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ORIGINAL PAPER

Characteristic of groundwater potentialities in West Nile Valley South, Minia Governorate, Egypt

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Abstract
The main aim of the present study is to detect the status of groundwater resources in west Mallawi area which represented one of the new reclamation lands. In order to achieve this aim, the hydrogeological and hydrogeochemical studies are carried out, based on the results of 21 pumping tests and chemical analysis of 29 water samples. Two water-bearing units are detected in the study area, namely, the Eocene fractured limestone aquifer which occupies the east portion of the studied area. The second aquifer consists of friable sediments of sand and gravel and may be related to the late Oligocene–early Miocene age and overlies the limestone rocks in the west, and this aquifer were studied for the first time in this work. Regionally, the groundwater flow in the area under study occurs toward the north and east directions. There is a hydraulic connection between both aquifers through the structural pattern affected the area. The partial recharge of the both aquifers takes place through the upward leakage from deep aquifers and the Nile water. There is a general decrease in the water salinity from west to east direction. The groundwater of both aquifers was evaluated for the different purposes and concluded that, it is considered suitable for different uses.

Keywords Groundwater potentialities · Minia governorate · Hydrogeology · Hydrogeochemistry · Irrigation uses

Introduction

Water resources play an important role in the development of any region especially in arid and semi-arid areas (like Egypt). The understanding of water resources is fundamental to future developments and planning. Distribution of fresh water resources and its availability is becoming scarce day by day, owing to population growth and diverse human activities. In the absence of fresh surface water resources, groundwater is exploited to meet the demand exerted by various sectors. In Egypt, the growing population and the consequent agricultural and city expansion stressed the water resources. Moreover, the development of the region has posed threats to groundwater quality from anthropogenic activities. The availability and quality of groundwater resources have been affected by activities and projects associated with rapid development. Groundwater preservation and protection measures have been generally overlooked in the majority of the practices (Shaibani 2008). In the area under investigations due to the scarce rainfall and total utilization of available surface water, the only way to overcome the problem of water resources decreasing lies on the development of additional groundwater. The quality of groundwater for different uses was studied by many authors, among them are the following: Faten et al. (2016) studied the hydrochemical characterization and used the physicochemical data to evaluate the groundwater of the Oligocene and Mio-Plio-Quaternary aquifers for different uses. Penumaka et al. (2016) used GIS to analyze the collected groundwater samples of the Chevella sub-basin for drinking purpose. Annapoorna and Janardhana (2015) studied the physicochemical characteristics of the groundwater in and around a defunct copper mine located in a semi-arid region as well as assessed it for drinking purposes. Ismail (2013) used hydrochemical, geophysical and remote sensing studies to evaluate the groundwater for different

