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ORIGINAL ARTICLE

Hydrogeochemical Evaluation of Middle Eocene Limestone Aquifer Using Multivariate Statistics and Visual Models, East El Minia Governorate, Egypt

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Abstract

East Minia is considered as one of the most promising areas for the establishment of numerous sustainable development projects. The Middle Eocene Limestone aquifer is the main water source needed for the establishment of these projects. Therefore, 32 collected samples from different wells and chemically analyzed to determine the suitability of that water for drinking and irrigation, as well as mentioned to the various factors controlling the water quality through the application of hydrochemical diagrams and statistical analysis. TDS value of the studied water samples was ranged from 271 to 2328 ppm which indicates that nearby is 93.8% of the investigated water samples are acceptable for drinking uses, while total hardness value ranged from 32.19 to 1035.44 which indicates that there is 93.8% of the studied groundwater samples are suitable for domestic uses. Statistical analyses, Gibbs and End-member diagrams indicate that the water−rock interactions, geochemical process (Redox), besides anthropogenic activities are the essential contributor to the investigated groundwater chemical composition. Thus, the studied water is suitable for irrigation purposes based on the calculated sodium hazards and salinity.

Keywords: Drinking and irrigation uses, East El Minia, Groundwater quality, Hydrogeochemistry, Statistical analysis

1. Introduction

Over the past few decades, there has been a constant demand for more water needed to meet Egypt's growing population growth and the land expansion projects. At present, reclaiming desert areas requires the exploration of new water resources, where rainfall and surface water availability are scarce. Therefore, there is an urgent need to develop groundwater resources for Egyptian desert reclamation projects. The groundwater quality depends on; 1) the origin of water, 2) the type of the bearing rock, and 3) the water flow are important factors Abdel-Shafy and Kamel [1].

Carbonate aquifer is the main aquifer in the investigated area and one of the poorest aquifers in Egypt. It covers about 50% of Egypt; Located basically in the North and center of the Western Desert. It covers about 500 000 km^2 of Egypt. It is characterized by many karst features in the Western and Eastern Deserts. Generally, the carbonate rocks overlie the Nubian Sandstone complex. The aquifer recharge depends mainly on the upward leakage from the Nubian Sandstone aquifer that underlines it and occasionally from rainfall El Tahlawi and colleagues [2]. The carbonate aquifer in the investigated area is represented by Samalut Formation that made up of hard, white, fossiliferous, cavernous

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and fractured limestone with thin marl and shale intercalations and characterized by large thickness with an average value of about 100 m Said [3].

Generally, the groundwater suitability for different purposes depends on water chemistry. Hence, extraction of the hydrochemical processes that regulate the groundwater chemistry are essential to overcome related problems Said and colleagues [4]. One of the most useful tools to determine the relationship between groundwater variants and their origin is the multivariate statistics. Principle component analysis (PCA) was applied widely to reduce the datasets for a few easily interpretable factors Said and colleagues, Said and colleagues [4,5], through the correlation between variants from which the main processes can be concluded.

1.1. Location and climate

The study area lies in the east of the Nile Valley from Mallawi to Beni Mazar and bordered by the Nile River from the West and Red Sea governorate from the East (Fig. 1). It lies between latitudes 27° 10′ and 28° 48′ N, and longitudes 30° 30′ and 31° 30′ E and located 245 km south of Cairo.

The investigated area lies within the North African arid belt, so its climate is hot with high evaporation rate, rainless and dry in summer, while in winter it is mild, warm with rare rainfall in winter. The rainfall months in this area are from October to May, the highest rainfall record is about 19.6 mm/year. The evaporation rate increases relatively with wind speed and air temperature Ahmed and colleagues [6]. According to the collected data from the Egyptian Meteorological Authority (EMA) [7] and the National Oceanic and Atmospheric Administration (NOAA) [8] for the years 1961–1990, the mean values are shown in (Fig. 2a), while the data for the years 1991–2021 are present in (Fig. 2b).

1.2. Geology

Geologically, the investigated area is mainly covered by the Middle Eocene carbonate rocks and to less extent the quaternary sediments (Fig. 3). These rocks are mainly represented by carbonate sediments intercalated by cherty layers of, sandy, and clayey limestones Bishay [10]. It can be represented by: Minia, Samalut, Maghagha, Qarara and Observatory formations Conoco, Said [9,11]. The quaternary sediments represented by the Nile silt deposits and Wadi Deposits (gravel, sand, and silt) that represents the country rocks weathering product.

The dominant structures affecting the study area are normal faults; they are represented by a large number of major NW–SE directed faults with a few NE–SW faults as shown in (Fig. 4). The large number of faults gives rise to other structural features such as horst and graben systems.

1.3. Hydrogeology

Hydrologically, Minia, Samalut, and Maghagha formations are the main water bearing rocks in the studied area Yousef and colleagues, Salem [12,13]. Minia Formation composed of alveolinal cross bedded limestone intercalated with chalk at the lower part, however it is cavernous limestone at the upper. Samalut Formation is formed of white, soft, cavernous, nummulitic limestone intercalated with marly, clayey and coquina beds and characterized by many large caves and vugs. Maghagha Formation is formed of marly and chalky limestone interbeds with few clay intercalations. Samalut Formation represents the main productive aquifer in East of El Minia Abo Habibah and colleagues [14]. Its recharge sources are represented in occasional storms over the eastern watershed (32% of aquifer recharge) and Nile water infiltration in the west (36% of the recharge) Mosaad and colleagues, El Ammawy and colleagues [15,16] and possibly from the upward leakage from the underlying Nubian sandstone aquifer through faults Ibrahim, Abu Heleika and colleagues [17,18].

2. Materials and methods

2.1. Sampling and analyses

A total of 32 collected groundwater samples from pore wells (Fig. 1). These samples were collected in polypropylene bottles and tightly closed. The parameters of pH, temperature, electrical conductivity (EC) and TDS were measured in field by using a digitally combined electrode (HANNA HI 991300). Redox potentiality (Eh) was measured in field by using a portable electrode (HANNA HI 98120). The collected samples were filtered in the laboratory by using a 45 μm filter and analyzed for chemical components. Whole water samples were analyzed one day after collecting samples and storage at 4 °C. A flame photometer was used to measure both K and Na. Volumetric methods were used to determine Mg, Ca, CO_3, HCO_3, and Cl. A spectrophotometer (HANNA HI 83215) was used to determine the SO_4, NH_4 and NO_3. at the Agricultural Directorate lab, El Minia, Egypt.

