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EVALUATING THE SUITABILITY OF GROUNDWATER QUALITY FOR DRINKING AND IRRIGATION PURPOSES IN EL-MINIA GOVERNORATE, EGYPT

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ABSTRACT

Groundwater is an essential source for industrial, agricultural, and domestic water supply, especially in arid regions. The paper aims to assess groundwater quality and evaluate its suitability for drinking and irrigation uses in El-Minia Governorate, Egypt, using geographic information system (GIS) and hydrochemistry analysis. Twenty-seven groundwater samples were collected and analyzed for Physico-chemical parameters, and the spatial distribution of these parameters were mapped using GIS. 96 % of the collected groundwater samples are suitable for drinking according to the World Health Organization (WHO) and Egyptian water standards, while 4 % of them are not, due to their high levels of salinity (>1,000 ppm of dissolved solids). The quality of collected water for irrigation was assessed using salinity hazard, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), Kelly's ratio (KR), sodium percentage (Na %), and Permeability Index (PI). All water samples are suitable for irrigation according to EC and SAR, but 52 % of the samples are not safe for irrigation when KR is considered. 74% of the wells are suitable for irrigation if Na% is considered, and 78% for RSC, 55.5% for PI, but only 33 % for MH. Assessing the groundwater quality in El-Minia Governorate provides baseline information for policymakers and water resource experts to develop proper management, utilization, and planning of water resources for sustainable management.

Keywords: *Groundwater quality, Hydrochemistry, GIS, Drinking and irrigation, El-Minia Governorate, Egypt.*

1. INTRODUCTION

Although Egypt's water resources are limited by the Nile River, which has a fixed quota of 55.5 Bm^3/y according to the Nile Water Agreement in 1959 [1], [2], it faces rising levels of pollution.

The primary sources are discharging domestic, industrial wastewater, and flashflood. Over the last years, an increase of pollutants resulting from the expansion of industrial, commercial, and agricultural activities and an increaseinthe amount of sewage water on the Nile and canals led to the deterioration of water quality [1]–[3].

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WHO/UNICEF [4]Reported that more than three million people die every year in the world from water-related diseases and that around 80% of the diseases and deaths within the developing countries are associated with water pollution. Protecting such a limited amount of freshwater is essential to preserve the nation's development [5]. The importance of groundwater is increasing due to the inadequacy of available surface water and the increasing demand for irrigation and drinking water. Groundwater for drinking is used approximately by one-third of the world's population [6]. Hence, groundwater has already become the primary source of water supply for industrial, domestic, and agricultural sectors of several countries. Unfortunately, groundwater tends to be poorly managed, undervalued, and inadequately protected [7]. In Egypt,the interactions between surface water and groundwater are the subject to increasing pollution [8], [2]. Therefore, it is essential to assess groundwater quality.

Analysis of water quality is considered to be one of the most challenging aspects of groundwater studies. The hydrochemical analysis helps to classify certain those water masses that are suitable for drinking and irrigation purposes [9]. It represents the basis of water quality analysis relating to source, climate, geology, and use. It is essential to investigate methods of reporting analytical data and the geochemistry of dissolved constituents [10]. Excessive amounts of dissolved ions in irrigation water influence agricultural and plant-soil chemically and physically, therefore, reducing productivity. These ions reduce the osmotic pressure in the plant's structural cells and try to prevent water from entering the leaves and stems, thereby disrupting the metabolism of the plant [11]. Groundwater is rapidly becoming scarce, and its untested contamination restricts its use. Once contaminated, remediation and cleaning costs would be very costly [12]. Therefore, the quality of groundwater needs to be assessed regularly.

In the studied area, it has been calculated that the discharge from drains to the Nile river and Youssef canal is about 6 million m^3/day [13]. The agricultural drainage water contains the remains of pesticides and chemical substances. Municipal and industrial wastes and the use of fertilizers and pesticides for agriculture have contributed to a continuous increase of heavy metals in soils [14]. This research aims to study the hydrochemical characteristics of groundwater resources in El-Minia Governorate and assess the groundwater composition and its impact on groundwater quality to help manage and protect it.

Many powerful methods are available to assess the water quality such as the principal component analysis [15], neural network model [16], Bayesian discrimination method [17], entropy method [18], water pollution index method [19], grey method [20], statistical analysis method [21] and others. Each has its characteristics, applicable scope, and limitations. A statistical analysis method is a vital tool in the analysis of groundwater chemistry.

This study evaluates groundwater quality in El-Minia governorate for drinking and irrigation uses. Hydrochemistry and Geographic information system (GIS) is used in the analysis, and it has played a main role in offering an appropriate method to integrate physicochemical data analysis of the studied groundwater [22]. The kriging technique is used to visualize the spatial relationship between the sample points, typically employed for spatial mapping inconsistency [23]. The groundwater quality has been evaluated according to the Egyptian and World Health Organization [24] standards for drinking water.

2. STUDY AREA

2.1 Location

The western plain of El-Minia governorate is the study area situated in central Egypt on the west bank of the Nile and occupies a prime location on the Nile River (Figure 1). The study area covers about 1,600 Km^2 as part of El-Minia Governorate. The study area is distinguished by geographical location as it is a passage to many water sources: Nile River and Youssef, and Ibrahimia canals.

