, $CaSO_4$, Ca $(HCO_3)_2$
(29.03% of all studied samples)

Group III: NaCl, Na_2SO_4, Ca $(HCO_3)_2$
(8.06% of all studied samples)

Group IV: NaCl, Na_2SO_4, $CaSO_4$, Ca $(HCO_3)_2$
(3.23% of all studied samples).

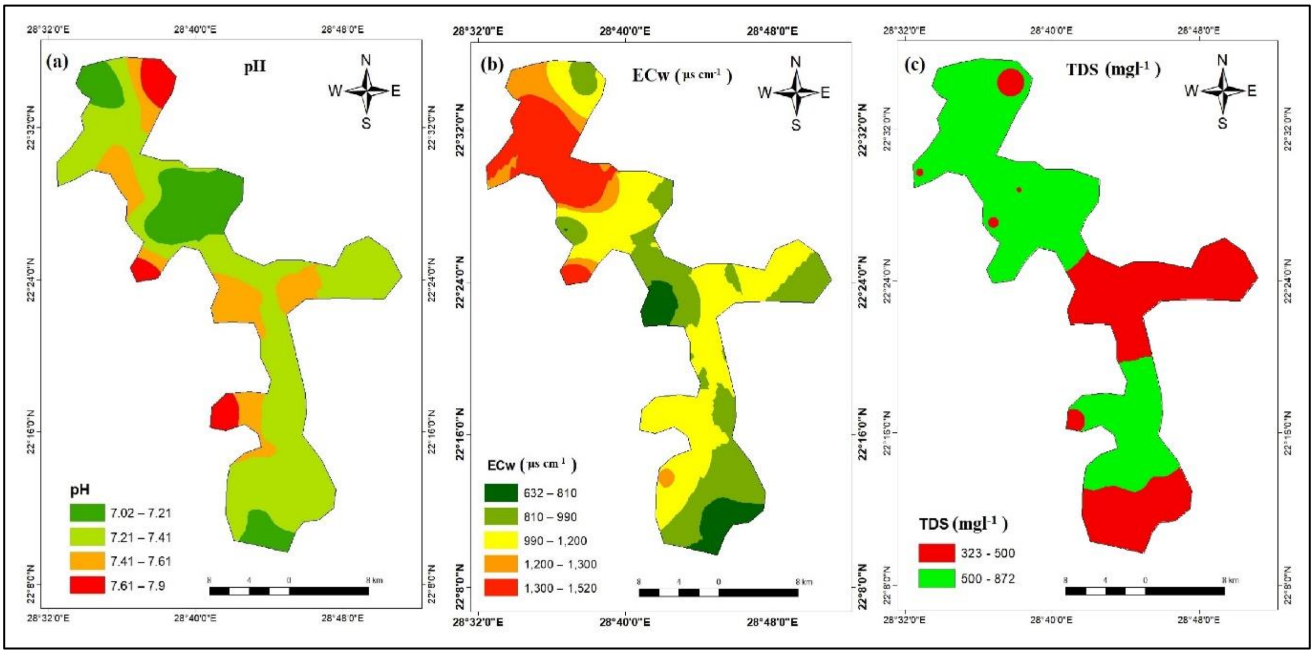

Fig. 4. Maps of the spatial distribution of groundwater samples in the study region (a) pH, (b) electrical conductivity (ECw μscm^{-1}), and (c) TDS (mgl^{-1}).

Canadian Water Quality Index (CCME-WQI)

Depending on WHO agency rules, the Canadian Council of Ministers of Environment (CCME-WQI) has been utilized to evaluate the water quality of the studied groundwater samples for human consumption. The CCME WQI calculated characteristics, including major and minor ions and trace elements to better understand the acceptable water quality. Figure 9a display the calculated CCME-WQI outcomes for drinking purposes. The CCME-DWQI values estimated from groundwater samples (62 wells) in the East El-Owainat area vary from marginal (56 index value) to excellent (100 index value). The spatial distribution map highlights that in the East El-Owainat region, the majority of groundwater quality values fell within the excellent and good class for drinking purposes (Figure 10a). This map is an effective tool for regulating water quality and reducing adverse effects on the surrounding environment.

In Figure 10b, the calculated CCEM-IWQI for irrigation and groundwater rating depending on the CCME-WQI is provided. Following the CCME-IWQI spatial distribution map study, it identifies two categories of water index values on groundwater availability for irrigation purposes in the studied region. A majority of 97% of groundwater samples fall into the excellent category, while 3% fall into the good category, allowing them to be utilized freely for irrigation without any restriction.

A total of 62 groundwater samples were examined for 12 hydrochemical properties. Microsoft Excel is the tool utilized to calculate the CCME. Macro Excel is extremely resilient especially when it is used for calculating indicators according to a wide variety of databases and water quality factors. The parameters chosen are determined by the accessibility of easily manipulated data. The results are shown in the form of a table summarizing the values of F1, F2, and F3, as well as the CCME WQI score in Table 2b. The ratio of failed parameters in the total number of parameters is 58% for drinking and 8% for irrigation (Table 2b). For drinking, the rate of failed tests is 9%, whereas for irrigation, it is 0.27%. The amplitude levels that do not reach their aims for drinking and irrigation are 12 and 0.10, respectively. The CCME-WQI calculated drinking and irrigation category scores are 65 and 95, respectively, indicating that the groundwater in East El-Owainat is fair for drinking and excellent for irrigation.

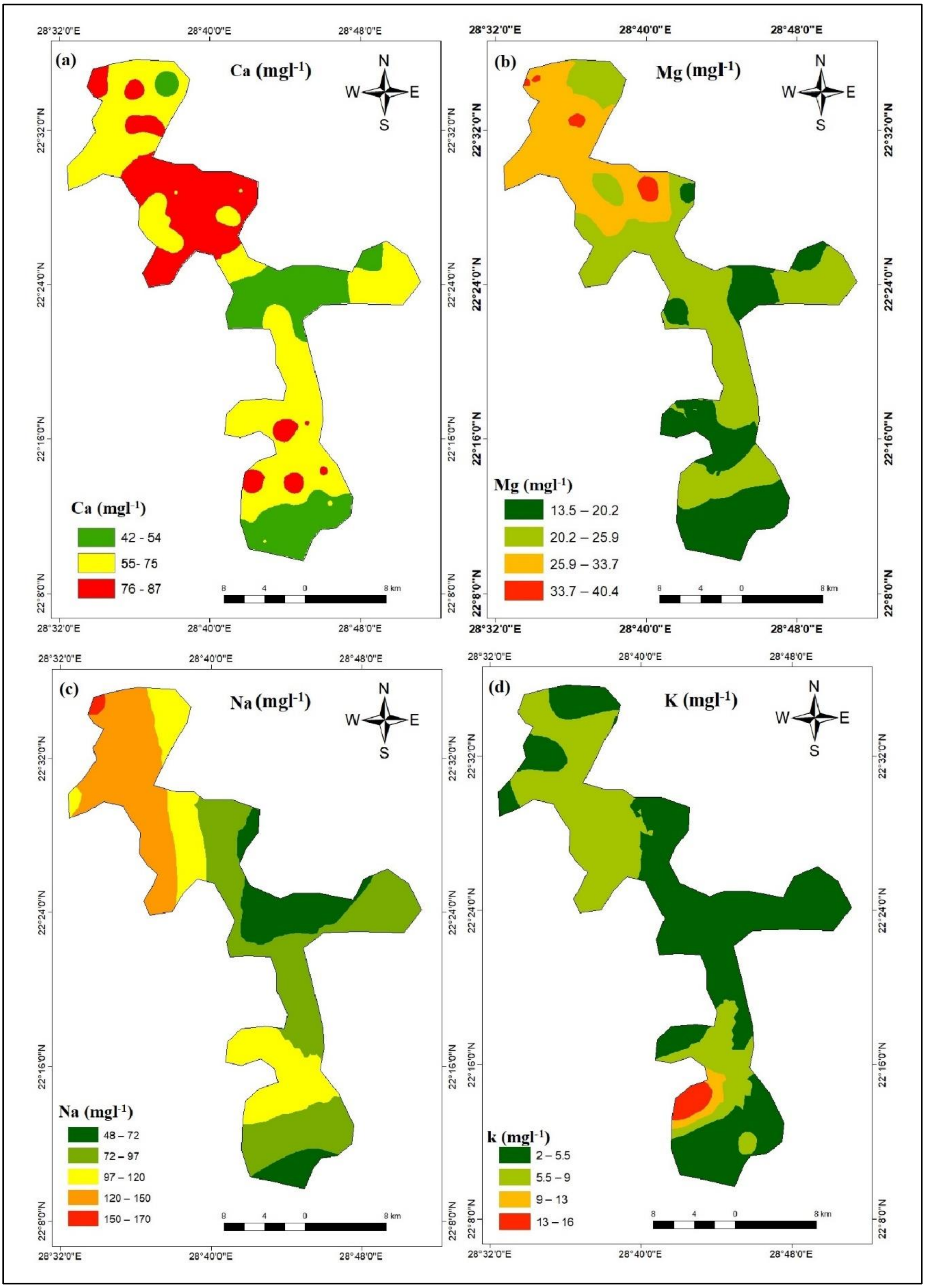

Fig. 5. Maps of the spatial distribution of groundwater samples in the study region for (a) Ca, (b) Mg, (c) Na, and (d) K ions (mgl^{-1}).