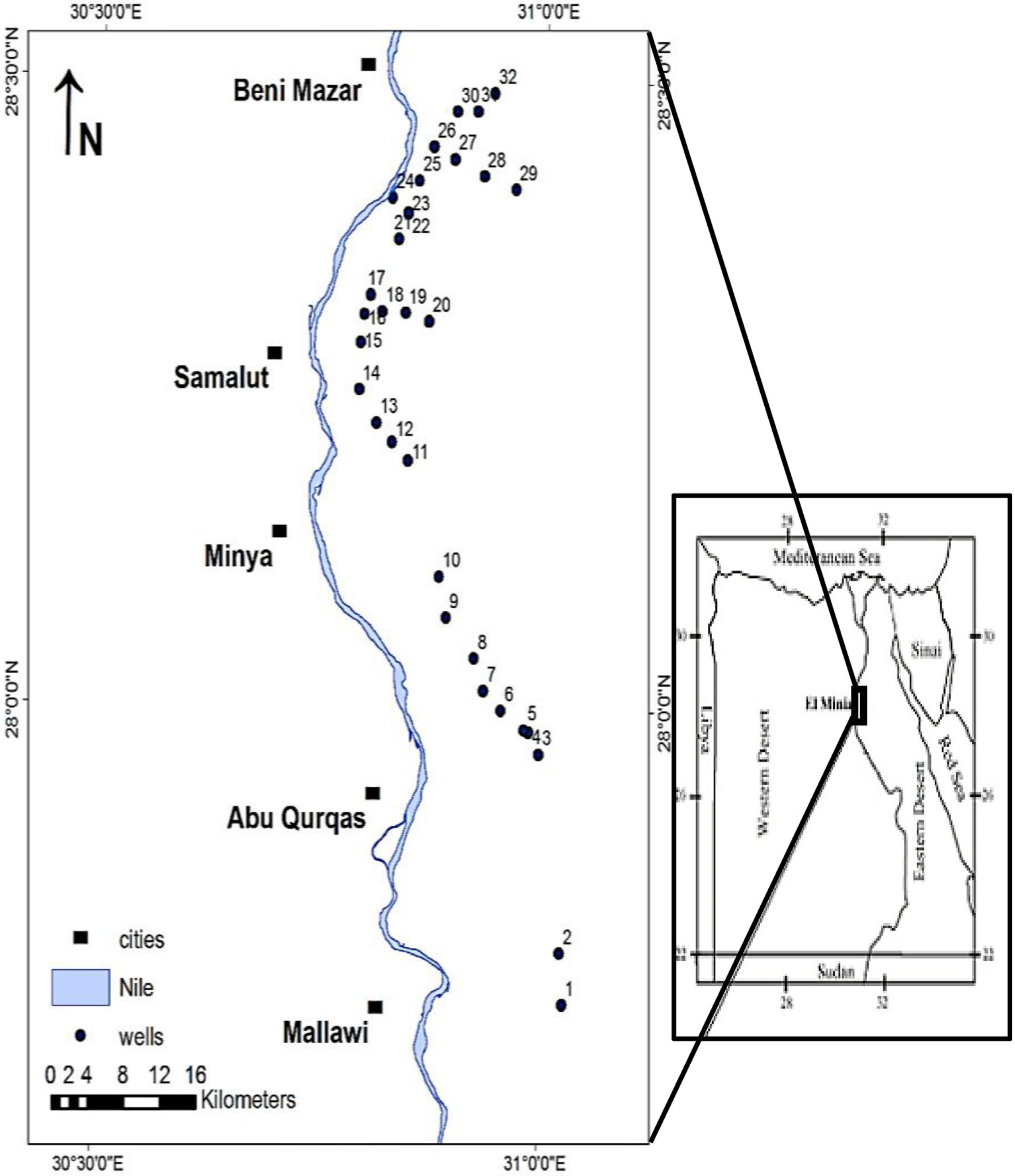

Fig. 1. Location map of the investigated area and sampling sites.

The studied wells location was detected by using of handheld Garmin (GPS) and plotted on the map by using Arc Map (Ver. 10.8) program. The geological cross-sections between different investigated points that determined the structure of study area were made by using Global Mapper (Ver.18) and Surfer (Ver.12) software programs. The analysis chemical data of the studied water were plotted on Piper, Schoeller and Durov's diagram by using of Aquachem program.

2.2. *Statistical analysis*

All statistical analyzes were conducted by using SPSS 16.0 software. Descriptive statistics were performed to detect the groundwater parameters distribution. To determine the essential process that controls groundwater composition, PCA was performed through Varimax rotation. Kaiser-Meyer-Olkin measure of sampling adequacy (KMO), with Bartlett's test for sphericity, was applied.

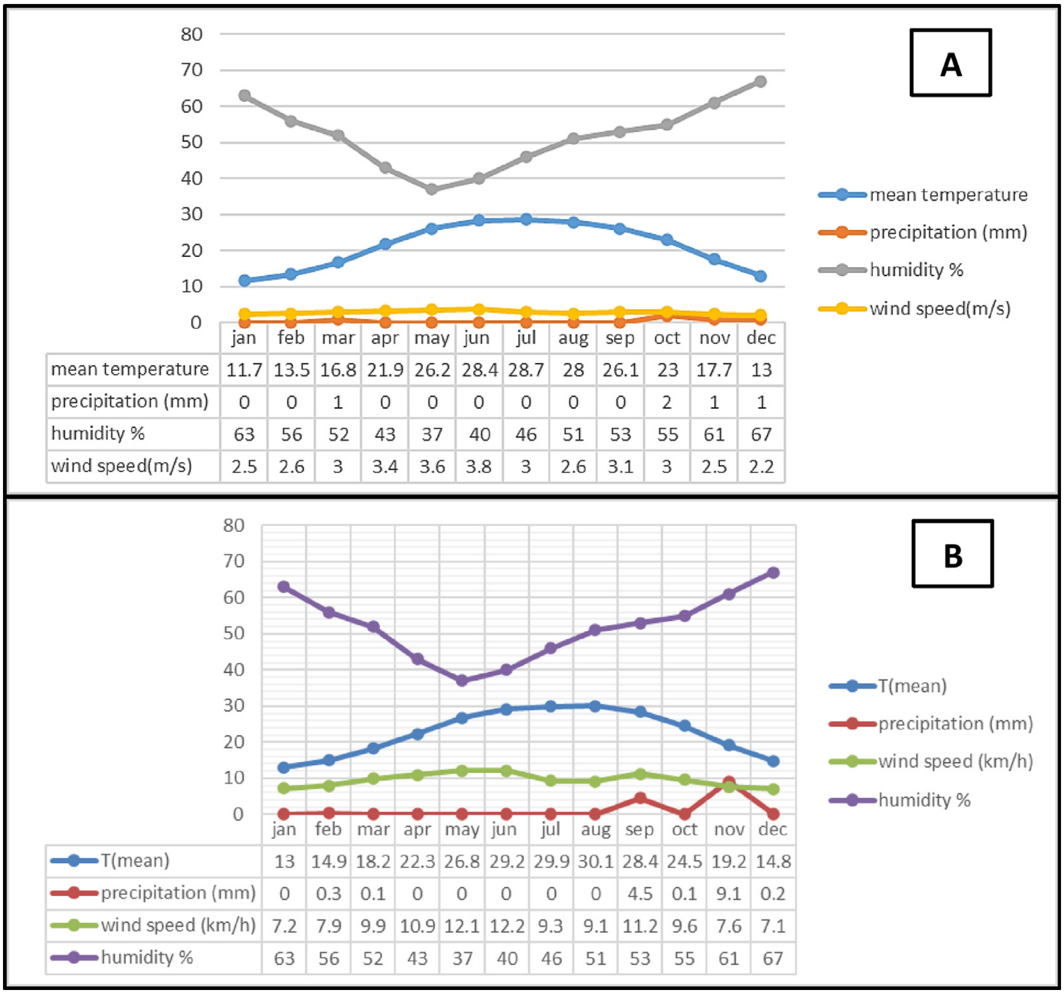

Fig. 2. Climate of the investigated area according to [7,8]; where (A) is the climate from 1961 until 1990, while (B) is from 1991 until 2021.