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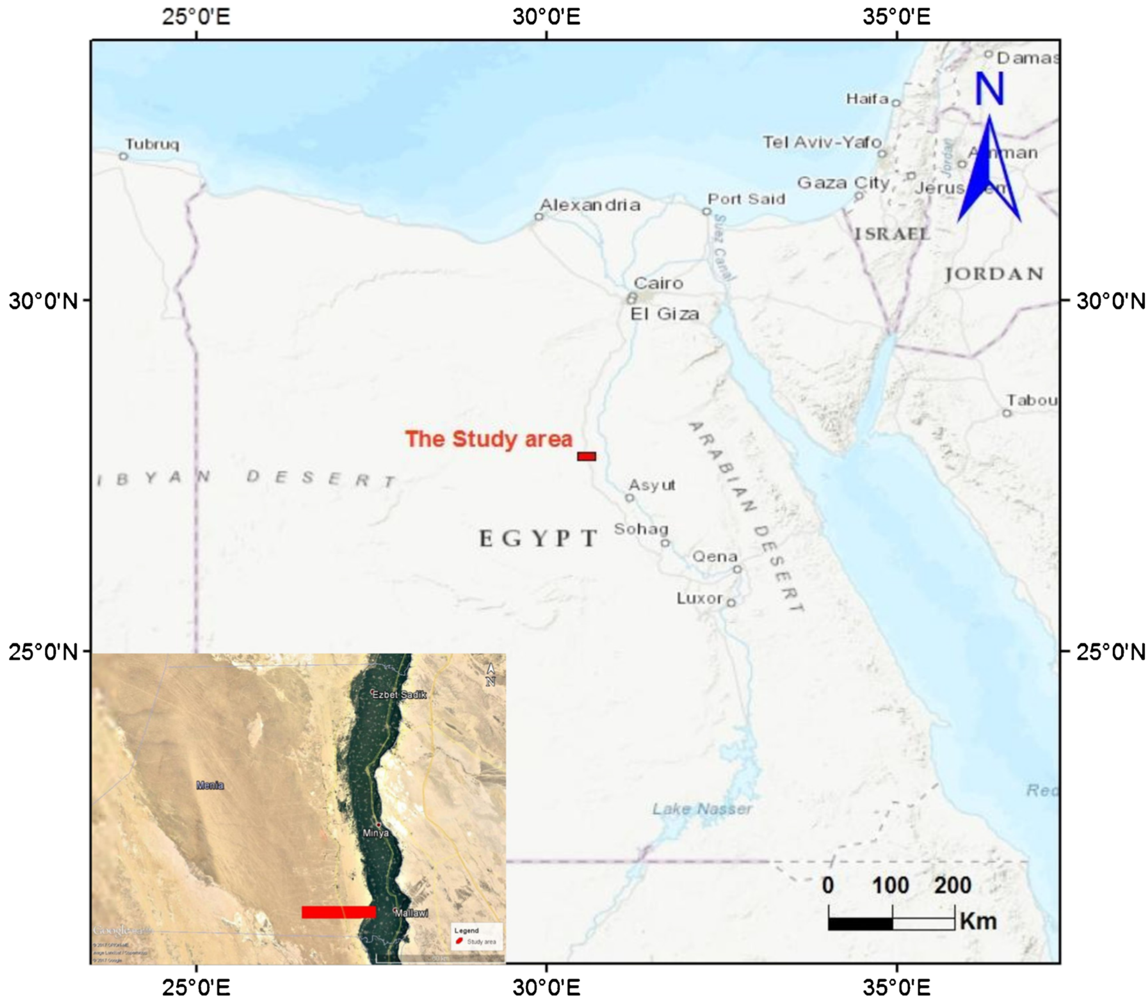


Fig. 1 Location of the study area

purposes of west Tahta Region, Upper Egypt. The present work studied the hydrogeological and hydrogeochemical conditions of the area under investigation as well as used the hydrogeological potentiality and hydrogeochemical data to evaluate the groundwater aquifers for different purposes.

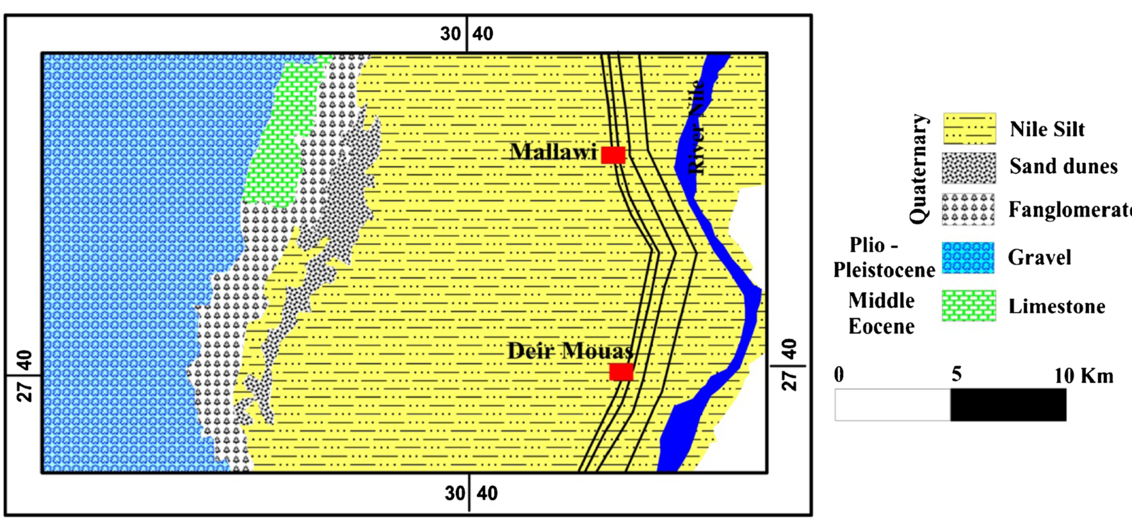


Fig. 2 Geologic map of the study area (modified after Said 1981)