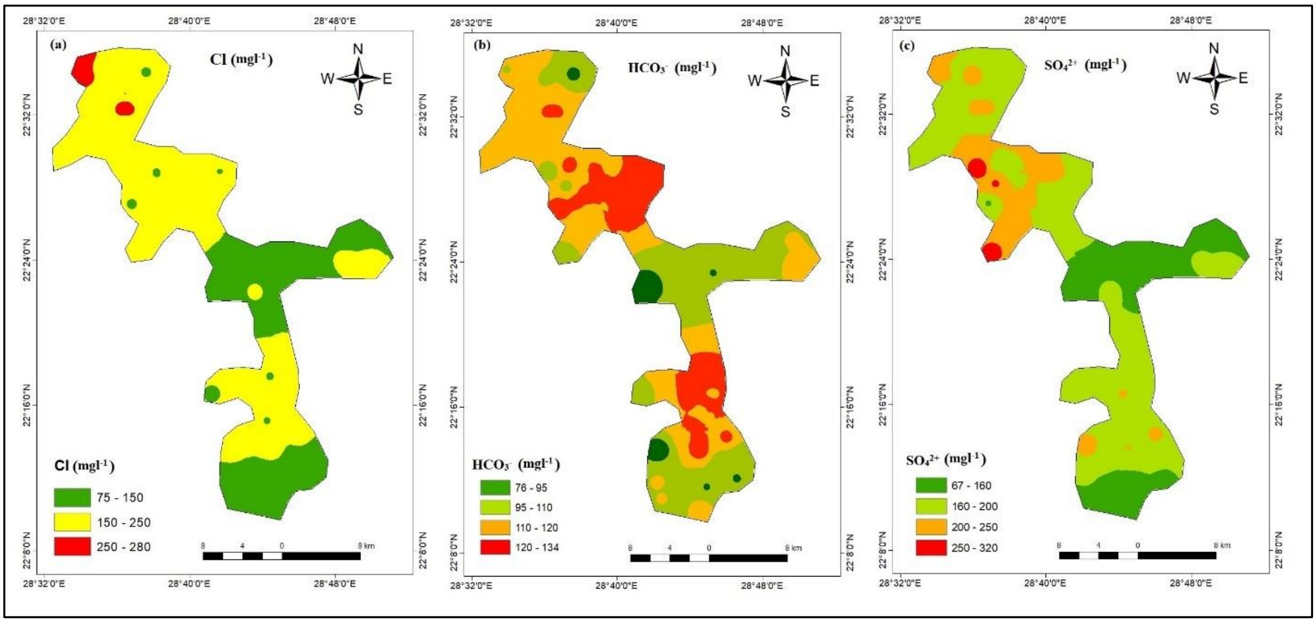

Fig. 6. Maps of the spatial distribution of groundwater samples in the study region for (a) Cl, (b) HCO_3^-, and (c) SO_4^{2-} ions (mgl^{-1}).

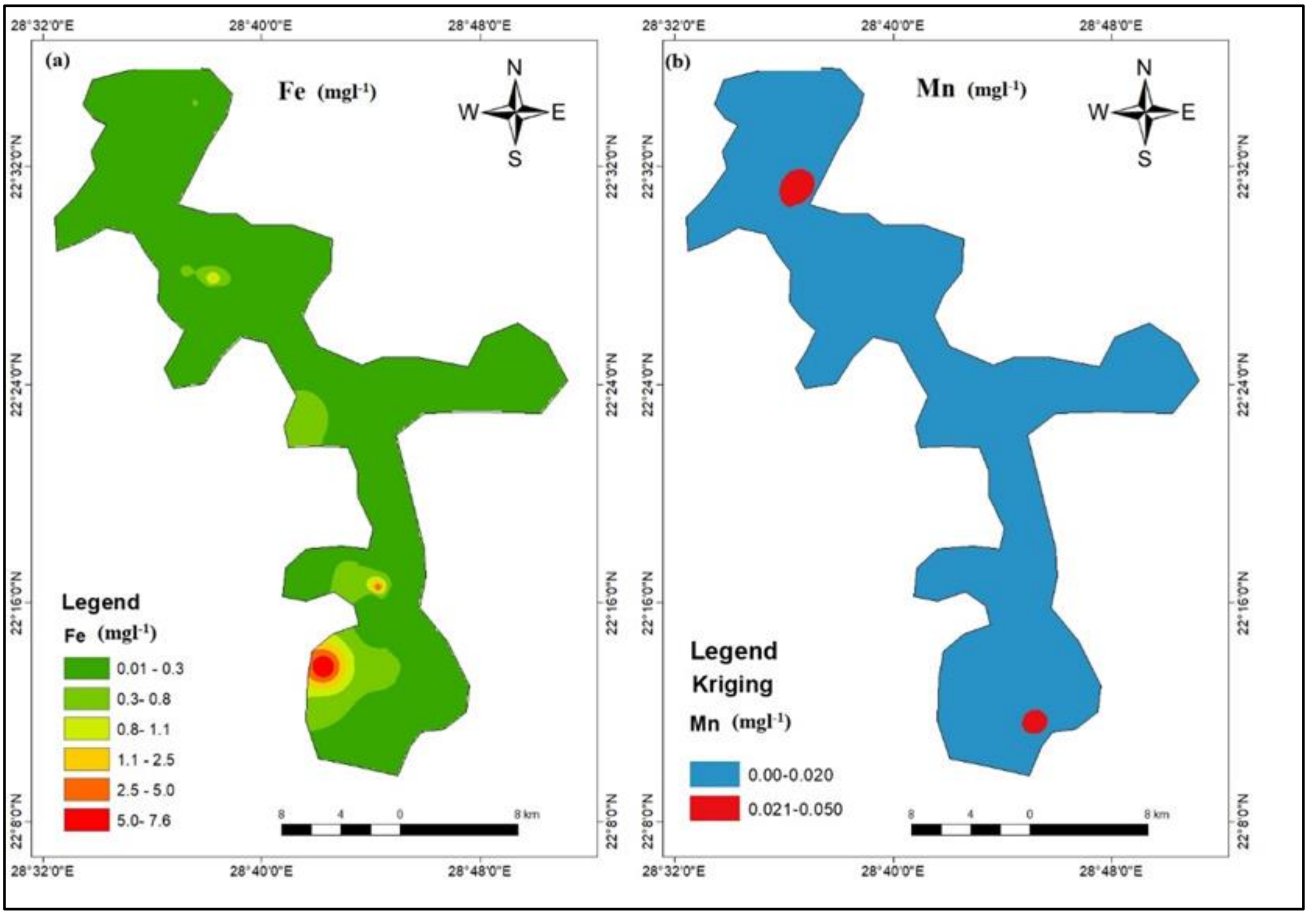

Fig. 7. Maps of the spatial distribution of groundwater samples in the study region for (a) Fe and (b) Mn ions (mgl^{-1}).