2.3. Irrigation water quality evaluation

There are some irrigation quality indicators which applied to evaluate the investigated water samples suitability for irrigation uses such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), sodium percentage (Na%) and Kelly's index (KI). These indicators were calculated by the following equations, respectively.

High values of SAR indicate sodium replacing adsorption calcium and magnesium, this replacement results damaging of the soil structure. The sodium concentration is very important in the groundwater quality evaluation to signify reactions with the soil and indicate the permeability reduction. Sodium adsorption ratio plays an important role in detecting of the water suitability for irrigation uses and calculated using the following equation Sakram and Adimalla, Adimalla and Venkatayogi [19,20]:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{+2}+Mg^{+2}}{2}}}(epm) \qquad (1)$$

The residual sodium carbonate is a very important indicator that detects the irrigation water suitability for irrigation uses as it effects on the soil physical properties by organic matter dissolution in soil that remains on drying a black stain on its surface. The calculating equation of RSC can be estimated by Eaton, Raghunath [21,22] as the following:

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

In all natural waters, the sodium hazard plays an important role in water suitability evaluation for irrigation purposes. The sodium percentage can be computed through the following equation according to Wilcox [23]:

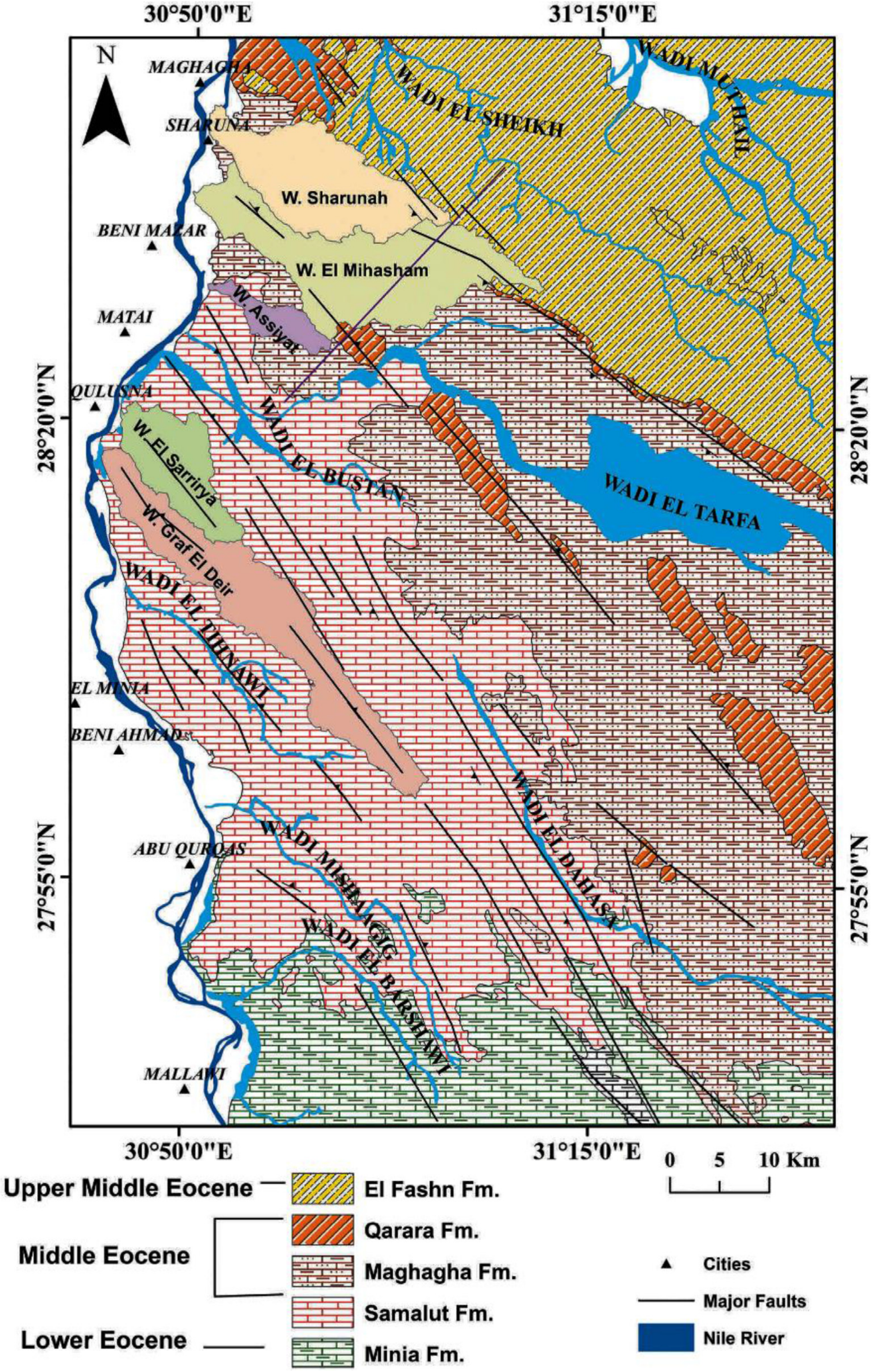

Fig. 3. Geological and Geomorphological map of the investigated area (After [9]).