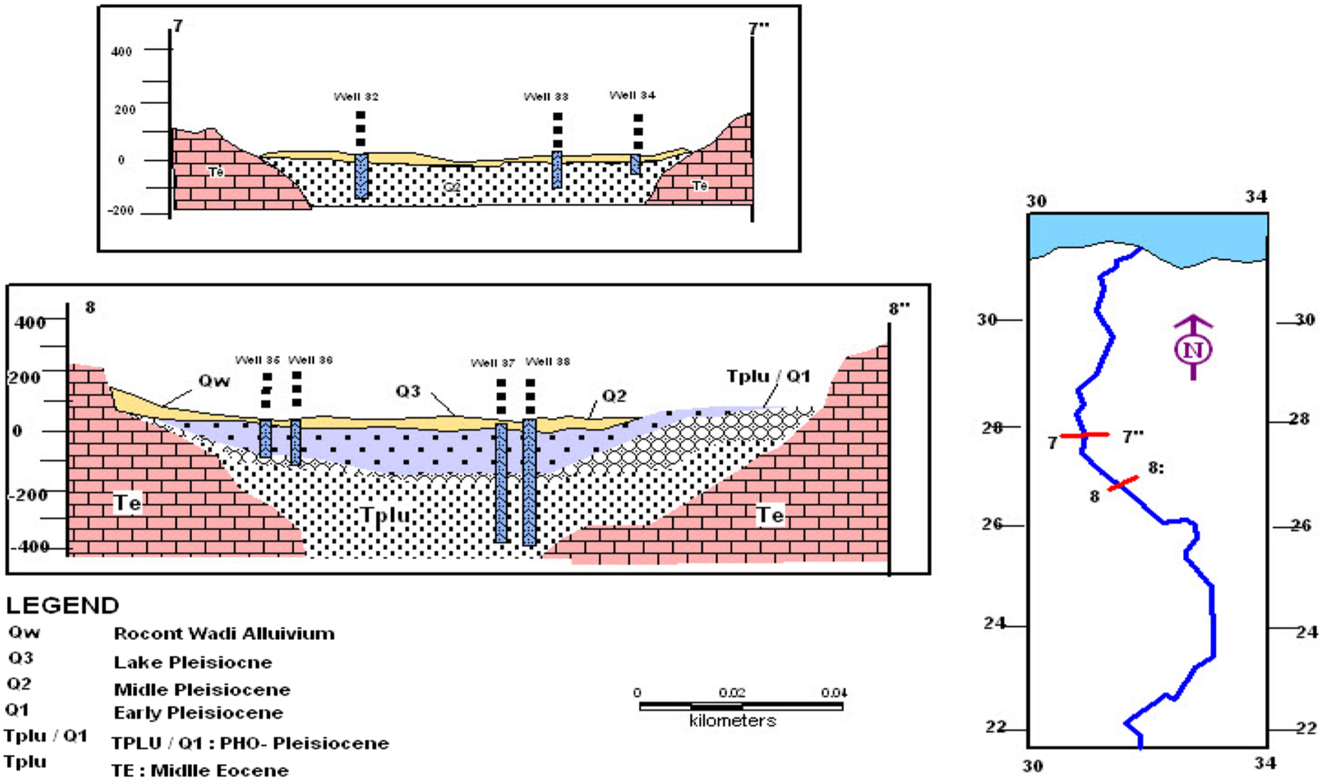


Fig. 3 Subsurface geological cross section Malawi district (Said 1981)

Study area

The study area located to the west of Mallawi area which extend to more than 20 km (north-south) and more than 30 km (west in the direction of the western desert). It extends for about 70 km from south west El Minia City to Malawi, approximately between longitudes 30° 26′ and 30° 41 and latitudes 27° 44′ and 27° 50 (Fig. 1). This area plays an important role in the agricultural extension in Upper Egypt especially in Minia district. The area under study is characterized by an arid climate; the evaporation rate is 4897.91 mm/year. The mean annual rainfall ranged from 23.05 to 33.15 mm/year, and the temperatures in winter ranges from 5 to 20 °C with the maximum one about 42 °C in summer. The mean monthly relative humidity during day time ranged from 62% in May to 29% in December (Korany et al. 2008).