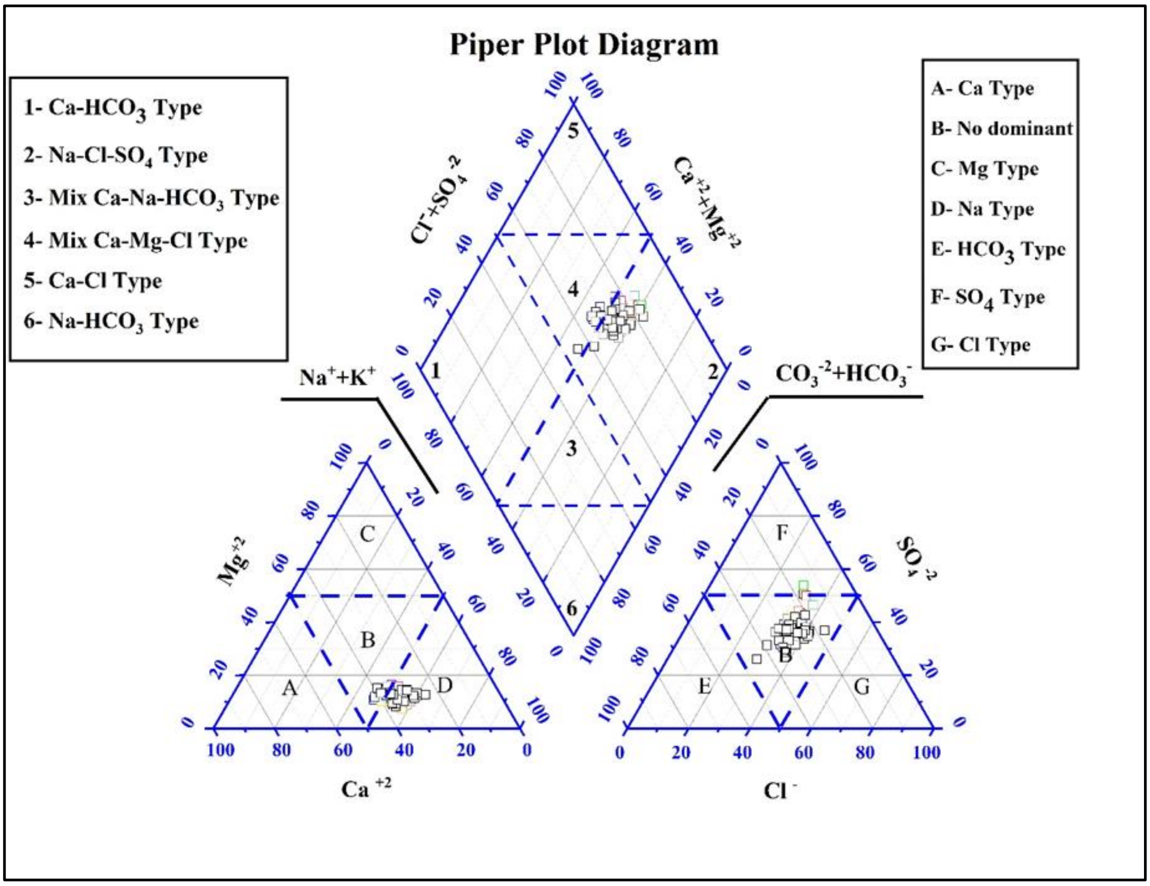

Fig. 8. Piper trilinear diagram showing groundwater hydrogeochemical facies in the study region.

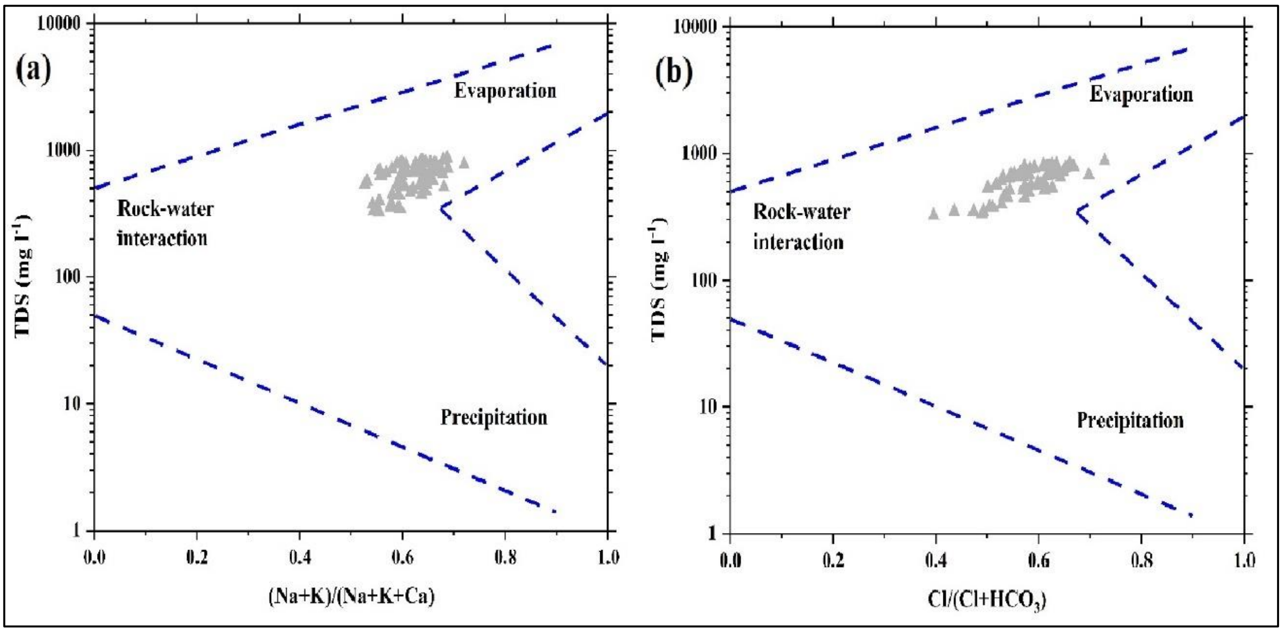

Fig. 9. Gibbs scatter plots for the hydrogeochemical processes controlling groundwater chemistry in the study region: (a) TDS vs. Cations and (b) TDS vs. Anions.

Table 2a. The irrigation variables including electrical conductivity (ECw), sodium adsorption ratio (SAR), total dissolved solids (TDS), total hardness (TH), residual sodium carbonate (RSC), soluble sodium percentage (Na%), Kelley's ratio (KR), magnesium hazard (MH), permeability index (PI), salinity potential (SP), and Langelier saturation index (LSI).

Index	Class	Range	Water Class	Num. of samples	Samples %	References
ECw	C1	<250	Low			(Wilcox 1955)
	C2	250-750	Medium	٨	13	
	C3	750-2250	High	54	87	
	C4	>2250	Very high			
SAR	S1	<10	Low	62	100	(Richards 1954)
	S2	10-18	Medium			
	S3	18-26	High			
	S4	>26	Very high			
TDS		<500	Desirable for drinking	14	23	(Freeze and Cherry 1979)
		500-1000	Permissible for drinking	48	77	
		1000-3000	Useful for irrigation			
		>3000	Unfit for drinking and irrigation			
TH		<75	Soft			(Sawyer and McCarty 1967)
		75-150	Moderately high			
		150-300	Hard	49	79	
		>300	Very hard	13	21	
Na %		<20	Excellent			(Wilcox 1955)
		20-40	Good	5	8	
		40-60	Permissible	57	92	
		60-80	Doubtful			
		>80	Unsuitable			
RSC		<1.25	Safe	62	100	(Richards 1954)
		1.25-2.5	Doubtful			
		>2.5	Unsuitable			
MH		<50	Safe	62	100	(Szabolcs 1964)
		>50	Unsuitable			
KI		<1	suitable	50	81	
		>1	Unsuitable	12	19	
PI		>75	Good			(Doneen 1964)
		25-75	Fair	62	100	
		<25	Poor			
PS		<3	suitable	79	49	(Langelier 1936)
		>3	Unsuitable	21	13	
LSI		<0	Non-scaling	56	90	
		0-0.5	Medium Scaling	6	10	
		>0.5	Severe Scaling			

Table 2b. CCEM-WQI values were calculated for all groundwater samples in the study region.

CCME-WQI	F1	F2	F3	WQI	Class
CCME-DWQI	58	9	12	65	Fair
CCME-IWQI	8	0.27	0.10	95	Excellent