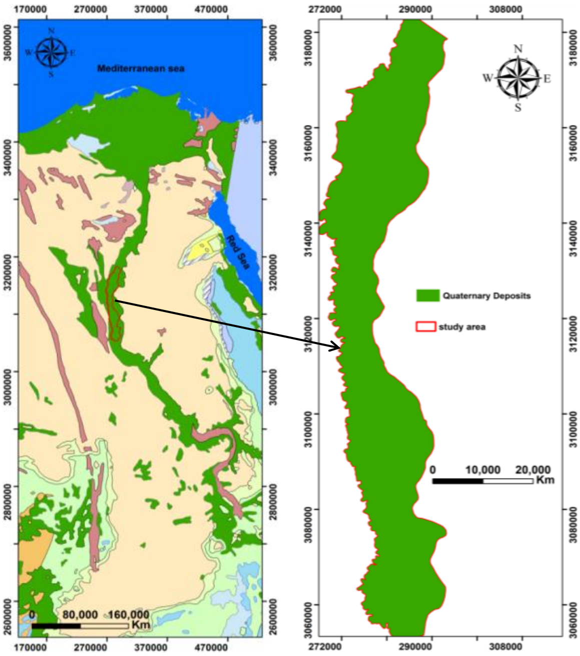

Fig.1. Geological formation of the study area.

2.2 Sources of surface and groundwater pollution

El-Minia governorate's primary potential sources of surface and groundwater pollution are from the agricultural, municipal, and industrial sectors. The discharge of agricultural drainage water from drains into the Nile River and the Youssef Canal is the primary source of water pollution as agricultural drainage water contains residues of pesticides and chemical substances. In the study area, there are 14 drains with branches that discharge water into the Nile River and the Youssef Canal. The volume of drainage water discharge is 6 million m^3/day [13]. Another pollution source is the sewage system in most of the villages of the governorate. Eight sewage stations discharge water into the drains and into the Nile River or the Youssef Canal, four sewage stations that affect the study area with a capacity of 180,000 m^3/day. Also, industrial drainage pollution has not been treated. One sugar factory with a capacity of 4,500 m^3/day discharges industrial drainage into the Etleeder drain, then the El-Mohit drain and finally the Nile River **[**13].

2.3 Topography, climate, and Geology

The study area elevation ranges from 50 m above sea level in the south to 30 m at the north of the studied area (Figure 2a). The climate of the study area is tropical (hot and mild are subjective). The main annual temperature of the study area is about 12°C. The highest temperature was recorded in July with 40°C, while the lowest temperature recorded in December was around 29°C[25]. The study area is rainless in summer and mild with rare precipitation in winter. The average annual precipitation is 14 mm/year and falls at any time in the year except summer months (June, July, and August) [25]. The total monthly rainfall in winter and spring are about 2.2 mm and 1.4 mm, respectively, that becomes the total monthly rainfall for the year is about 4.6 mm/year from 1975 to 2006 [26]. The study area is hot and dry. Consequently, the amount of evapotranspiration is high, about 1950 - 4000 mm/year [25].The annual average evapotranspiration rate was 3759.5 mm/year from 1975 to 2006 [26]. The evapotranspiration estimated in this model is about 255.5 mm/year.

The Quaternary deposits cover the whole Nile Delta aquifer since they extend to the north and south directions while they are limited from the east and west by the Tertiary deposits [27]. They are considered as a semi-confined aquifer, as shown in Figure 3 [28]. The hydraulic conductivity values of the upper aquifer (Holocene sediments, silty clay) are 0.2 m/day, and the hydraulic conductivity values of the lower aquifer (quaternary aquifer, which is formedbysand and gravel with clay intercalations) are 20-75 m/day [29]. The mean depth of the groundwater level ranges between 30 and 127 m below the ground surface (Figure 2b)