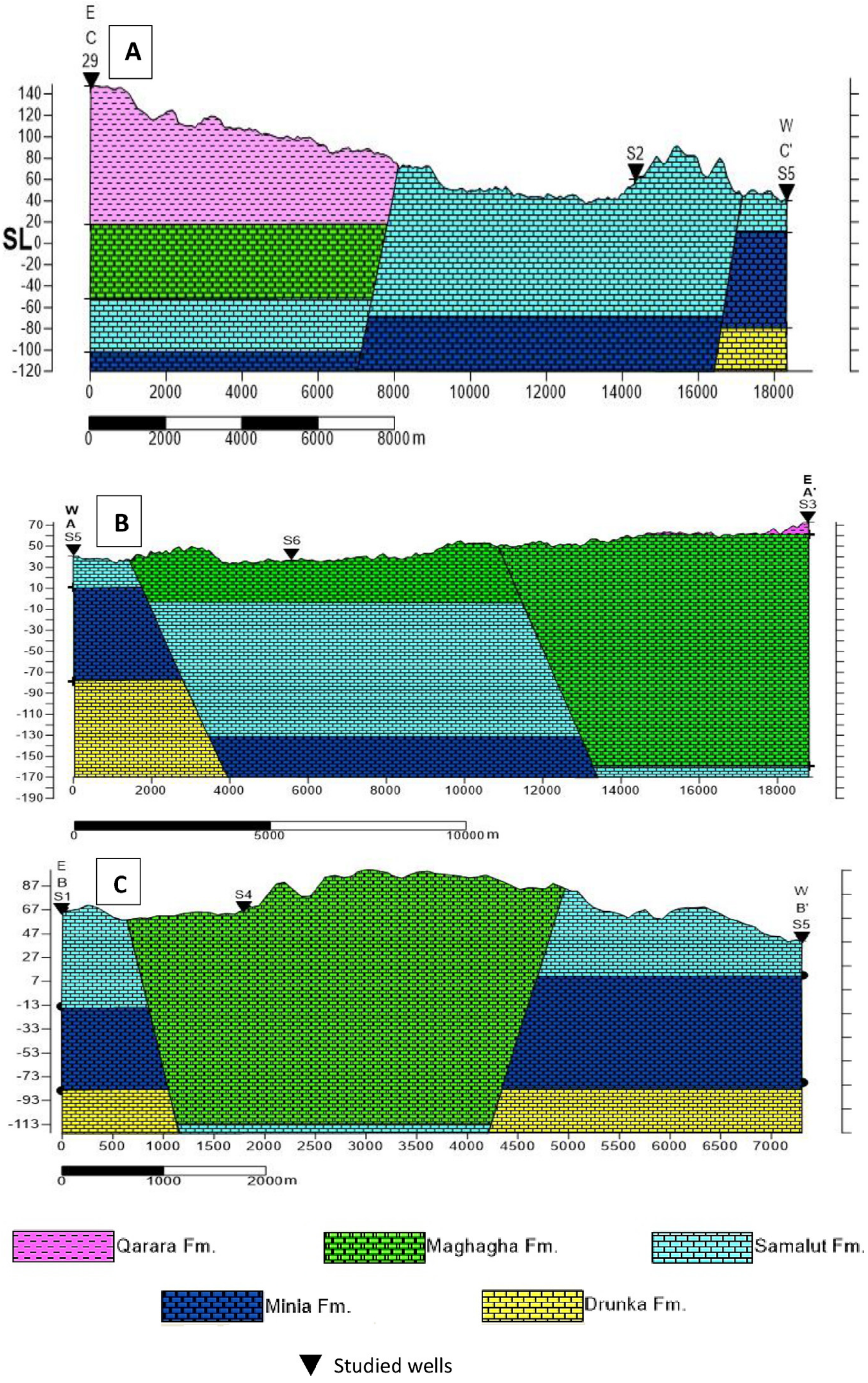

Fig. 4. Geological cross-sections illustrate the normal faults cut the investigated sequence.

$$\mathbf{Na\%} = \frac{(Na+K)}{(Ca+Mg+Na+K)} \times \mathbf{100}\ (epm) \tag{3}$$

Kelly [24] Detected alkaline earths and sodium relation. If the content of sodium is greater than the concentration of alkaline earths in the studied samples, it is classified as unacceptable for irrigation uses.

$$\mathrm{KI} = \frac{Na}{(Ca+Mg)}\,(epm) \tag{4}$$

3. Results and discussion

3.1. Hydrogeochemistry

The hydrogeochemical analysis records of investigated samples for the East Minia area are quoted in (Table 1). Hydrogen ion concentration (PH) values of the studied samples ranged from 7.50 to 9.70 with an average 7.85 which indicates a slightly alkaline media. TDS values ranged from 271.20 to 2327.80 mg/L with an average 668.20 mg/L. The groundwater is classified according to TDS as fresh water, if it is less than 1000 mg/L; slightly saline, if it is in between 1000 and 3000 mg/L; moderately saline, if it varies from 3000 to 10 000 mg/L; and highly saline, if it varies from 10 000 to 35 000 mg/L [26]. The TDS values of 30 studied samples are classified as fresh water, while in two studied wells (1 and 29) increased this value due to the leaching and dissolution of the aquifer materials. Ec values ranged from 509.40 to 4235.60 μS/cm with an average 1218.23 μS/cm the total hardness (TH) values of the analyzed samples ranged from 32.19 to 1035.44 mg/L with an average 196.83 mg/L. Thirty samples are classified as acceptable according to [25], while two studied wells (7 and 29) are unacceptable because of the leaching and dissolution of magnesium and calcium bearing deposits (limestone).

The major ions concentration in the investigated wells is presented in (Fig. 5). In the case of calcium (Ca) ion concentration, it ranged from 11.02 to 271.97 mg/L with an average value 58.71 mg/L, its concentration in 28 samples is acceptable according to [25] maximum allowable limits, while increased in four studied wells (1, 2, 29, and 32) indicating gypsum bearing deposits leaching and dissolution. The magnesium (Mg) concentration values ranged from 3.34 to 165.03 mg/L with an average value 21.90 mg/L, its concentration in 31 are acceptable, while increased in only one sample of well (29) due to leaching on the limestone. Sodium (Na) ranged in the studied area from 60.39 to 415.48 mg/L with an average 145.54 mg/L, its concentration in28 are acceptable, while increased in four samples (1, 2, 29, and 32) indicating old marine water origin in limestone.

The potassium (K) concentrations ranged from 3.77 to 10.58 mg/L with an average value 5.20 mg/L, its concentration in 31 are acceptable, while increased in only one sample of well (29) due to Maghagha and Qarara shale. Chloride (Cl) ranged from 49.15 to 385 mg/L with an average value 124.65 mg/L, its concentration is acceptable in all samples except (5 and 24) samples which indicates the chlorine bearing deposits leaching laid down under marine conditions in wells. Bicarbonates (HCO_3) ranged in the analyzed water from 89.57 to 708.28 mg/L with an average 313.86 mg/L indicating carbonate rocks dissolution and the carbon dioxide (CO_2) content in the soil zone in all the studied wells

Table 1. Statistical summary of the measured parameters in investigated samples in comparison with the [25].

Parameters	Concentration in groundwater samples			WHO MAL*	Percent of samples	
	Maximum	Minimum	Mean		Below MAL	Above MAL
PH	9.70	7.50	7.85	9.2	96.8%	3.2%
TDS	2327.80	271.20	668.20	1000	93.8%	6.2%
EC	4235.60	509.40	1218.23	1500	84.4%	15.6%
TH	1035.44	32.19	196.83	500	93.8%	6.2%
Ca	271.97	11.02	58.71	75	87.5%	12.5%
Mg	165.03	3.34	21.90	50	96.8%	3.2%
Na	415.48	60.39	145.54	200	87.5%	12.5%
K	10.58	3.77	5.20	10	96.8%	3.2%
Cl	385	49.15	124.65	250	93.8%	6.2%
HCO3	1708.28	89.57	277.3	100	9.4%	90.6%
SO4	414.26	10.60	101.59	400	96.8%	3.2%
NO3	12.80	0.67	4.11	50	100%	–
NH4	1.68	0.34	0.88	0.5	15.6%	84.4%

[*] MAL: Maximum Allowable Limits.