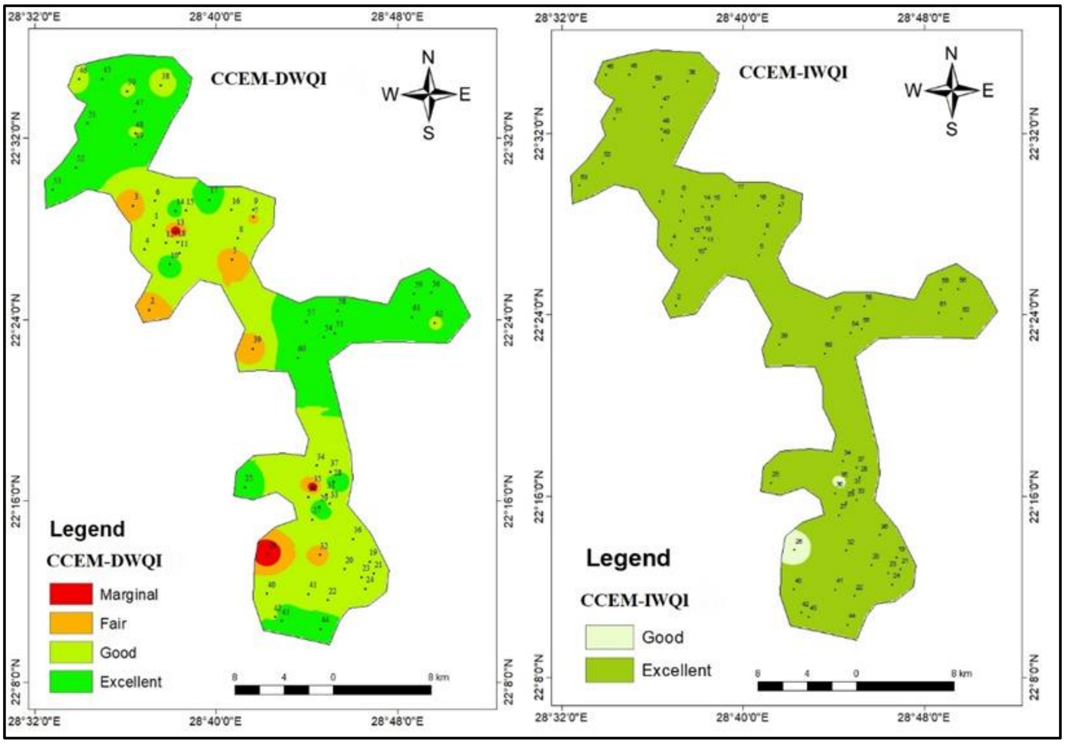

Fig. 10. a CCME WQI for Drinking. b CCME WQI for Irrigation.

3.3. Evaluating the water's suitability for irrigation purposes

Various indices were calculated to evaluate the obtained groundwater samples for irrigation purposes; the findings are shown in Table 2a. Total hardness (TH) ranged from 166.08 to 383.62 mgl^{-1}. The spatial distribution map of TH indicates that groundwater hardness is rising in the north of the study area (Figure 11a).

The groundwater's sodium percentage (Na%) values ranged from 37.96 to 53.99 %. The spatial distribution map of the Na% values illustrated that the Na% in groundwater declined in the middle region while increasing in the north and south (Figure 11b).

The values of the sodium adsorption ratio (SAR) in groundwater vary from 1.58 to 3.95%. The spatial distribution map of SAR values showed that SAR in groundwater decreased in the center-east part of the study area (Figure 11c). The developed US Salinity Diagram is applied to explain the influence of both salinity dangers (ECw) plus sodium risks (SAR) on the soil. Most of the groundwater samples are highlighted and categorized into the C3S1 group on the US salinity plot (Figure11d), which specifies a high salinity with a low Na type. The remaining water samples are classified as C2S1, which specifies medium salinity and a low Na type.

The RSC of the groundwater in the study ranged from -1.50 to -5.55 $meql^{-1}$. The spatial distribution map of RSC values reveals that RSC in groundwater is raised towards the southern section of the study area (Figure 12a). Magnesium hazard (MH) assessment in the examined groundwater ranged from 25.78 to 46.25%. The spatial distribution map of MH values demonstrated that MH in groundwater tends to increase in the northern direction of the study area (Figure 12b). The KR in the present research varied from 0.59 to 1.14. The spatial distribution map of KR values demonstrated that KR follows the same pattern of distribution as SAR (Figure 12c).

Another irrigation quality indicator is salinity potential (SP); it is a Cl^- and SO_4^{2-} dominance index. The SP of the groundwater in the study ranged from 1.84 to 3.33. The spatial distribution map of SP (Figure 12d) displays that most of the groundwater analysis assessments in the East El-Owainat area were under the suitable category for irrigation. While the permeability index (PI) assessment ranged from 52.02 to 67.06. The spatial distribution map of PI showed that the PI increased toward the southern part of the study area (Figure 12e). The groundwater on evaluation has Langelier saturation index (LSI) values ranging from -0.48 to -0.40. The LSI spatial distribution map illustrated that most of the groundwater testing results in the East El-Owainat area were suited to irrigation (Figure 12f).

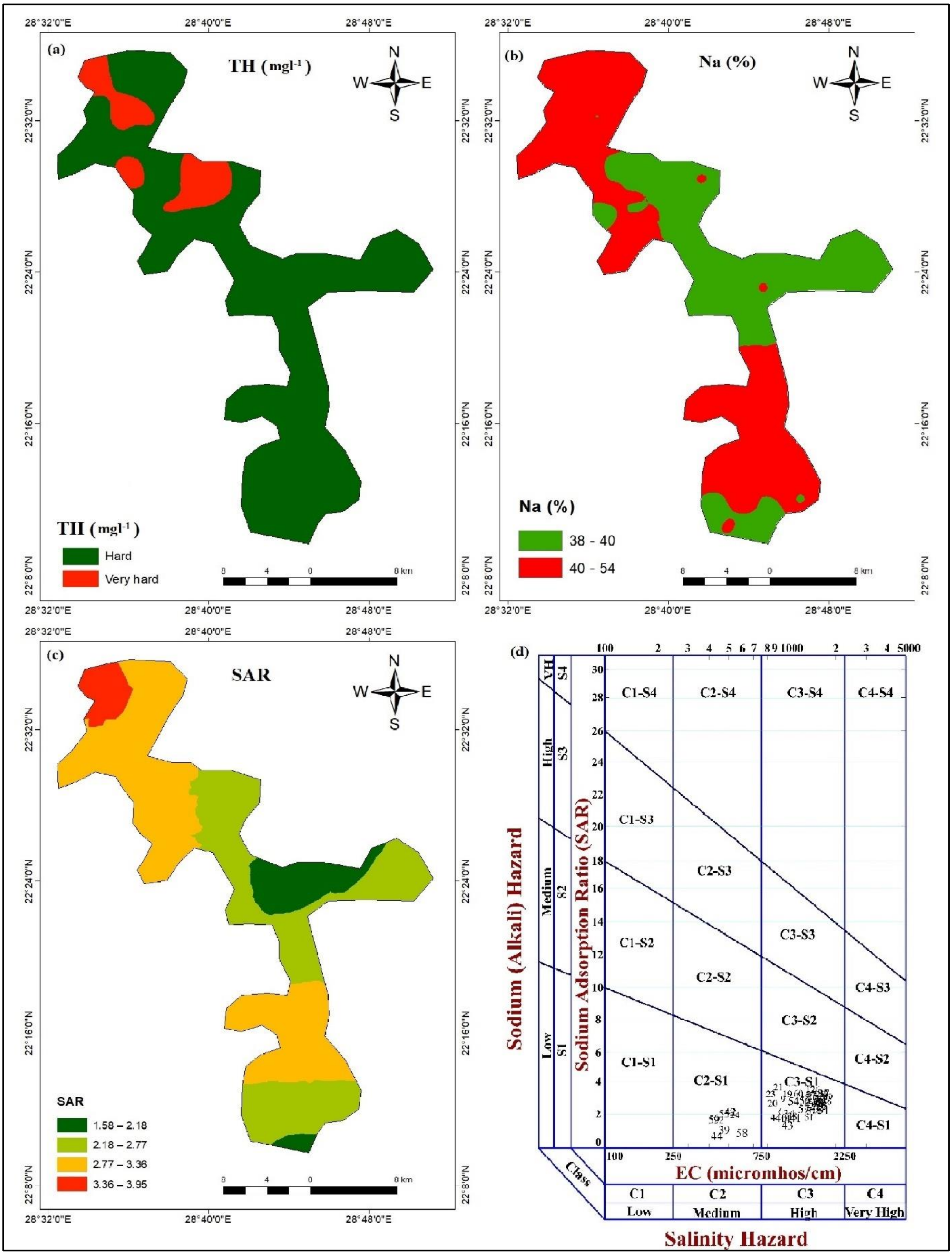

Fig. 11. Maps of the spatial distribution of groundwater samples in the study region for (a) total hardiness (TH %), (b) soluble sodium percentage (Na %), (c) sodium adsorption ratio (SAR), and (d) US Salinity diagram.