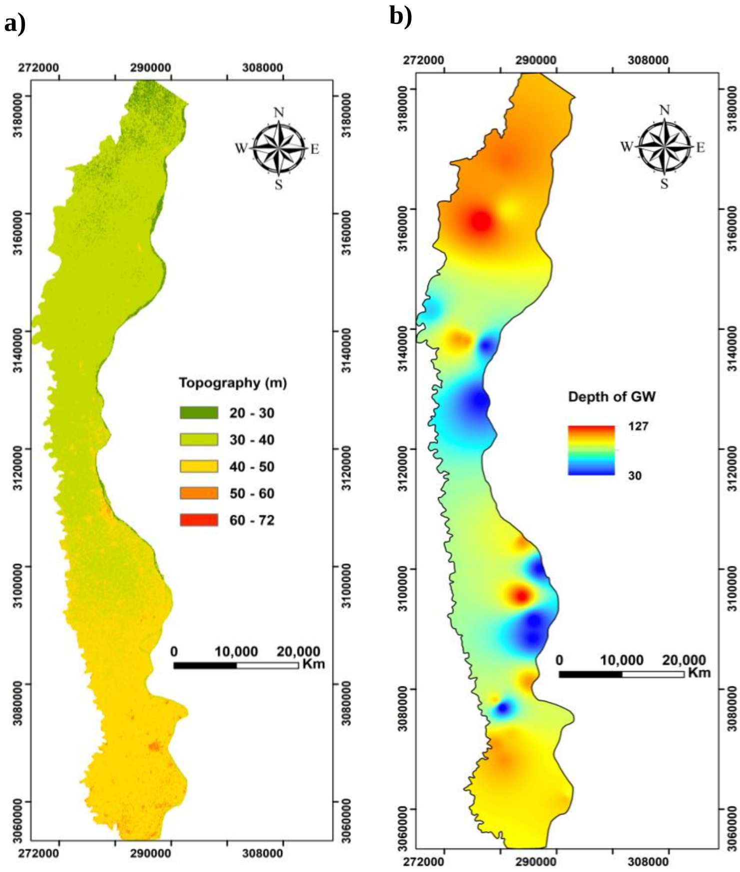

Fig.2. The topography (a) and groundwater level (b) of the studied area.

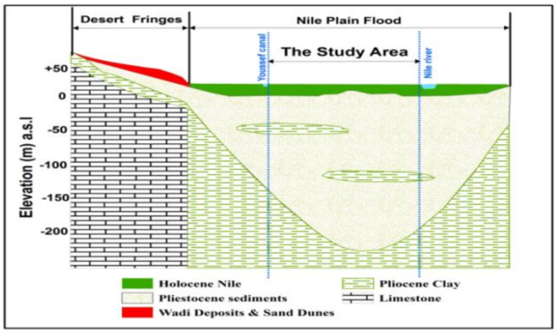

Fig.3. Hydrogeological section at the plain flood of El-Minia modified from RIGW [30]

3. MATERIALS AND METHODS

Groundwater samples were collected from 27 pumping wells located from different locations of the studied area (Figure 4) during the spring season. The abstracted groundwater from these wells is mainly used for irrigation and drinking purposes. The water samples were transferred into acid-washed plastic bottles. The volume of each sample was 1000 ml.

Samples were analyzed for the Physico-chemical attributes like pH, electrical conductivity (EC), total hardness (TH), dissolved silica, major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), and major anions (Cl^{-}, CO_3^{2-}, HCO_3^{-} and SO_4^{2+}). The analyzed data were compared with the WHO [24] and Egypt drinking standards for drinking use. A classification of the collected water samples has been made according to the major anion and cation distribution. The groundwater quality for its suitability for irrigation was defined with the help of different parameters as adsorption ratio (SAR), residual sodium carbonate (RSC), and Kelly index (KI), sodium percentage (Na%), permeability index (PI), and magnesium hazard (MH). ArcGIS 10.1 software has been used, applying the inverse distance weighted interpolation technique to plot the spatial distribution maps of the mentioned water-quality parameters.

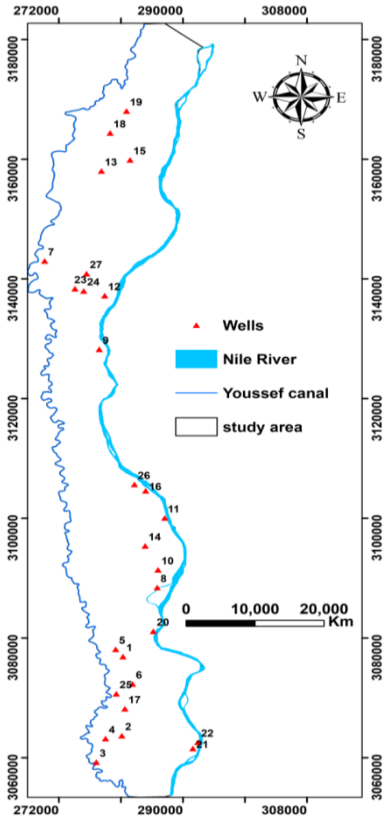

Fig. 4. Map of the study area with water samples locations.

4. RESULTS AND DISCUSSIONS

4.1 Hydrogeochemical characteristics of groundwater

Table 1 shows the results of the major cations and anions of the collected groundwater samples and the calculated values of total hardness (TH), SAR, sodium percentage (Na), RSC, KR, MH, and PI. Table 2 shows a statistical analysis of the Physico-chemical elements in groundwater samples and the permissible limits of the elements based on WHO [24] and Egyptian water standards. The pH values range from 7.0 to 8.6, with an average of 7.60, which indicates that the majority of the collected samples are within the allowable limit. The EC is a measure of water capacity to convey electric current that is directly correlated with salinity, and then the potential suitability for irrigation. The measured values range from 570 to 1990 μS/cm, with an average of 1059 μS/cm (Table 2). About 7.5 % of the samples were above the maximum allowable limit according to WHO standards.