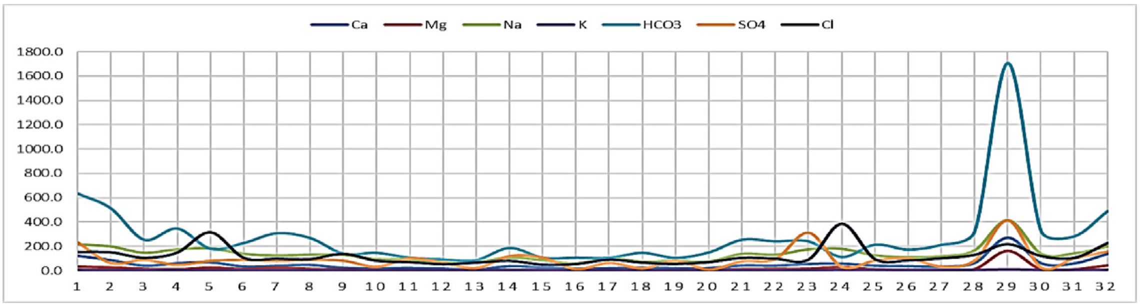

Fig. 5. Major ions concentrations in the studied wells of the investigated area.

except wells (12 and 13). Sulphates (SO_4) concentrations ranged from 10.60 to 414.26 mg/L with an average value 101.59 mg/L, its concentration is acceptable in all samples except well (29) because of fertilizers using and irrigational sewage in addition to presence of evaporates such as gypsum and anhydrite in Maghagha and Qarara shales. Nitrates (NO_3) ranged from 0.67 to 12.80 mg/L with an average value 4.11 mg/L (Fig. 6) which shows that all water samples are acceptable according to [25] maximum allowable limits. Ammonia (NH_4) concentration in the investigated area ranged from 0.34 to 1.68 mg/L with an average value 0.88 mg/L indicating waste water and fertilizers contamination in all studied wells except (5, 21, 26, 27 and 32).

High ammonia concentrations may result many dangerous diseases such as liver disease, kidney failure and genetic disorders. It may also irritate and burn the skin, mouth, throat, lungs, and eyes [27]. These high (NH4) concentrations in the studied groundwater samples are a result of fertilizers contamination due to (N) fertilizers usage; Ammonia-azoten and Biogen fertilizers Ahmed and colleagues [28].

The identified groundwater types by RockWare Aq.QA software was mainly Na–HCO_3 (75%), Na–Cl (15.6%) and Na–SO_4 (9.4%) showing that this groundwater is essentially of bicarbonate facies affected by River Nile surface recharge, occasional flashfloods and irrigation surplus. Piper Ravikumar and Somashekar [29] diagram is very important in making of four basic conclusions; water type, precipitation or solution, mixing and ion exchange Furtak and Langguth [30]. From Fig. 7, it determined that alkalis exceed alkaline earths (Na + K > Ca + Mg) in the majority of samples (93.75%). The majority of studied samples (78%) are classified as alkaline water with prevailing SO4 and Cl Kaur and colleagues [31] which indicates the excess gypsum and halite dissolved in the water samples. This class indicated the evaporites weathering Ikhlil [32] as well as surface salts infiltration into groundwater because of irrigational activities in the investigated area. These also mean that this water courses have been subjected to contamination by sewage and fertilizers, contamination appears by the results shifting to the middle of piper plot Ravikumar and Somashekar [29]. About 22% of the studied samples (1, 2, 4, 7, 18, 20, 29, and 30) are alkaline water with prevailing bicarbonate. While only 1 sample (Nos. 29 and 32) is earth alkaline water with increase of alkalis with prevailing HCO_3 and 1 sample is earth alkaline water with increase of alkalis with prevailing SO_4 and Cl. The left triangle (for cations) indicates that the majority of water samples are present in the sodium type field, while

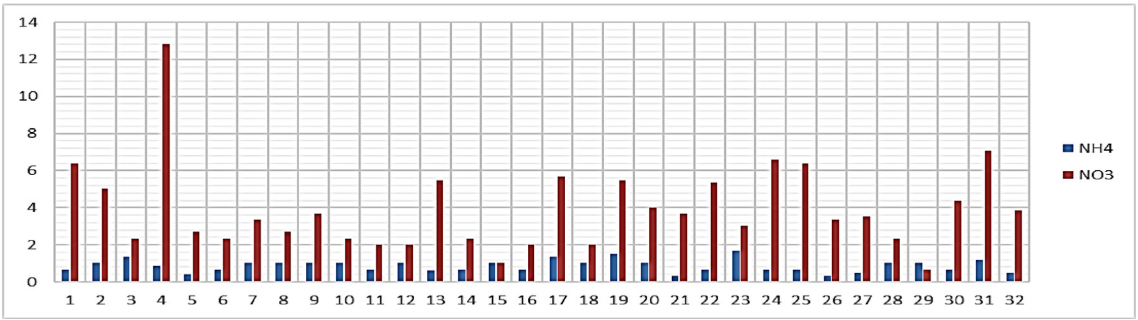

Fig. 6. Nutrients concentrations in the studied water samples of the investigated area.

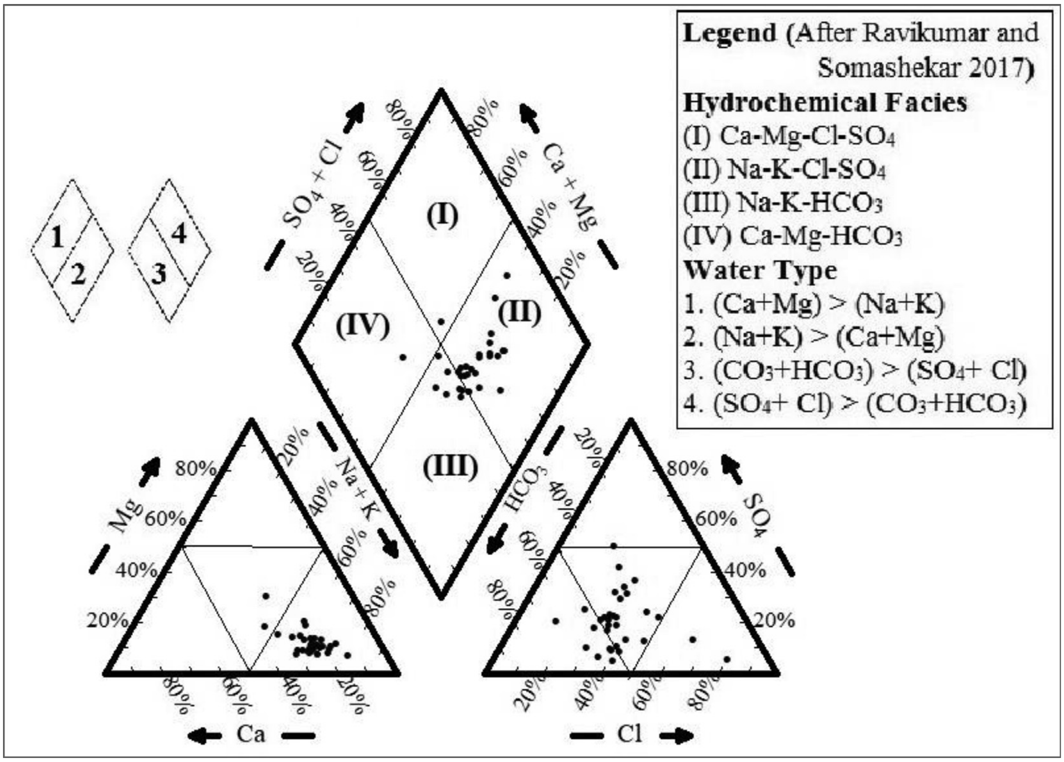

Fig. 7. Piper diagram for the analyzed water samples classification.

right triangle (for anions) shows that the most of water samples are of no common anion and only 25% plotted in the bicarbonate type field.