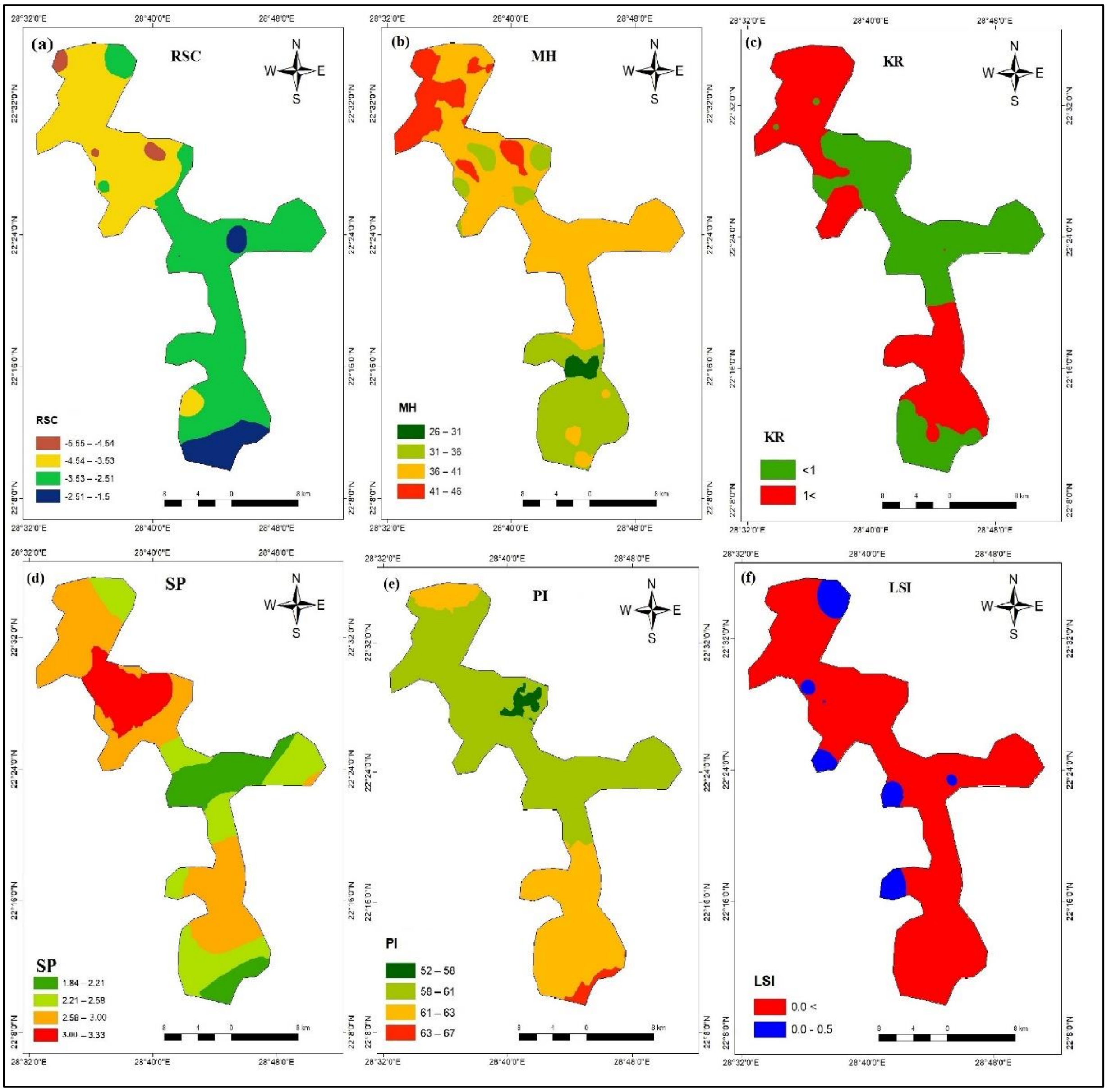

Fig. 12. Maps of the spatial distribution of groundwater samples in the study region for (a) residual sodium carbonate (RSC), (b) magnesium hazard (MH), (c) Kelley's ratio (KR), (d) salinity potential (SP), (e) permeability index (PI), and (f) Langelier saturation index (LSI).

3.4. Multivariate statistical analysis

The principal component analysis (PCA) has been applied to recognize the most important variables influencing the hydrochemistry of the tested groundwater samples. Generally, appropriate findings have been determined by analyzing twelve parameters (EC, pH, TDS, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, SO_4^{2-}, HCO_3^-, Fe^{3+}, and Mn^{2+}) to determine the main components of the 62 groundwater samples. The PCA was obtained using Varimax orthogonal rotation with KMO normalizing. As a result, the KMO test value was 0.602, suggesting that the findings were of statistical significance. Further evidence that the data are consistent and appropriate for PCA relates to the findings of p-value in the Bartlett sphericity test was significant for all data sets ($p < 0.000$). Three components were identified to explain almost all the variance according to eigenvalues (over one) plus varimax rotation, with a sum cumulative variance of approximately 79.55% across the groundwater samples (Table 3).

4. Discussion

The pH value of groundwater is a significant factor when assessing whether it is suitable for drinking and irrigation since it allows for the evaluation of the acidity or alkalinity of the water. It is possible that the bicarbonate ions constituted the cause of the pH of the groundwater studied samples. The neutral pH level of the groundwater was impacted by these ions that were produced when free CO_2 was combined with water to produce carbonic acid (Tantawy et al., 2015).

According to (Ayers and Westcot 1994) and WHO, (2011), all analyzed water samples fell within the permissible pH limit (6.5-8.5) for irrigation and drinking, with no potential health risks or adverse impacts on plant growth.

Electrical conductivity (ECw) is the main variable to assess salinity risks and its suitability for irrigation purposes. In our study, nearly 87 % of the studied wells have high-salinity water ranged from an ECw of 750-2250 µs cm^{-1}. The high salinity levels in the groundwater can primarily be attributed to the leaching and hydrolysis of shale present in the aquifer sediments (M. Gad et al. 2016). As a result, when utilizing such water for irrigation, a suitable amount of leaching water must be used, and crops with moderate salt tolerance can be cultivated in most cases without additional salinity control practices. According to the Wilcox water classification, roughly 13 % of the investigated samples (8 samples) had a medium salinity of 250-750 µs cm^{-1} and can be utilized to irrigate the majority of crops (Table 2a).

The variance in TDS might be due to groundwater's longer resident period or an alteration in the rock composition and structural layout of those formations that contain water (Hamdan et al. 2012). The well position, the subsurface structural, structure of water-bearing strata, and lithological variances all influence salinity concentration in the East Oweinat region (El Nahry et al. 2010; Mustafa and Hamed 2021). According to the water classification by Hem, (1970), the TDS values of the groundwater samples indicated that the water is freshwater (Table 2b).

The relative abundance of various geochemical processes operating in the subsurface hydrogeologic system affects the supply of soluble ions in the groundwater system. Four cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and three anions (SO_4^{2-}, HCO_3^{-}, and Cl^{-}) are among the most frequent ions observed in the groundwater. The chemical properties of groundwater are controlled by these ions, which can be found here in quantifiable concentrations. According to principal component analysis (PCA), the first component (PC1), which accounts for 54.806% of the total variance, has variables such as ECw (0.979), TDS (0.929), Na (0.949), Cl (0.929), SO_4 (0.917), Mg (0.839), and Ca (0.782) with significant positive loadings. It was identified as the salinization component and is caused by ion exchange and groundwater-rock exchanges, both of which are linked to the natural water source (Abu Salem et al. 2023; Mohseni et al. 2022; Abd El-rhman et al. 2015). This indicates that the water quality is affected positively by dissolving chloride and sulphate salts in PC1. Component 2 (PC2) covers approximately 15.33% of the overall variance, with substantial positive loadings on HCO_3 (0.754). There are additionally negative loadings on pH (0.783) and Mn (0.589). The reason for this may be referred to the dissolution of the carbonate rocks caused by the hydration of the HCO_3^{-} ion in water as well as the erosion of mineral silicates.

Table 3. Principal component analysis (PCA) of the ions assessed in the tested groundwater samples.

Index	Component		
	1	2	3
pH	0.016	**-0.783**	-0.021
ECw	**0.979**	0.093	0.137
TDS	**0.929**	0.301	0.098
Ca	**0.782**	0.406	0.188
Mg	**0.839**	0.059	-0.062
Na	**0.949**	0.050	0.101
K	0.493	-0.123	**0.692**
Cl	**0.929**	0.206	0.075
HCO_3	0.342	**0.754**	-0.355
SO_4	**0.917**	-0.034	0.222
Fe	0.031	0.052	**0.913**
Mn	-0.101	**-0.589**	-0.071
Total	**6.577**	**1.839**	**1.130**
% of Variance	**54.806**	**15.326**	**9.418**
Cumulative %	**54.806**	**70.132**	**79.551**

Significant load values (greater than 0.5) are shown by bold entries. Technique of extraction: a principal component analysis. Rotation method: varimax with Kaiser normalization.

PC3 provides for approximately 9.42% of the overall variance, with high to moderately positive loadings on Fe (0.913) and K (0.692). This is related to the greater Fe content of the New Valley soils, which will result in Fe (II)-bearing materials dissociating and introducing significant Fe contents into the aquifer (Yehia et al. 2017; Embaby and Ali 2021; Abdelhafez et al. 2021).