Table 1: Hydrogeochemistry of all samples in the study area.

s. no.	pH	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO^{-}_{3}	Cl^{-}	SO^{2-}_{4}	TH	SAR	RSC	KP	MH	PI
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	%	%	mg/L
1	7.68	1170	650.4	56	23	98	2.1	317	85.3	69	234.5	2.8	0.51	0.91	40.38	73.1
2	8.1	1170	555	24	39	65	3.2	292.8	49	82	220.4	1.9	0.39	0.64	72.83	69.4
3	7.79	840	575.9	14.4	25.3	122	3.2	244	105	62	140.1	4.5	1.20	1.89	74.34	90.1
4	7.61	1100	668.7	24	42.7	114	3.2	292.8	138	54	235.6	3.2	0.09	1.05	74.58	73.9
5	8.6	1200	710	25.8	51.1	110	9.7	221.2	146.2	146	274.7	2.9	-1.87	0.87	76.56	65.1
6	8.5	1140	731.4	86.6	31.7	60	3.7	495	38.9	15.5	346.7	1.4	1.18	0.38	37.65	57.2
7	7.2	1990	1206.9	89	42	266	2.9	251	521	35	395.1	5.8	-3.78	1.46	43.77	69.9
8	7.69	990	617.2	65	32	80	3.2	214	125	98	294.0	2.0	-2.37	0.59	44.81	57.2
9	7.6	890	552.9	90	30	40	0.9	122	170	100	348.2	0.9	-4.96	0.25	35.48	36.3
10	7.69	1200	608.6	50	36	69	0.6	210	210	33	273.0	1.8	-2.02	0.55	54.29	57.4
11	7.88	920	601	60	30	80	1	214	150	66	273.3	2.1	-1.95	0.64	45.20	59.9
12	7.59	1650	652.2	65	36	100	0.2	148	210	93	310.4	2.5	-3.78	0.70	47.74	56.0
13	7.76	570	354.6	16	24	55	0.6	144	90	25	138.7	2.0	-0.41	0.86	71.22	76.1
14	7.02	730	476.2	40	29	60	0.2	210	115	22	219.2	1.8	-0.94	0.60	54.46	63.9
15	7.2	1270	793.6	24	48	152	0.6	317	198	54	257.4	4.1	0.05	1.28	76.74	75.6
16	7.18	1020	701.4	8	24	160	0.4	361	90	58	118.7	6.4	3.54	2.93	83.19	100.6
17	7.17	830	494.3	17	22	110	0.3	202	99	44	133.0	4.1	0.65	1.80	68.10	88.7
18	7	730	451.7	6.4	9.7	120	0.6	192	90	33	55.9	7.0	2.03	4.67	71.43	110.4

19	7.4	1180	775.1	4.8	19	199	0.3	405	105	42	90.2	9.1	4.84	4.80	86.72	107.4
20	7.4	1200	686.4	16	38	130	0.4	317	120	65	196.3	4.0	1.27	1.44	79.66	82.8
21	7.24	790	508.9	9.6	19	118	0.3	217	80	65	102.2	5.1	1.51	2.51	76.55	97.8
22	7.3	920	609.2	11	24	136	0.2	317	69	52	126.2	5.3	2.67	2.34	78.25	97.1
23	7.2	720	434.4	27	29	66	0.4	144	99	69	186.8	2.1	-1.37	0.77	63.92	66.7
24	7.8	1390	715.2	56	34	100	0.2	364	99	62	279.7	2.6	0.37	0.78	50.04	68.3
25	7.3	760	504.2	16	29	92	0.2	234	99	34	159.3	3.2	0.65	1.26	74.93	82.9
26	7.6	790	386.4	24	18	69	0.4	136	98	41	134.0	2.6	-0.45	1.12	55.30	79.1
27	7.8	1440	929.2	96	58	101	0.2	395	238	41	478.4	2.0	-3.09	0.46	49.91	49.7

Table 2: Statistical analysis of different elements of water samples of the study area.

Elements	Min	Max	Mean	WHO limit	Egypt limit
pH	7.0	8.6	7.60	8.5	7 - 8.5
Electrical Conductivity (EC) (μS/cm)	570	1990	1059	1,500	-
Total Dissolved Solids (TDS) (mg/l)	355	1207	628	1,000	500
Calcium (Ca^{2+}) (mg/l)	5	96	38	75	75
Magnesium (Mg^{2+}) (mg/l)	10	58	31	30	50
Sodium (Na^{+}) (mg/l)	40	266	106	200	200
Potassium (K^{+}) (mg/l)	0.2	9.7	1.45	10	-
Bicarbonate (HCO_3^{-}) (mg/l)	122	495	258	100	-
Chloride (Cl^{-}) (mg/l)	39	521	135	200	200
Sulfate ($SO4^{2-}$) (mg/l)	15.5	146	58	200	400
Total Hardness (TH) (mg/l)	56	478	223	600	500
Sodium Adsorption Ratio (SAR) (meq/l)	0.93	9.12	3.45	-	-
Sodium percentage (Na %)	20.20	82.76	51.34	-	-
RSC	- 4.96	4.84	- 0.22	-	-
Magnesium hazard (MH %)	35.43	86.70	62.48	-	-
Permeability Index (PI %)	30	99.60	65.50	-	-
Kelley Index (KI %)	0.25	4.80	1.39	-	-

According to Hem [31], 96 % of the studied groundwater samples are freshwater with TDS less than 1,000 mg/L (Table 3), whereas 4 % are slightly saline. Figure 5 shows the spatial distribution of the TDS. It shows that the low TDS describes the southern part due to its connection to the irrigation system, while the higher TDS describes the northern part due to mineral dissolution and lack of recharge.