Schoeller's [33] diagram is a linear pattern diagram which used in comparing the study data and also as a monograph for the major ions. It represents the cations and anions concentrations expressed in epm through line which drawn by connecting points. The collected samples of the investigated area are plotted in (Fig. 8) and indicate that sodium is the prevailing cation and chloride is the predominant anion.

Durov's Roy and colleagues [34] diagram is composed of two triangles; the upper right triangle for anions and the other lower left for cations; and a rectangle shaped to determine the water type depending on the relationships between cations and anions. It is used for detecting of the geochemical processes which effect on the water genesis. Depending on the high mobility of anions in the groundwater it classifies the groundwater through detecting of the anions content in water, while it uses cations as subordinate to anions as a result of its medium mobility in the groundwater. By representing the collected groundwater samples on Durov's diagram in (Fig. 9) we found that, the collected samples are mainly fall in the 6th and 5th fields (mixing and cations exchange waters) and (mixing reaction from various origins). The upper right triangle (for anions) shows that the investigated samples are plotted in the bicarbonate type field and intermediate type field, while the lower left triangle (for cations) shows that the investigated samples are mainly fall in the sodium type field.

3.2. Statistical analysis

For understanding groundwater chemistry, PCA was performed to define basic hydrochemical processes controlling water hydrochemistry. To ensure neutrality in the statistical results “0.5” was set as a base value in the model dealing Liu and colleagues [35]; bold values refer to the highest loading variants in each factor. Statistical analysis of groundwater data showed that there are four main components that control water chemistry, explaining 83.83% of the variance (Table 2). The first component (PC1) is responsible for 56.9% of the total difference and indicates large positive loads of TDS, EC, TH and major ions (Mg, Ca, K, Na, Cl, SO_4, HCO_3) with well depth, indicating the normal factor controlling its distribution. Hence, PC1 can be called a geogenic component. The main behavior of exchangeable ions (Ca, Mg, Na, K) follows significantly the same

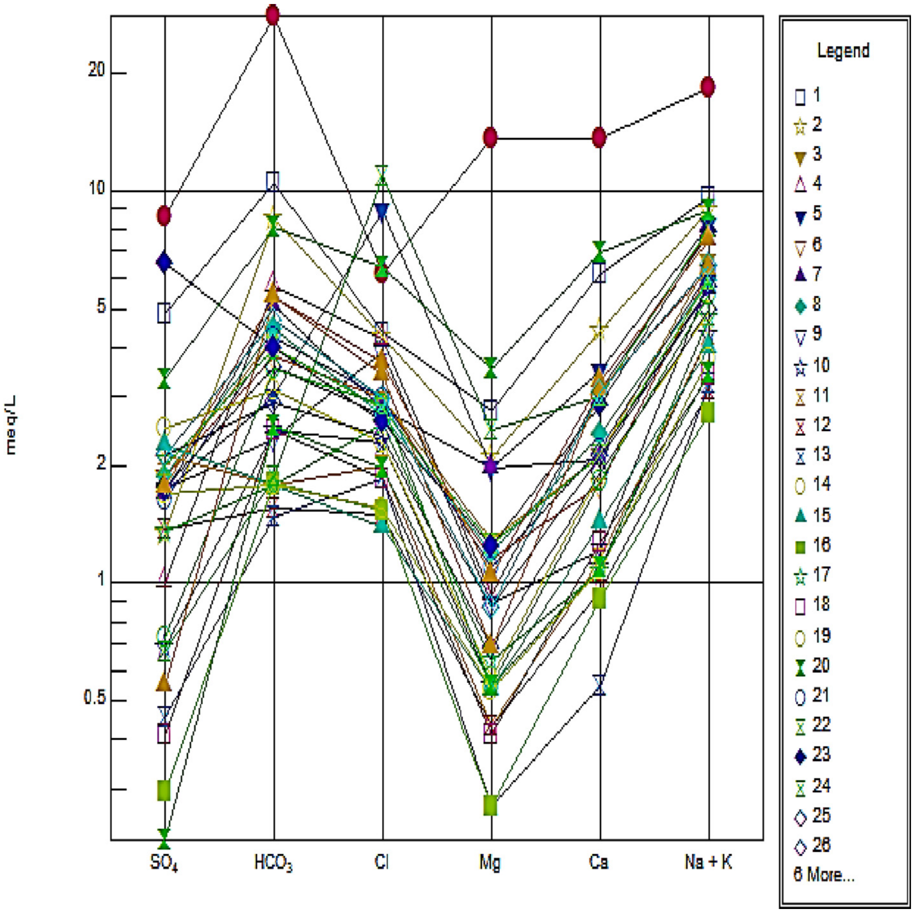

Fig. 8. Schoeller's diagram for the studied groundwater samples.

trend of TDS indicating the mineralization process as the essential salinity source. The PC1 was possibly caused by interaction of groundwater geological medium and natural groundwater hydrogeochemical evolution. High scores of this component indicate high mineralization of groundwater. The presence of magnesium and calcium in groundwater might cause the hardness enhancement and contribute the EC augmentation. To elicit the role of the weathering process and the aquifer rocks mineral composition on the water chemistry, the ions were modeled in terms of their natural origin by using Gibbs [36] and end-member Gaillardet and colleagues [37] hydrochemical diagrams. The Gibbs diagram (Fig. 10) showed that the groundwater formation affected by the minerals of the aquifer, which means that the rock–water interaction controls the groundwater chemistry. The Na/(Na + Ca) ratio >0.5 on the Gibbs diagram shows the ion exchange process Gibbs [36]. Consequently, silicate weathering and evaporites are responsible for the groundwater formation evolution (Fig. 11). The PC2, accounts for over 11.22% of the variance, has positive loading of the depth to water table and NH_4, indicating the role of the reduction process and the lack of oxygen with depth, which led to ammonia concentration increase; NH_4 doesn't oxidized into NO_3. This factor can be called “Redox factor”. PC3 comprises nearly 8.33% of the total variance. It has a positive loading for NO3, Cl and T, as well as weak loading of Eh and the depth to water table reflecting clearly the influence human activities. Appelo and Postma, Roy and colleagues [38,39] concluded that the atmospheric precipitation, using of fertilizers, and domestic sewage discharges are generally the essential sources of Cl and NO_3 in water. The loading of T, Eh and WT in this factor support the anthropogenic nature of this factor. PC4, which accounts for over 7.37% of the total variance, has + ve loadings of pH, and Cu and −ve loading of T indicating the role of natural process (climatic) on the reactivity of groundwater.