A high concentration of Ca^{2+} in drinking water can be harmful to human wellness since it can lead to stomach problems that cause scaling and encrustation (Rawat et al. 2018). Also, high levels of Mg^{2+} and Ca^{2+} ions can cause water hardness, which is calculated as the sum of Ca^{2+} and Mg^{2+} concentrations in water. Some studies have revealed that increased water hardness can alter the levels of blood pressure (Abdelhafez et al. 2021). In the current investigation, 23% of the underground water samples surpassed the WHO's recommended drinking limit for Ca (75 mgl^{-1}). Higher Ca^{2+} and Mg^{2+} are advantageous for agricultural applications because they can mitigate the negative impacts of high Na+. Nevertheless, it might have an indirect impact on the plants because of an accumulation of carbonates, which are made up of Ca^{2+} and Mg^{2+} ions, which would negatively of water irrigation systems (Abdelhafez et al. 2021). Based on the FAO, all the underground water samples were within the permissible irrigation limits. However, all the groundwater samples tested were within the limits under Mg concentration that are suitable for irrigation and drinking, as proposed by FAO and WHO. Sodium (Na^+) is certainly the main cation present in all examined groundwater samples. The sodium concentration rise has been caused by the leaching and disintegration of halite deposits in the reservoir material. According to FAO (1994) and WHO, (2011), all of the water samples were within the permitted limits for irrigation and drinking. As stated by FAO and WHO, all the underground water samples within the permitted levels under K for irrigation and drinking, except for well No. 26, which passed the WHO drinking standard (12 mgl^{-1}).

Because the concentration of Cl^- was below the maximum limit of acceptable values, there are no possible hazards connected with using such water for human consumption or irrigation. Apart from well No. 46, which exceeded the WHO drinking water standards (250 mgl^{-1}). According to FAO guidelines (Ayers and Westcot 1994), all groundwater samples were suitable for irrigation. Excessive HCO_3^- levels in irrigation water may reduce the availability of certain nutrients, such as Ca, Mg, and K, by forming insoluble compounds; also, it could limit water movement through the soil (Aly, 2014; Zaman et al. 2018). According to the WHO, (2011), around 34% of the samples (21 wells), had HCO_3^- concentrations higher than the limit that is safe for human consumption (Table 1). The most prevalent anion in all groundwater According to Figure 10a, more than 80% of the tested samples were good to excellent for human consumption. Also, it can be observed that there is a minor deviation from the natural state based on the calculated variables and tested samples. The WHO's recommended drinking limit for Ca^{2+}, HCO_3^-, and Fe samples is sulfate. According to the WHO, (2011), the SO_4^{2+} contents in about five percent of the analyzed samples (3 samples) exceeded the maximum allowable limit for drinking. Even though all the groundwater samples analyzed were within the FAO's allowable irrigation limits.

Iron (Fe) is required for the survival of animals, humans, and plants. In this regard, the maximum permitted Fe concentration in irrigation water is 5 mgl^{-1}, but only 0.3 mgl^{-1} in drinking water. Iron in groundwater samples might be formed by chemically dissolved ferruginous rocks and minerals as well as iron minerals present in the aquifer materials (Yehia et al. 2017; Embaby and Ali 2021). At wells No. 26 and 35, Fe concentrations were over the FAO-recommended maximum acceptable for irrigation purposes. Whenever the iron content more than 5 mgl^{-1}, the availability of vital phosphorus and molybdenum might be reduced (Aly 2015). In accordance with the WHO, (2011), the Fe concentration in about 39% of the analyzed samples (24 samples) surpassed the maximum permissible limit for human consumption. Manganese concentrations in all tested water samples fell within the permissible levels of FAO and WHO for irrigation and human consumption.

Based on the Piper plot, our results showed that the chemistry of aquifers is significantly influenced by the mineral composition of the reservoir through which water flows aquifers (Abd El-rhman et al. 2015; Saleh et al. 2023; Sharaky et al. 2019). Several groundwater samples from the East El-Owainat wells have been distinguished into salt assemblages (Group I, Group II, Group III, and Group IV). Group I is at an earlier phase of chemical advancement than the other groups. Group II reveals the influence of marine facies aquifer nature, with the potential impact of cation exchange phenomena caused by clay incorporated with the Nubian sandstone reservoir in the research location (Abdel-gawad et al. 2020). Group II (three sulphate salts) and Groups I and IV (two sulphate salts) indicate intermediate phases of chemical evolution and display the impacts of leaching and dissolution of evaporated deposits (M. Gad et al. 2016).

Canadian water quality index (CCME-WQI) is a great method for converting complicated data into an accessible water quality index by utilizing chemical and trace elements features, that assess water quality based on purity utilizing the most commonly determined water quality characteristics (Selmane et al. 2023; Abdelhafiz et al. 2021; Wagh et al. 2017). This study evaluated the water quality utilizing a newly developed CCME WQI which is designed to be easily comprehensible for farmers, customers, policymakers, leaders, and government officials

was exceeded in 23%, 34%, and 39% of the water samples, respectively according to the actual measured results. The detected excessive Ca^{2+} and HCO_3^- might be attributable to chemically dissolved terrestrial salts from origin rocks rich in dolomite, calcite, and gypsum minerals. High Fe concentrations in groundwater samples can be linked to the Nubian sandstone aquifer having a corrosive effect on iron metal (Mohamed Gad et al. 2018; M. Gad et al. 2016). The CCME-IWQI spatial distribution map assessment (Figure 10b) identifies two types of water index values on groundwater suitability for irrigation purposes in the investigated region, with no restrictions on irrigation usage.

Excessive water hardness promotes calcium and magnesium carbonates to precipitate, which may disturb the irrigation system and soil infiltration. If Ca^{2+} and Mg^{2+} levels exceed 100 and 43 mgl^{-1}, respectively, the precipitation of phosphate fertilizers within irrigation drippers may be affected (Muniz et al. 2020). According to Sawyer and McCarthy (1967) total hardness (TH), approximately 79% of samples had a hard water index (150–300), with 21% falling into the very hard class.

Sodium percentage (Na%) represents one of the indicators applied to assess the suitability of water for irrigation purposes. An excessive Na% in groundwater increases the chemical exchange process between soil and water that might reduce soil porosity, damage soil structure, and complicate cultivation operations, making it unsuitable for growing crops (Abdelhafez et al. 2021; Abu Salem et al. 2023). Based on the Na% assessments, groundwater samples were classified as 8% as "good" quality, and most of the studied samples, 92%, were classified as "permissible" quality (Table 2a).

Sodium adsorption ratio (SAR) is a significant indicator for determining the propriety of water for irrigation usage since it reflects the percent of sodium that will be absorbed into the soil as a result of irrigation water utilization. A high SAR value demonstrates Na^{+} in the water might substitute Ca^{2+} and Mg^{2+} ions in the soil, possibly resulting in structural degradation and reducing water conductivity (Abd El-rhman et al. 2015; Chaudhary and Satheeshkumar 2018). According to Richards (Richards 1954), all investigated water samples had low levels of sodium ions consequently assessed as excellent for irrigation since the SAR values <10 (Table 2a). Due to the dispersing impact caused by a high level of sodium in the soil exchange complex, SAR and ECw indicators should be assessed together to identify potential soil infiltration rate decreases and surface hard crust creation trouble (Tomaz et al. 2020). Groundwater with a high salinity hazard category (C3) is acceptable for irrigation but may hurt sensitive crops. In contrast, water samples from the medium salinity hazard category (C2) are usually suitable for irrigation without needing specific salinity management strategies. In order to establish the risky impact of CO_3^{2-} and HCO_3^{-} on water suitability for irrigation, residual sodium carbonate (RSC) was additionally calculated. A minus RSC value suggests that sodium accumulation is improbable because there are more ions of magnesium and calcium than might be precipitated as CO_3^{2-}. In terms of RSC standards, all groundwater samples in the study area fall into the safe class for irrigation (Table 2a). The magnesium (Mg) concentration of water is one of the many essential quality parameters in establishing the suitability of irrigation water since a high level of Mg degrades the soil environment, which leads to low crop yields (Abu Salem et al. 2023). As reported by Szabolcs (1964), all groundwater samples in the research area are safe for irrigation (Table 2a). Kelley's ratio (KR) for groundwater irrigation is acceptable when the ratio of sodium to calcium and magnesium is less than 1, while values higher than one are not acceptable. Most of the tested groundwater samples (almost 81%) showed significant suitability for irrigation, while a minimal percentage of samples (approximately 19%) are unacceptable in accordance with the KR ratio (Table 2a).