Table 3: Water classification according to Hem [31].

Water type	TDS (mg/L)	No. of Samples	% of Samples
Freshwater	< 1,000	26	96 %
Slightly saline	1,000 – 3,000	1	4 %
Moderately saline	3,000 – 10,000	-	-
Very saline	10,000 – 35,000	-	-
Brine	> 35,000	-	-

According to the TH-based groundwater classification [32] (Table 4), approximately 18 % of the groundwater samples are in the very hard zone, 48 % of the groundwater samples are in the hard zone, 30 % of the groundwater samples can be classified as moderately hard, and 4 % of the groundwater samples are in the soft zone.

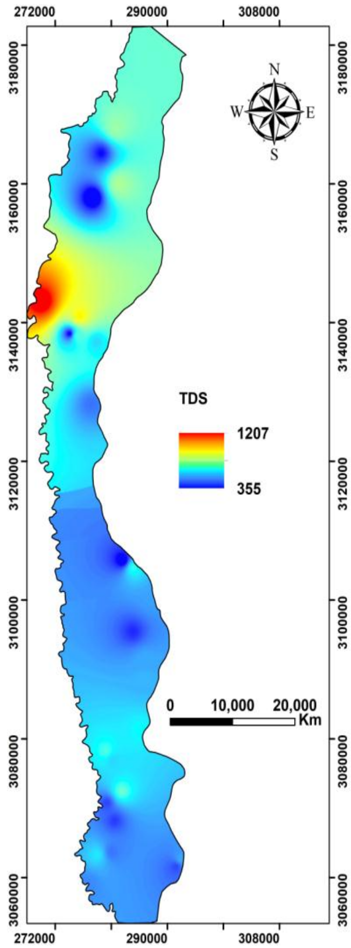

Fig. 5. TSD distribution map for the study area.

Table 4: Water classification according to TH**.**

TH (mg/l)	Classification	No. of Samples	% of Samples
< 75	Soft	1	4 %
75−150	Moderate hard	8	30 %
150−300	Hard	13	48 %
> 300	Very hard	5	18 %

Figures 6 and 7 show the spatial distribution of the major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and major anions (HCO_3^{-}, Cl^{-}, SO_4^{2-}), respectively. Approximately 15 % of groundwater samples are above the maximum permissible calcium limit of 75 mg/L. The magnesium concentration ranges from 10 to 58 mg/L, which shows that approximately 45 % of the samples surpass the allowable WHO limit of 50 mg/L. Magnesium-bearing minerals in rocks are the main sources of Mg_2^{+} in natural water, while the animal, domestic and industrial waste is the secondary source. About 4 % of the sodium concentration exceeds the allowable limit of 200 mg/L, as per the WHO standard.

According to the WHO, all groundwater samples for potassium are within the allowable limit of 10 mg/L. Bicarbonate content is higher than the allowable limit of 100 mg/L, according to the WHO standard. Groundwater passes through soil and becomes charged with CO_2 during infiltration, saturating with respect to calcite. Chloride in drinking water originates from industrial effluents, natural sources, urban runoff containing dissolved salts, sewage , and saline intrusion [33]. About 15 % of the groundwater samples for chloride ion concentration exceed the permissible limit of 200 mg/L as per the WHO standard. And about 96 % of the groundwater samples can be considered suitable for all crops, and the remaining 4 % are suitable for high, medium, and low salt-tolerant plants.

Sulfate is naturally found in water because of gypsum leaching and other common metals.