Geologic setting

Geomorphologically, the study area occupies the old alluvial plain and it is bounded from the west by the structural plateau which represents reclaimed lands. The general decreasing of slope is from south to north

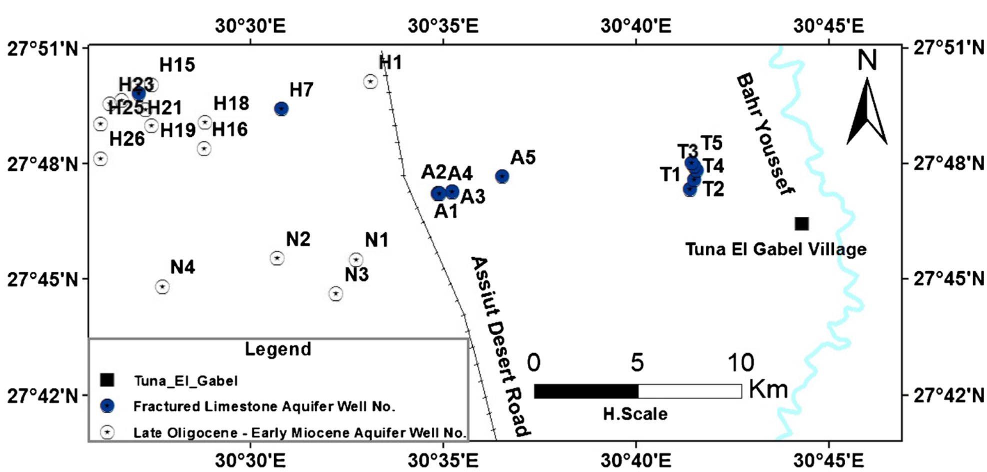


Fig. 4 Well location map of the studied water sample

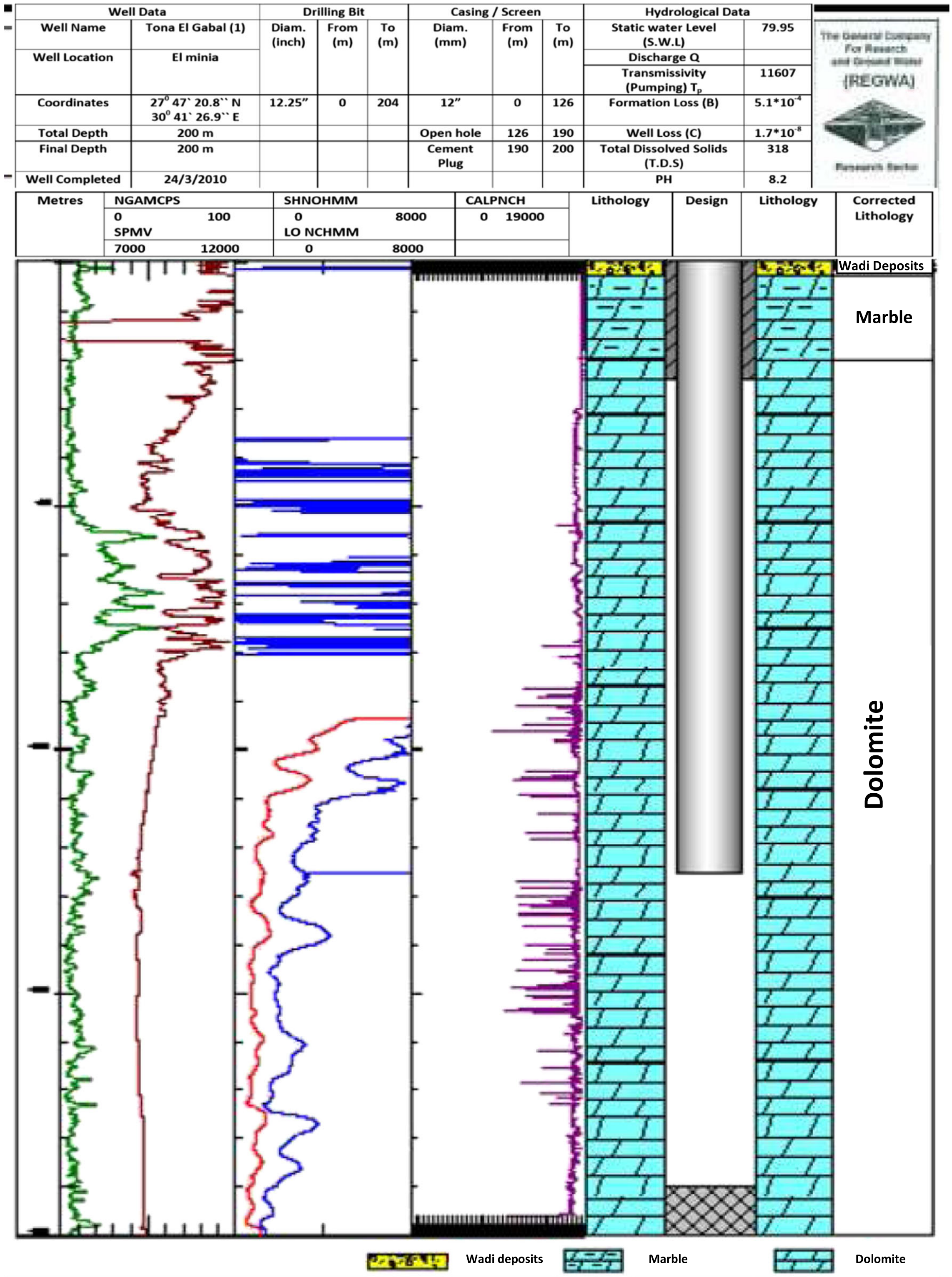


Fig. 5 Well logging and lithology in fractured limestone well

and from west to east. The old alluvial plains are bordering the young alluvial ones from the west. They are in the form of terraces of various heights above the young alluvial plains.

Geologically, El Minia district and its vicinities are covered by a sedimentary rocks that ranging in age from Eocene to Recent (Said 1981, 1990). The stratigraphic sequence is built-up of from base to top as follows: The Eocene rocks consist mainly of the