The salinity potential (SP) is important because all Cl salts and Mg-$NaSO_4$ are very soluble, resulting in a salinity condition. So, water that includes different SO_4 cation mixtures will result in an accumulation of dissolved salts in the soil if utilized for irrigation. It causes 50% of the SO_4 to dissolve as $CaSO_4$, whereas the 50% remains soluble in the soil form Na-$MgSO_4$ (Rawat et al. 2018; Kamaraj et al. 2021; Doneen 1964). About 79% of the tested groundwater samples revealed suitability for irrigation, whereas only about 21% of the samples are unsuitable according to the SP factor (Table 2a). The permeability index (PI) of the soil is influenced by the overall salt content of the water as well as the amounts of Na^{+} and HCO_3^{-}. In accordance with Doneen (1964), the estimated PI values from the evaluated groundwater samples fell within the fair category (Table 2a), indicating that the water is suitable for agriculture. The dissolving of limestone and dolomite in the primary formations of aquifers and cation interactions might be the cause of the higher PI values in the investigated groundwater samples.

The Langelier saturation index (LSI) evaluates the impartiality of water and the establishment of water erosion by evaluating the capability of irrigation water to dissolve or precipitate $CaCO_3$ (Langelier 1936). High levels of LSI in groundwater can cause health issues, irrigation techniques to corrode, and the continual discharge of toxic elements into the water supply (Kamaraj et al. 2021). Nearly 90% of the total samples were non-scaling, indicating there is water erosion (Table 2a). The slight scaling of 10% of the groundwater might result in carbonate precipitation in the soil after irrigation.

5. Conclusions and recommendations

The current study evaluated the suitability of groundwater for drinking and irrigation using FAO (Ayers and Westcot 1994) and WHO, (2011) recommendations as indices for a several of properties. Furthermore, the CCME WQI model was used to calculate the water quality index for drinking and irrigation. The drinking and irrigation category scores computed by the CCME-WQI for all groundwater samples are 65 and 95, respectively, indicating that the groundwater in East El-Owainat is fair for drinking and excellent for irrigation. The NaCl type predominates the groundwater chemistry. The interaction of water with the rocks of the Nubian Sandstone Reservoir has a significant impact on its chemical components. According to WHO (WHO 2011), the main ions in the groundwater influencing its quality are Fe, Ca, and HCO_3, which are present in levels that are higher than what is suitable for human consumption. According to the principal component analysis, salinization is caused by ion exchange and groundwater-rock interactions, both of which are related to the natural water source. Finally, there are no limits on the use of this water. Plants with medium salt tolerance can be grown without any hazardous effects. Early detection tools could help policymakers assess the quality of drinking and irrigation water on a regular basis.

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6. References

Abd El-rhman, A. E., Gameh, M., M. A., and El-Sayed, M. M., (2015). Evaluating the Groundwater Quality for Irrigation of the Western Limestone Plateau in Assuit Region, Egypt. *Assiut Journal of Agricultural Sciences*, 46 (2), 229–47; https://doi.org/10.21608/ajas.2015.570.

Abdel-gawad, A. M.; Sayed, E.; Abd, A. El and Gedamy, Y. R. (2020). Geological Characteristics of Shallow Groundwater Aquifer and its Relation to Hydrochemical Features and Bacteriological Pollutants in Siwa Oasis, Egypt. International Journal of Environment, 117–147.

Abdelaty, E. F.; Abd-El-Hady, A. M. and Abouzahw, S. (2022). Classification Approaches to Assess Groundwater Quality (Wadi El-Natron, Egypt). Egyptian Journal of Soil Science, 62, 267–291.

Abdelhafez, A. A., Abbas, M. H. H., Kenawy, M. H. M., Noureldeen, A., Darwish, H., Ewis, A. M. G., and Hamed., M. H. (2021). Evaluation of underground water quality for drinking and irrigation purposes in New Valley Governorate, Egypt. *Environmental Technology and Innovation,* 22, 101486; https://doi.org/10.1016/j.eti.2021.101486.

Abdelshafy, M., Saber, M., Abdelhaleem, A., Abdelrazek, S. M., and Seleem, E. M. (2019). Hydrogeochemical processes and evaluation of groundwater aquifer at Sohag city, Egypt. *Scientific African,* 6, e00196; https://doi.org/10.1016/j.sciaf.2019.e00196.

Abu Salem, H. S., Albadr, M., M. El Kammar, M., Yehia, M. M., and El-Kammar, A. M. (2023). Unraveling the hydrogeochemical evolution and pollution sources of shallow aquifer using multivariate statistical analysis and hydrogeochemical techniques: a case study of the Quaternary aquifer in Beni Suef area, Egypt. *Environmental Monitoring and Assessment*, 195 (6); https://doi.org/10.1007/s10661-023-11206-9.

Al Temamy, A. M. M., and Barseem, M. S. M. (2010). Structural Impact on the Groundwater Occurrence in the Nubia Sandstone Aquifer Using Geomagnetic and Geoelectrical Techniques, Northwest Bir Tarfawi, East El Oweinat Area, Western Desert. *Egyptian Geophysical Society,* 8(1), 47–63.

Alexakis, D. E. (2022). Applying Factor Analysis and the CCME Water Quality Index for Assessing Groundwater Quality of an Aegean Island (Rhodes, Greece). *Geosciences (Switzerland),* 12(10); https://doi.org/10.3390/geosciences12100384.

Aly, A. A. (2014). Impact of irrigation management on shallow groundwater fluctuation and soil salinity: The Saltmed model. *Egypt. J. Soil Sci*, 54, 355–371.

Aly, A. A. (2015). Hydrochemical characteristics of Egypt western desert oases groundwater. *Arabian Journal of Geosciences,* 8 no. (9), 7551–7564; https://doi.org/10.1007/s12517-014-1680-8.

Araffa, S. A. S., and Bedair, S. (2021). Application of Land Magnetic and Geoelectrical Techniques for Delineating Groundwater Aquifer: Case Study in East Oweinat, Western Desert, Egypt. *Natural Resources Research,* 30(6), 4219–4233; https://doi.org/10.1007/s11053-021-09937-y.

Asadi, E., Isazadeh, M., Samadianfard, S., Ramli, M. F., Mosavi, A., Nabipour, N., Shamshirband, S., Hajnal, E., and Chau, K. W. (2020). Groundwater quality assessment for sustainable drinking and irrigation. *Sustainability (Switzerland)* 12, no. 1: 1–13, https://doi.org/10.3390/su12010177.

Ayers, R. S., and D. W. Westcot. (1994). *Water quality for agriculture*, Vol. 29. Food and Agriculture Organization of the United Nations Rome.

CCME. (2007). Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canada: Canada.

Chaudhary, V., and Satheeshkumar, S. (2018). Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. *Applied Water Science* 8, (8), 1–17; https://doi.org/10.1007/s13201-018-0865-9.

Doneen, L. D. (1964). Notes on water quality in agriculture. Department of Water Science and Engineering, University of California, Davis.

El Nahry, A., Elewa, H. H., and Qaddah, A. A. (2010). Soil and Groundwater Capability of East Oweinat Area, Western Desert, Egypt Using GIS Spatial Modeling Techniques. *Nature and Science,* 8 (8), 1–17; http://www.sciencepub.net/nature.

Elnazer, A. A., Seleem, E. M. M., Zeid, S. A. M., Ismail, I. S. A., Bahlol, H. A., and Salman, S. A. (2021). Hydrochemical evaluation of the quaternary aquifer and its suitability for different purposes at south Al Waqf city, Qena, Upper Egypt. *Groundwater for Sustainable Development,* 12, (October) 2020: 100517; https://doi.org/10.1016/j.gsd.2020.100517.

El-Osta, M. (2006). Evaluation and management of groundwater in East-Oweinat area, Western Desert, Egypt. Monifia Univ.

El-Rawy, M., Ismail, E., and Abdalla, O. (2019). Assessment of groundwater quality using GIS, hydrogeochemistry, and factor statistical analysis in Qena governorate, Egypt. *Desalination and Water Treatment,* 162, (September), 14–29; https://doi.org/10.5004/dwt.2019.24423.

Embaby, A., and M. Ali. (2021). Hydrogeochemical processes controlling groundwater in Western Sohag Governorate, Upper Egypt. *Arabian Journal of Geosciences*, 14 (9); https://doi.org/10.1007/s12517-021-07097-0.

ESRI, A. (2014). 10.2. 2 for Desktop. *Redlands, CA, USA: Environmental Systems Research Institute*.

Freeze, R.A. and Cherry, J.A., 1979.Ground Water. Prentice-Hall, Englewood Cliffs, NJ, 553p.

Gad, M., Dahab, K., and Ibrahim, H. (2016). Impact of iron concentration as a result of groundwater exploitation on the Nubian sandstone aquifer in El Kharga Oasis, western desert, Egypt. *NRIAG Journal of Astronomy and Geophysics,* 5 (1), 216–237; https://doi.org/10.1016/j.nrjag.2016.04.003.