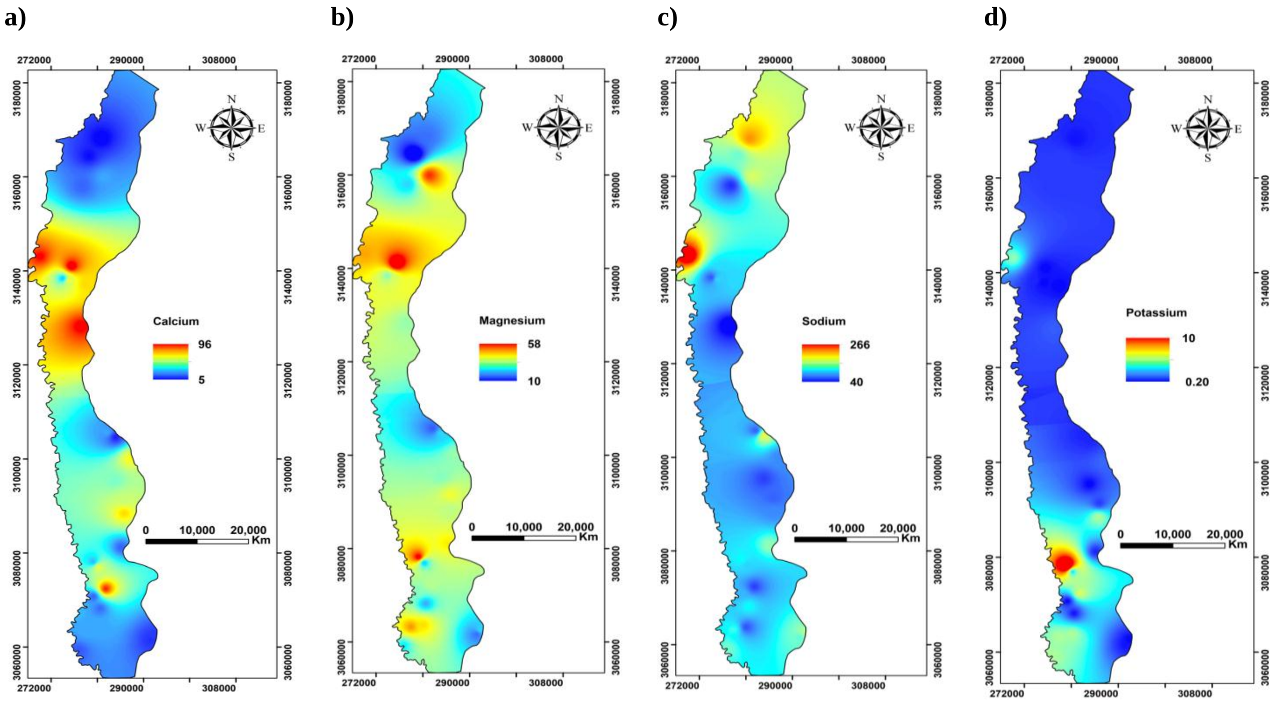

Fig.6. Spatial distribution of the major cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} in the study area.

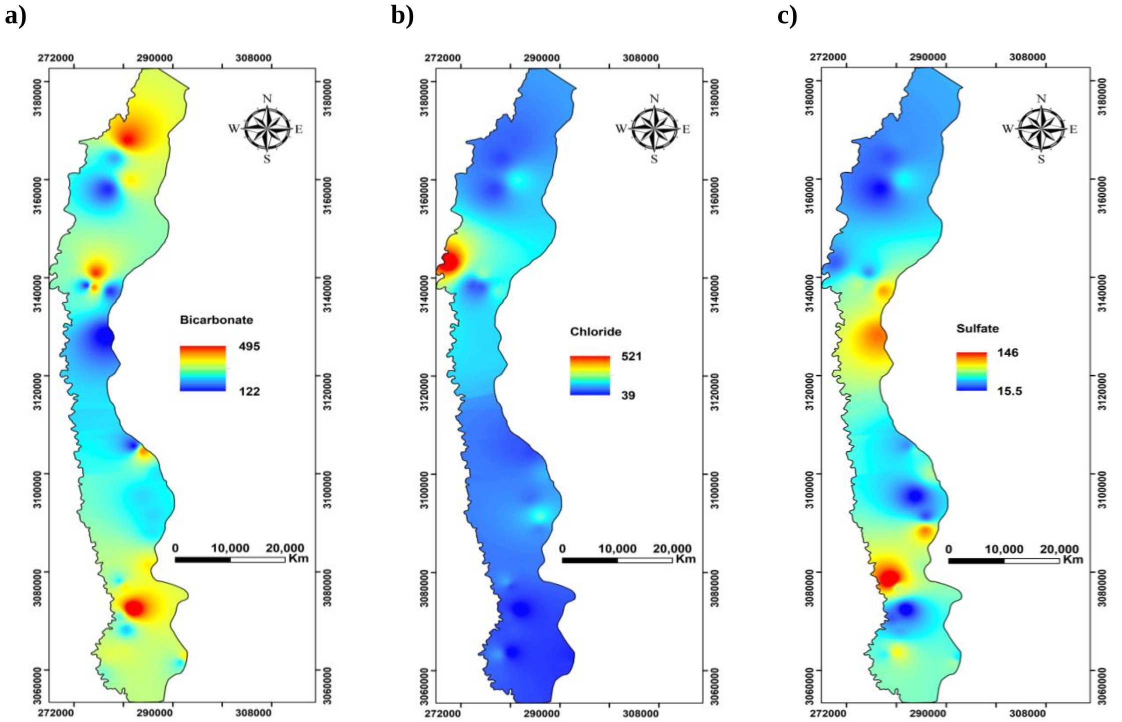

Fig.7. Spatial distribution of the major anions HCO^{3-}, Cl^{-}, and SO_4^{2-} in the studied area.

4.2 Groundwater quality evaluation for drinking and domestic uses

Drinking water should be free from the specific taste, colour, excessive amounts of dissolved salts, and turbidity [34]. According to the drinking water standards of the WHO [24] and Egyptian [35], 96% of groundwater samples are suitable for drinking, whereas 4% are not suitable due to their high salinity. Hardness is an important parameter in groundwater assessment for domestic and industrial uses. According to the hardness (TH), approximately 66% of the samples are in hard to very hard water, representing such waters as unsuitable for domestic and industrial purposes, whereas the remaining 34% are suitable.