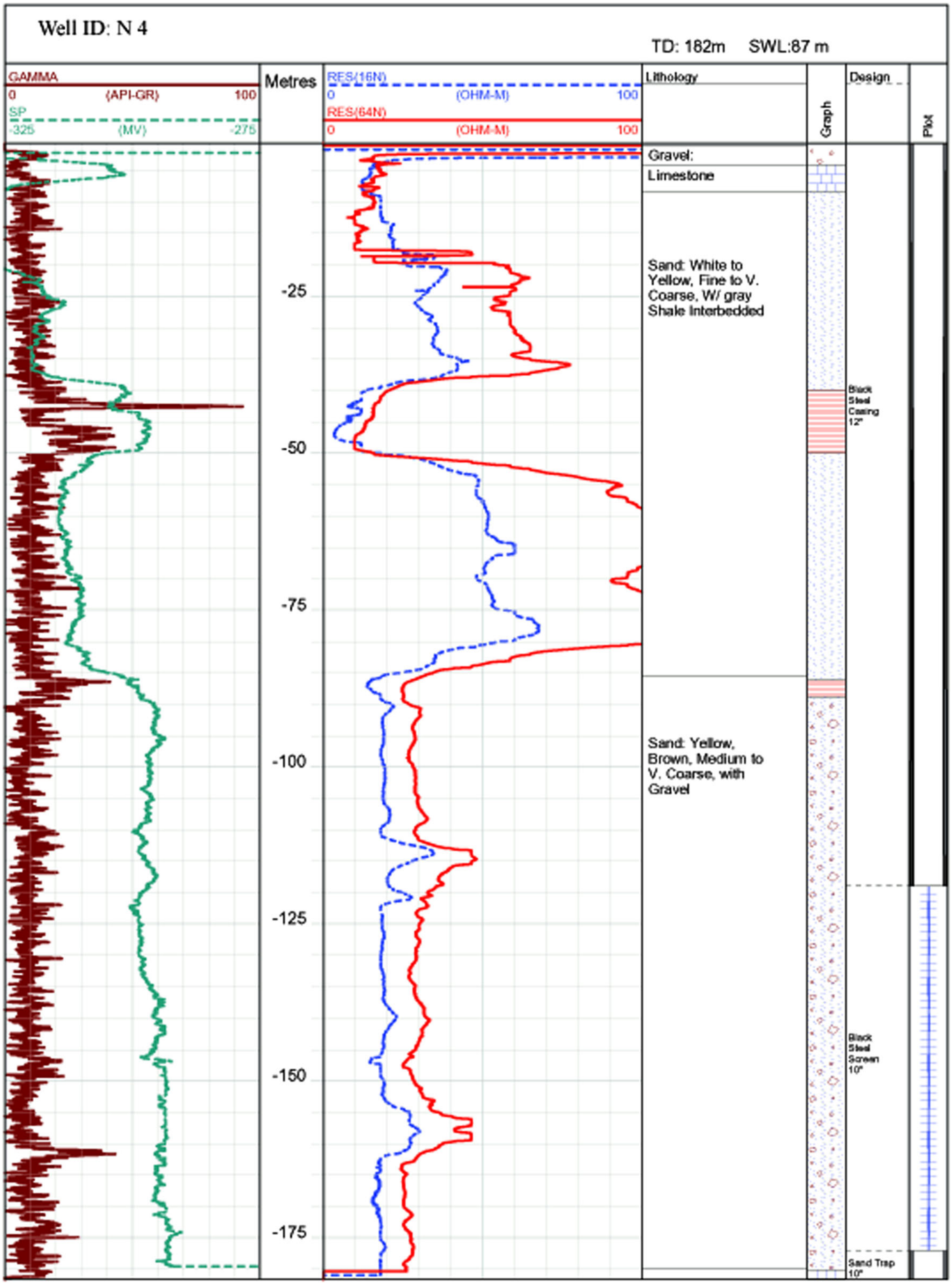


Fig. 6 Well logging and lithology in late Oligocene–early Miocene well

limestone plateau and represented in the study area by Drunka Formation, El Minia Formation, and Samalut Formation; Pliocene sediment, undifferentiated sands, clays, and conglomerates; Oligocene-Pleistocene gravel and sand, covers a wide area and composed mainly of gravel, sand, and limestone fragments varying in size with dark brown color. These sediments form series of various heights above the flood plain of the Nile valley, covering both sides of the Nile banks at the foot of the scarps and considered as a good local aquifer in the desert fringes. Pleistocene sand and gravel