Gad, M., Dahab, K., andIbrahim, H. (2018). Applying of a geochemical model on the Nubian sandstone aquifer in Siwa Oasis, Western Desert, Egypt. *Environmental Earth Sciences,* 77 (11), 1–14; https://doi.org/10.1007/s12665-018-7580-6.

Gheorghe, A. (1978). Processing and synthesis of hydrogeological data.

Ghoubachi, S. Y. (2019). Contribution to the hydrogeology of Six Hills sandstone aquifer in East El-Oweinat area, south Western desert, Egypt. *Acque Sotterranee-Italian Journal of Groundwater,* 8 (3).

Gibbs, R. J. (1970. Mechanisms controlling world water chemistry. *Science,* 170 (3962), 1088–1090.

Hamdan, A. M., Omran, A. A. A., and Sawires, R. F. (2012). Evaluation of hydrogeochemical parameters of the groundwater in El-Bahariya Oasis, Western Desert, Egypt. *Assiut University Journal of Geology,* 41(1), 1–22.

Hem, J. D. (1970). Study and interpretation of the chemical characteristics of natural water. US Government Printing Office.

Ibrahem, S. M. M. (2019). Effects of groundwater over-pumping on the sustainability of the Nubian Sandstone Aquifer in East-Oweinat Area, Egypt. *NRIAG Journal of Astronomy and Geophysics,* 8 (1), 117–130,; https://doi.org/10.1080/20909977.2019.1639110.

Ismail, E., A. Abdelhalim, and M. A. Heleika. (2021). Hydrochemical characteristics and quality assessment of groundwater aquifers northwest of Assiut district, Egypt. *Journal of African Earth Sciences*,181 no. April 2020; 104260; https://doi.org/10.1016/j.jafrearsci.2021.104260.

ITT. (2017). ITT Corporation, ENVI 5.1 Software, 1133 Westchester Avenue, White Plains, NY 10604, USA.

Kamaraj, J., Sekar, S., Roy, P. D., Senapathi, V., Chung, S. Y., Perumal, M., and Nath, A. V. (2021). Groundwater pollution index (GPI) and GIS-based appraisal of groundwater quality for drinking and irrigation in coastal aquifers of Tiruchendur, South India. *Environmental Science and Pollution Research,* 28 (23), 29056–29074; https://doi.org/10.1007/s11356-021-12702-6.

Langelier, W. F. (1936). The analytical control of anti-corrosion water treatment. *Journal American Water Works Association,* 28 (10), 1500–1521.

Makki, Z. F., Zuhaira, A. A., Al-Jubouri, S. M., Al-Hamd, R. K. S., and Cunningham, L. S. (2021). GIS-based assessment of groundwater quality for drinking and irrigation purposes in central Iraq. *Environmental Monitoring and Assessment,* 193 (2); https://doi.org/10.1007/s10661-021-08858-w.

Masoud, M. H., Schneider, M., and El Osta, M. M. (2013). Recharge flux to the Nubian Sandstone aquifer and its impact on the present development in southwest Egypt. *Journal of African Earth Sciences,* 85, 115–24.

Mester, T.; Balla, D.; Kiss, E. and Szabo, G. (2018). Evaluation of Groundwater Quality Changes Following the Establishment of a Sewage Network. *Egyptian Journal of Soil Science*, 58, 457–462.

Mohseni, U., Patidar, N., Pathan, A. I., Agnihotri, P. G., and Patel, D. (2022). An Innovative Approach for Groundwater Quality Assessment with the Integration of Various Water Quality Indexes with GIS and Multivariate Statistical Analysis—a Case of Ujjain City, India. *Water Conservation Science and Engineering*, 7 (3), 327–349; https://doi.org/10.1007/s41101-022-00145-0.

Muniz, D. H. F., Malaquias, J. V.,, Lima, J. E. F. W., and Oliveira-Filho, E. C. (2020). Proposal of an irrigation water quality index (IWQI) for regional use in the Federal District, Brazil. *Environmental Monitoring and Assessment,* 192 (9); https://doi.org/10.1007/s10661-020-08573-y.

Mustafa, A.-R. A., and Hamed, M. H. (2021). Groundwater Assessment by using Water Quality Index in Some Agricultural Expansion Areas in Sohag Governorate, Egypt. *Alexandria Science Exchange Journal,* 42 (2), 297–306; https://doi.org/10.21608/asejaiqjsae.2021.167128.

Nabawy, B. S., Abdelhalim, A., and El-Meselhy, A. (2019). Step-drawdown test as a tool for the assessment of the Nubia sandstone aquifer in East El-Oweinat Area, Egypt. *Environmental Earth Sciences,* 78 (13), 1–22; https://doi.org/10.1007/s12665-019-8375-0.

Nofal, E.; Shahin, S.; El-Tarawy, A.; Eshewy, W. and El-Ramady, H. (2024). Growth and Quality of Brazilian Cherry (Eugenia uniflora L.) Ornamental Shrubs under Salinized Irrigation Water with Natural Siwa Halite. *Egyptian Journal of Soil Science,* 64, 0–0.

Rawat, K. S., Singh, S. K., and Gautam, S. K. (2018). Assessment of groundwater quality for irrigation use: a peninsular case study. *Applied Water Science,* 8 (8), 1–24; https://doi.org/10.1007/s13201-018-0866-8.

Richards, L. A. (1954). Diagnosis and improvement of saline and alkali soils. Vol. 78. LWW.

Saleh, A., A. Gad, A. Ahmed, H. Arman, and Farhat, H. I. (2023). Groundwater Hydrochemical Characteristics and Water Quality in Egypt's Central Eastern Desert. *Water (Switzerland),* 15 (5); https://doi.org/10.3390/w15050971.

Sawyer, C. N., and McCarty, D. L. (1967). Chemistry of sanitary engineers, nd McGraw Hill. New York, 518p.

Sayed, E., Dahab, K., and Ebraheem, A. M. (2004). Hydrogeological and hydrogeochemical aspects of the Nubian Sandstone aquifer in East Oweinat area, SW Egypt. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen*, 121–152.

Selmane, T., Dougha, M., Djerbouai, S., Djemiat, D., and Lemouari, N. (2023). Groundwater quality evaluation based on water quality indices (WQI) using GIS: Maadher plain of Hodna, Northern Algeria. *Environmental Science and Pollution Research*, 30(11), 30087–30106; https://doi.org/10.1007/s11356-022-24338-1.

Sharaky, A. M., E. S. A. El Abd, and E. F. Shanab. (2019). Groundwater assessment for agricultural irrigation in Toshka area, Western Desert, Egypt. *Conventional water resources and agriculture in Egypt*, 347–387.

Szabolcs, I. (1964). The influence of irrigation water of high sodium carbonate content on soils. *Agrokémia és talajtan*, 13, September, 237–246.

Tantawy, M. F.; Nada, W. M. and Abou Hussien, E. A. (2015). Evaluation of groundwater quality and its suitability for agriculture use in Minufiya Governorate, Egypt. *Egyptian Journal of Soil Science*, 55, 81–96.

Tomaz, A., Palma, P., Fialho, S., Lima, A., Alvarenga, P., Potes M., and Salgado, R. (2020). Spatial and temporal dynamics of irrigation water quality under drought conditions in a large reservoir in Southern Portugal. *Environmental Monitoring and Assessment*, 192 (2); https://doi.org/10.1007/s10661-019-8048-1.

Wagh, V. M., Panaskar, D. B., Muley, A. A., and Mukate, S. V. (2017). Groundwater suitability evaluation by CCME WQI model for Kadava River Basin, Nashik, Maharashtra, India. *Modeling Earth Systems and Environment,* 3 (2), 557–565; https://doi.org/10.1007/s40808-017-0316-x.

WHO. (2011). Guidelines for drinking-water quality. *WHO chronicle*, 38(4), 104–8.

Wilcox, Lv. (1955). Classification and use of irrigation waters. US Department of Agriculture.

Yehia, M., Baghdady, A., Howari, F. M., Awad, S., and Gad, A. (2017). Natural radioactivity and groundwater quality assessment in the northern area of the Western Desert of Egypt. *Journal of Hydrology: Regional Studies,* 12 May, 331–344; https://doi.org/10.1016/j.ejrh.2017.06.002.

Youssef, A. M. A. (1996). Geophysical study on the Nubia sandstone aquifer in East El-Oweinat area, Southwest Egypt. Ph. D. thesis, Fac. Sci., Ain Shams Univ., Egypt, 174p.

Zaman, M.; Shahid, S. A.; Heng, L.; Zaman, M.; Shahid, S. A. and Heng, L. (2018). Irrigation water quality. Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques, 113–131.