4.3 Water quality evaluation for irrigation purposes

In order to evaluate the groundwater quality for irrigation purposes, EC, percentage sodium (Na %), SAR, RSC, KR, MH, and PI parameters have been determined. EC values show that all groundwater samples are suitable for irrigation, with 15% good and 85% permissible (Table 5).

Table 5: Water classes for use in irrigation according to according to EC.

Level	Salinity (EC) (μS/cm)	Hazard	No. of Samples	% of Samples
C1	< 250	Excellent	–	–
C2	250−750	Good	4	15 %
C3	750−2,250	Permissible	23	85 %
C4	2,250−5,000	Doubtful	–	–
C5	> 5,000	Unsuitable	–	–

4.3.1 Sodium percentage (Na %)

The sodium percentage (Na %) can be calculated using the following equation Raghunath [36].

$$Na\,\% = \frac{(Na^{+} + K^{+}) * 100}{(Ca^{++} + Mg^{++} + Na^{+} + K^{+})} \qquad (1)$$

where all ionic concentrations are in milli-equivalents per liter (meq/L).

The distribution of groundwater and classification of the irrigation water based on the soluble sodium percentage are presented in (Table 6). It is observed that approximately 74% of the samples are good to permissible for irrigation; 26% of the samples are doubtful and unsuitable.

Table 6: Water classes according to Na%.

Sodium (%)	Water Class	No. of Samples	% of Samples
< 20	Excellent	–	–
20 − 40	Good	8	30 %
40 − 60	Permissible	12	44 %
60 − 80	Doubtful	5	19 %
> 80	Unsuitable	2	7 %

4.3.2. Sodium Adsorption Ratio (SAR)

The sodium hazard of irrigation water is estimated by SAR can be calculated using the following equation Karanth[37] :

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

All concentrations are in meq/L.
The groundwater classes in the study area according to SAR are presented in (Table 7). The SAR values of all samples fall below 10 in the low-sodium level (S1), an excellent irrigation level.

Table 7: Groundwater classes according to SAR.

Level	SAR	Hazard	No. of Samples	% of Samples
S1	< 10	Excellent	27	100 %
S2	10 – 18	Good	–	–
S3	18 – 26	Doubtful	–	–
S4	> 26	Unsuitable	–	–

4.3.3 Residual sodium carbonate (RSC)

To measure the impacts of Bicarbonate and carbonate and, RSC has been determined by the following equation [36]:

$$RSC = (HCO_3^{-} + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad (3)$$

All ionic concentration is in meq/L.
The high value of RSC in water results an increase in the absorption of sodium in the soil. Water samples with RSC values greater than 5 meq/L are harmful to plant growth, whereas those above 2.5 meq/L are not suitable for irrigation purposes. Table 8 shows the water classes according to the RSC. The RSC value for all samples is less than 2.5. About 78% of the samples are less than 1.25, suitable for irrigation, while 22% of the samples are doubtful and unsuitable.

Table 8: Water classes for use in irrigation according to RSC.

RSC (meq/L)	Water class	Hazard	No. of Samples	% of Samples
<1.25	Good	Low	21	78 %
1.25−2.5	Doubtful	Medium	6	22 %
>2.50	Unsuitable	High	–	–

4.3.4 Kelly's ratio

Kelly's ratio (KR) has been calculated using the following equation [38]:

$$\text{Kelley's ratio} = \frac{Na^{+}}{Ca^{++} + Mg^{++}} \quad (4)$$

All the concentrations are in meq/L.

KR ratio greater than one considered as unfit for irrigation. Table 9 shows the water classes according to the KR. KR varies from 0.25 to 4.80, with an average of 1.39, 48% of the samples with KR value < 1, indicating the water is suitable for irrigation, and 52% is unsuitable for irrigation (Table 9).

Table 9: Water classes according to KI.

KI	Water class	No. of Samples	% of Samples
> 1	Moderate	14	52 %
< 1	Good	13	48 %

4.3.5 Magnesium hazards (MH)

The MH of irrigation water can be calculated using the following equation [39]:

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

All ionic concentrations are in meq/L.

MH values greater than 50 meq/L are not suitable for irrigation [40]. Table 10 shows the water types according to the MH. Approximately 67% of the samples exceed the magnesium ratio of 50 and are therefore not suitable for irrigation.

Table 10: Water classes according to the MH.

MH (meq/L)	Water class	No. of Samples	% of Samples
< 50	Good	9	33 %
> 50	unsuitable	18	67 %

4.3.6 Permeability Index (PI)

The permeability index (PI) can be calculated by the following equation [41]:

$$\text{PI} = \frac{\text{Na}^{+} + \sqrt{\text{HCO}_3^{-}}}{(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^{+})} \times 100 \quad (6)$$

All concentrations are in meq/L.

According to the PI classification, there are three water classes as Classes I, II and III as shown in Table 11. PI values range from 36 to 110. 55.5% of the samples are good for irrigation, while 44.5% show a low quality for irrigation.

Table 11: Water classes according to PI.