Legend (After Roy et al., 2021)

1: mixing and reverse cation exchange waters of Cl-Ca type
2: mixing and reverse cation exchange reactions 3: mixing with sea water
4: calcite and gypsum dissolution 5: mixing reaction from various origins
6: mixing and cation exchange waters 7: infiltration waters of HCO_3-Ca type
8: cation exchange reactions 9: cation exchange waters of HCO_3-Na type

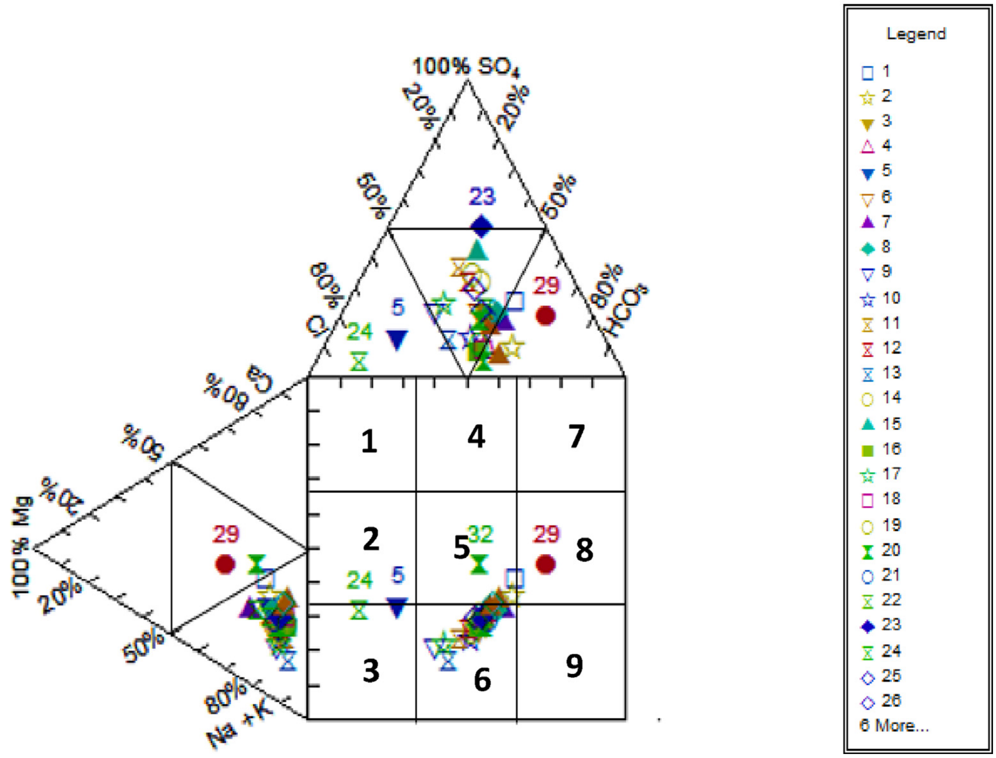

Fig. 9. Durov's diagram for the studied groundwater samples.

Table 2. Component matrix of groundwater data.

	1	2	3	4
WD	**0.766**	0.446	0.22	−0.025
WT	0.173	**0.804**	0.293	0.04
pH	0.165	0.123	0.029	**0.801**
EC	**0.972**	−0.112	0.085	−0.058
TDS	**0.971**	−0.1	0.11	−0.084
T	0.076	0.196	**0.57**	**−0.549**
TH	**0.987**	−0.003	−0.05	−0.068
Eh	−0.848	0.091	0.244	−0.008
Ca	**0.983**	−0.044	0.021	0.047
Mg	**0.963**	−0.022	−0.099	−0.128
Na	**0.968**	−0.041	0.104	0.049
K	**0.861**	−0.357	−0.108	0.102
HCO3	**0.961**	0.035	−0.083	−0.081
SO4	**0.801**	0.256	−0.347	0.138
Cl	**0.535**	−0.306	**0.528**	0.087
NH4	0.118	**0.807**	−0.136	0.117
NO3	−0.065	−0.191	**0.646**	0.463
Eigenvalues	9.673	1.908	1.416	1.253
% of Variance	56.903	11.224	8.331	7.373
Cumulative %	56.903	68.127	76.458	83.831

3.3. Suitability of groundwater for irrigation

Sodium is the essential contributor to irrigation water quality owing to its impact on soil permeability and osmosis pressure around plant roots and hence plant absorption of nutrients. So, sodium hazard was calculated through SAR, RSC, SSP (Na %), and KI (Table 3). The sodium adsorption ratio (SAR) values ranged from 3.4 to 5.58; all the studied water samples are classified as excellent according to Fipps [40] classification in (Table 4) which indicates that the analyzed groundwater is acceptable for irrigation uses.

According to Raghunath [22] classification of the residual sodium carbonate values of the studied samples in (Table 5), there are 78.1% of the collected water samples are classified as safe water. While 18.2% of the collected samples are classified as

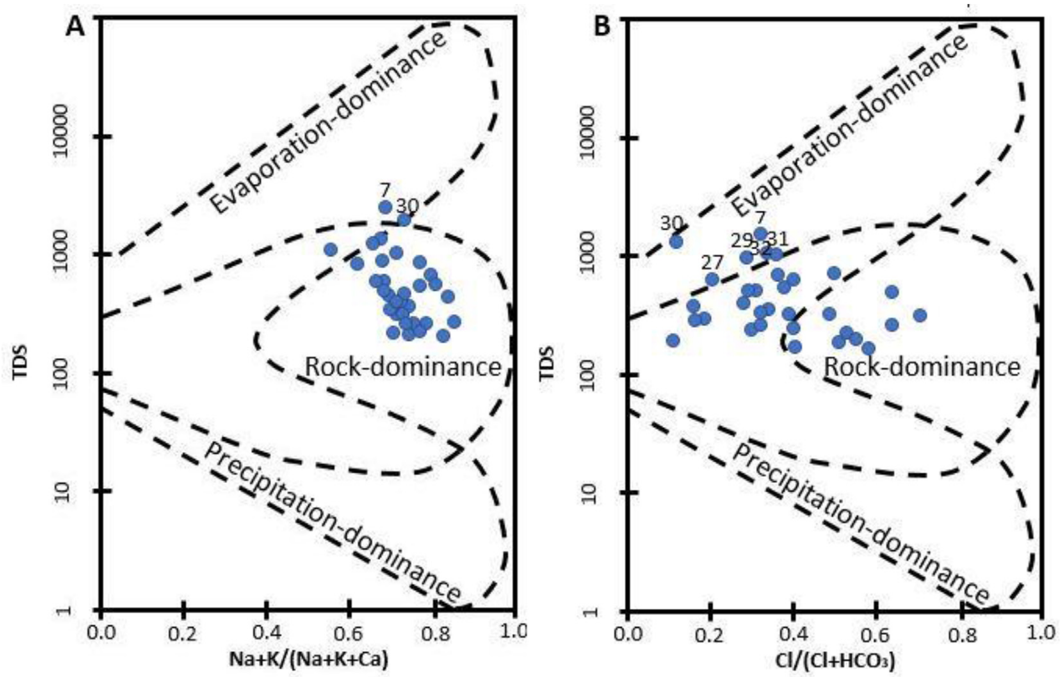

Fig. 10. Groundwater plot on Gibbs diagram.