PI	Water quality	Water class	No. of Samples	% of Samples
< 75	Class I	Good	15	55.5 %
= 75	Class II	Moderate	–	–
> 75	Class III	Poor	12	44.5 %

5. FACTOR ANALYSIS

The factor analysis produced three significant factors, which represented 89.4% of the total variance (Table 12). These factors have been reported as the major drivers of groundwater chemistry: F1 has an eigenvalue of 4.71 and 42.82% of the variance. It includes TDS, EC, TH, Mg, Cl, and Ca with loading values of 0.806, 0.798, 0.755, 0.644, 0.534 and 0.518. F1 has strong EC, TDS, and TH loads, moderate Ca, Mg, and Cl loads. F2 has an eigenvalue of 2.42 and 21.97% of the variance. Includes pH, Na, SO_4, and K with loading values of 0.606, 0.545, 0.365, and 0.354. While F3 has an eigenvalue of 1,268 and 11,526% of the variance, it includes HCO_3 with a loading value of 0.499.

Table 12: Factor analysis.

Parameters	F1	F2	F3
pH	0.151	**0.606**	0.069
EC	**0.798**	0.059	0.003
TDS	**0.806**	0.139	0.001
Ca	**0.518**	0.034	0.047
Mg	**0.644**	0.055	0.000
Na	0.145	**0.545**	0.079
K	0.165	**0.354**	0.065
HCO_3	0.144	0.043	**0.499**
Cl	**0.534**	0.162	0.154
SO_4	0.050	**0.365**	0.328
TH	**0.755**	0.056	0.023
Eigenvalue	4.710	2.417	1.268
Variability (%)	42.819	21.973	11.526
Cumulative %	42.819	64.792	89.400

6. CONCLUSIONS

Hydrochemical analysis is applied to evaluate the groundwater quality in El-Minia Governorate, Egypt. The groundwater salinity of the investigated area ranges from fresh to moderately saline, and the spatial distribution of TDS shows an increase toward the central west of the study area.

According to the WHO and the Egyptian water standard, the majority of the samples have salinity less than 1000 ppm, which is suitable for drinking. Irrigation quality parameters were evaluated to assess the groundwater suitability for irrigation. Among these parameters, EC and SAR reveal that all collected groundwater samples are suitable for irrigation purposes. RSC indicated that 78 % of the samples are suitable for irrigation, and 74 % and 55.5 % are suitable according to Na% and PI, respectively. MH indicates that 67% is unsuitable, and 33% of samples are suitable for irrigation. Most of the groundwater parameters within the acceptable limits of the WHO and Egyptian standards for irrigation uses. The results confirm that the use of GIS and hydrochemical analysis provides a powerful tool for assessing the quality of groundwater in the studied area.

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تقييم مدي ملائمة المياه الجوفية لأغراض الشرب والري في محافظة المنيا

الملخص العربي:

المياه الجوفية هي مصدر مهم لإمدادات المياه باغراض الإستخدام في الصناعة والزراعة والإستخدامات المنزلية، خاصة في المناطق القاحلة. تتمثل الأهداف الرئيسية لهذه الدراسة في تقييم جودة المياه الجوفية وتقييم إستخداماتها لاغراض الشرب والري في محافظة المنيا، مصر، بإستخدام نظام المعلومات الجغرافية (GIS) وتحليل الكيمياء الهيدرولوجية. في هذه الدراسة، تم جمع ٢٧ عينة من المياه الجوفية من أجل تحليل معلماتها الفيزيائية والكيميائية وثم تعيين التوزيع المكاني لهذه المعلمات بإستخدام نظم المعلومات الجغرافية. واظهرت النتائج بان ٩٦٪ من عينات المياه الجوفية التي تم جمعها صالحة للشرب وفقًا لمعايير منظمة الصحة العالمية (WHO) ومعايير جودة المياه المصرية، بينما ٤٪ منها غير صالحة للشرب، وذلك بسبب إرتفاع مستويات الملوحة (أكبر من ١٠٠٠ جزء في المليون). تم ايضا تقييم جودة المياه لأغراض الري بإستخدام مخاطر الملوحة، ونسبة امتصاص الصوديوم (SAR) ، وكربونات الصوديوم المتبقية (RSC)، وخطر المغنيسيوم (MH) ، ونسبة Kelly (KR) ، ونسبة الصوديوم (Na%)، و مؤشر النفاذية (PI). حيث أظهرت النتائج بانجميع عينات المياه الجوفية التي تم جمعها مناسبة للري على أساس ECو SAR ، ولكن ٥٢ ٪ من العينات ليست آمنة للري إذا تم أخذKR بعين الاعتبار. ٧٤٪ من الآبار مناسبة للري إذا تم اعتبار٪ Na و٧٨ % في حالة RSC و ٥٥.٥ % في حالة PIلكن ٣٣٪ فقط صالحة للري في حالة MH . يوفر تقييم جودة المياه الجوفية في محافظة المنيا معلومات أساسية لواضعي السياسات وخبراء الموارد المائية لتطوير الإدارة السليمة واستخدام الموارد المائية وتخطيطها للإدارة المستدامة.