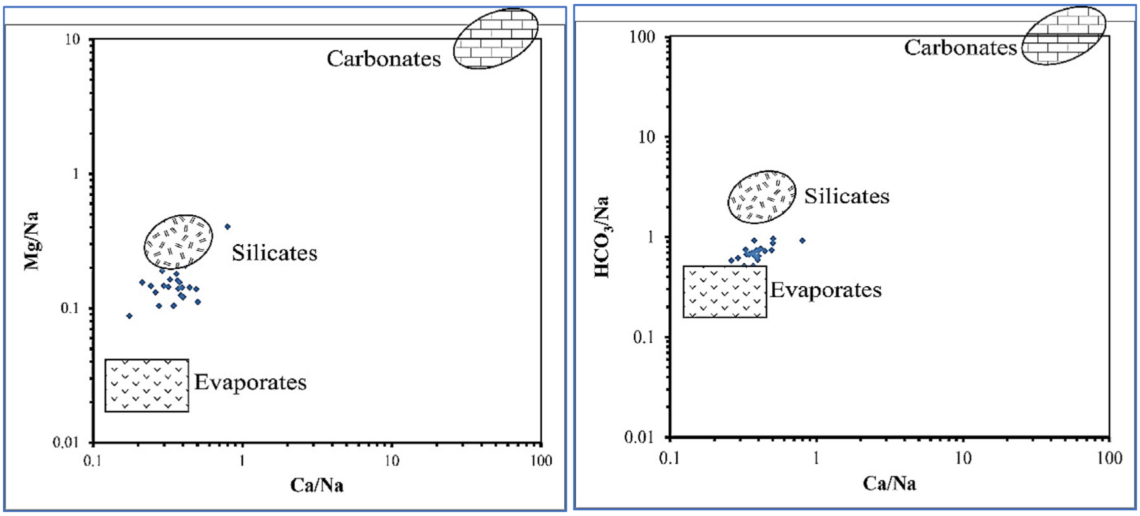

Fig. 11. End-member plot for the investigated groundwater samples.

suitable water, and 3.1% are classified as unsuitable water.

According to Paliwal [41] classification of the sodium hazard values of the investigated water samples in (Table 6), there are 18.7% of the collected groundwater samples have (40–60)% of sodium which classified as permissible water, while 81.3% of the collected groundwater samples have (60–80)% of sodium which classified as doubtful water.

According to Kelly [24] classification in (Table 7), there are 93.8% of the collected groundwater samples have kelly's index more than 1 which classified as unsuitable, while the rest of the collected samples are classified as acceptable for irrigation uses.

Table 3. SAR, RSC, SSP (Na%) and KI values in the studied groundwater samples.

	SAR	RSC	KI	SSP
1	4.51	1.52	1.63	51.98
2	4.85	1.94	0.67	57.73
3	4.87	0.85	1.71	65.46
4	5.43	1.67	2.22	65.99
5	4.90	−2.47	0.83	60.03
6	5.04	0.84	1.86	67.96
7	3.89	1.06	1.87	58.32
8	4.32	0.83	1.45	62.15
9	5.58	0.23	1.89	73.42
10	4.62	0.80	1.72	72.31
11	4.69	0.19	1.84	73.01
12	3.61	0.16	2.04	69.02
13	4.88	0.64	2.25	79.72
14	4.29	0.60	1.95	66.25
15	3.87	−0.19	2.56	66.91
16	3.40	0.60	2.21	69.64
17	4.74	0.16	2.16	72.41
18	3.60	0.75	3.80	66.83
19	4.05	0.14	1.92	69.80
20	3.70	0.86	1.95	67.68
21	4.75	0.91	2.63	65.30
22	4.47	0.62	2.54	63.73
23	5.40	−0.11	2.71	65.67
24	4.78	−3.58	1.59	59.58
25	4.56	0.57	1.61	65.72
26	4.26	0.27	1.91	65.64
27	4.85	1.16	1.48	69.43
28	5.01	1.02	2.08	63.47
29	4.90	0.86	1.37	40.32
30	4.48	1.58	1.86	62.49
31	4.46	0.71	1.35	61.96
32	3.82	−2.47	1.07	45.93
Min	3.4	−3.58	0.67	40.32
Max	5.58	1.94	3.8	79.72
Average	4.52	0.4	1.89	64.56

Table 4. Classification of the investigated water samples according to [40].

SAR (epm)	Water class	Comments	Sample No.
<10	Excellent	Used on sodium crops such as avocados	32
10–18	Good	Amendments (such as gypsum) and leaching needed	–
18–26	Fair	Generally unsuitable for continuous use	–
>26	Poor	Generally unsuitable for use	–

Table 5. Classification of the investigated water samples according to [22].

RSC (epm)	Water class	Sample No. (Percent %)
<1.25	Safe	25 (78.1%)
1.25–2.5	Suitable	6 (18.8%)
>2.5	Unsuitable	1 (3.1%)

Table 6. Classification of the investigated water samples according to [41].

Na%	Water class	Sample No. (Percent %)
<20%	Excellent	– (–)
20–40	Good	– (–)
40–60	Permissible	6 (18.75%)
60–80	Doubtful	26 (81.25%)
>80%	Unsuitable	– (–)

Table 7. Classification of the investigated water samples according to [24].

KI	Water class	Sample No. (Percent %)
<1	Suitable	2 (6.2%)
>1	Unsuitable	30 (93.8%)

4. Conclusions

The analytic groundwater quality was conducted to detect their suitability for irrigation uses. The following conclusions were written from the present paper:

(1) The PH indicates a slightly alkaline media and it is natural, while EC indicates that the enrichment of salts is low.
(2) The results of TDS, major ions indicate that most of investigated water samples are of acceptable quality for drinking uses. TH values of the most water samples ranged from soft to medium hard.
(3) According to WHO guideline (2017), all major ions in the most water samples have an acceptable concentration except HCO_3 which has unacceptable concentration.
(4) SAR of the studied water samples are classified as excellent for irrigation uses. RSC of 78.1% from the studied groundwater samples are considered as safe, 18.2% as suitable, while the rest of samples are unsuitable for irrigation uses. Sodium hazard of 81.3% water samples is doubtful, while the rest water samples are permissible for irrigation purposes. Kelly's Index (KI) is 93.8% indicate that the analyzed groundwater samples are unsuitable, while the rest are classified as unsuitable for irrigation purposes.

Conflicts of interest

The authors declare that there is no conflict of interest.

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