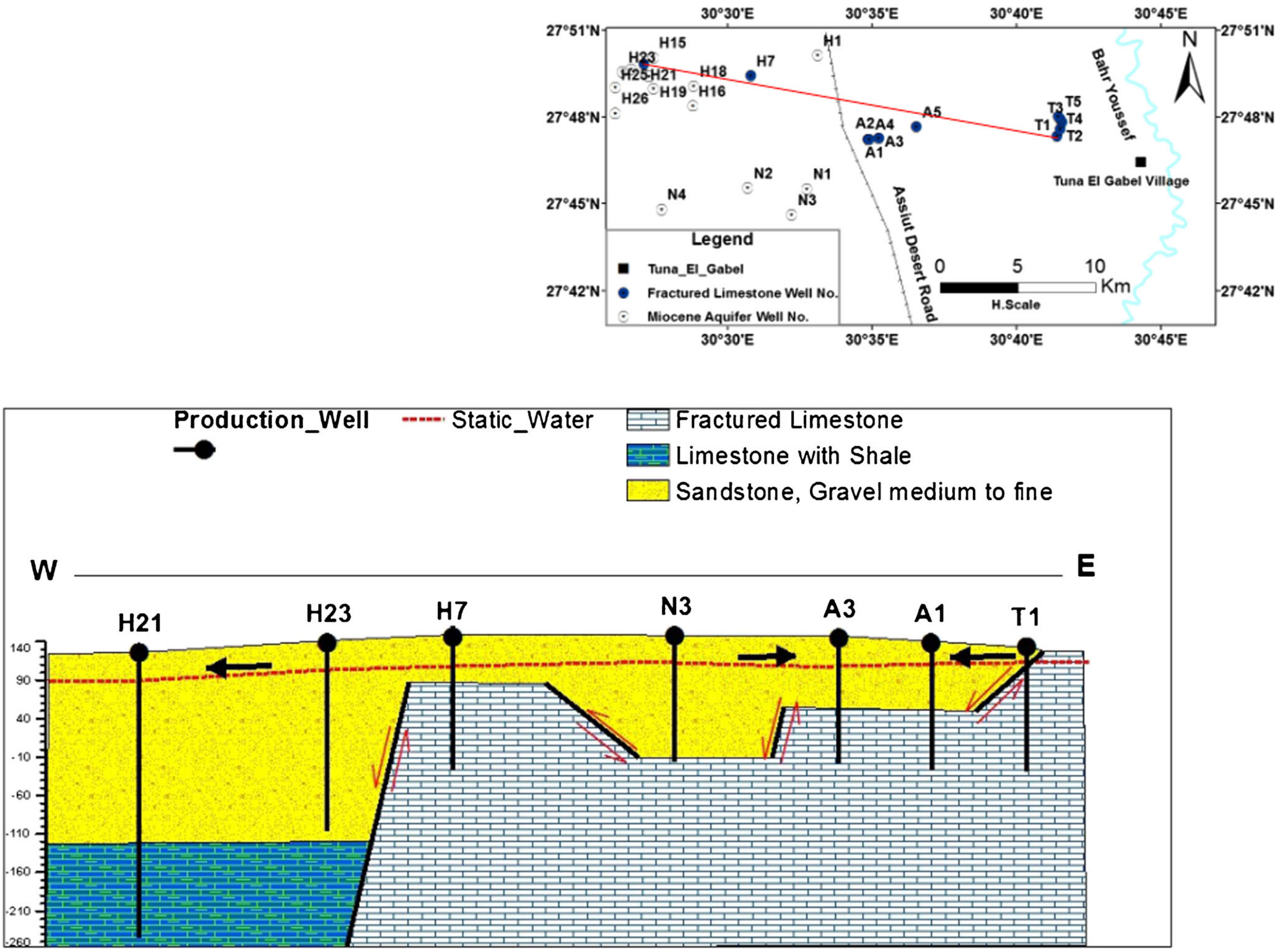


Fig. 7 Hydrogeological cross section tapping drilled wells

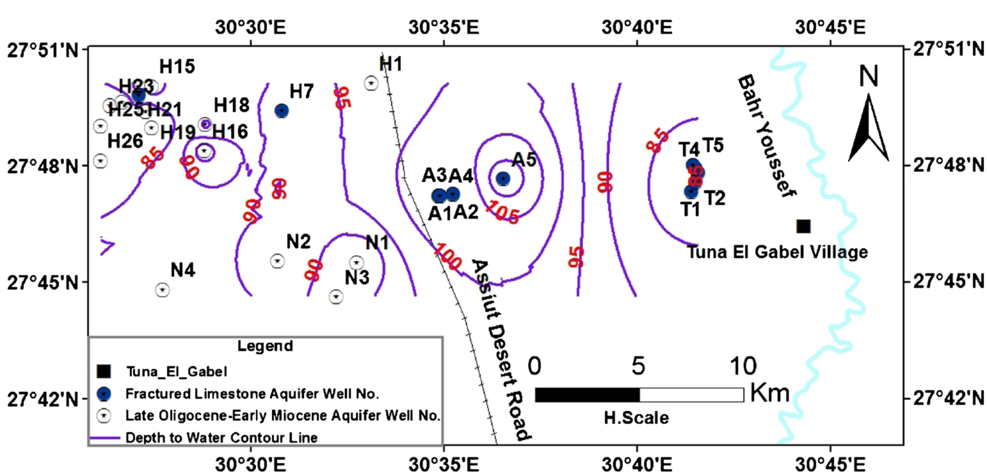
with clay lenses; and Holocene silt and clay (Figs. 2 and 3).

Structurally, normal faults are the main predominate deformational structure affecting the area under investigation. They are represented by a number of major NW-SE faults, together with a few NE-SW ones.

Material and methods

To achieve the study objectives, data were collected from 29 wells in 2015 representing the both aquifers (Fig. 4). Ground elevation of studied water points was measured by using Global Positioning System (GPS). Water level, depth to water

Fig. 8 Depth to water contour map (from the ground surface)



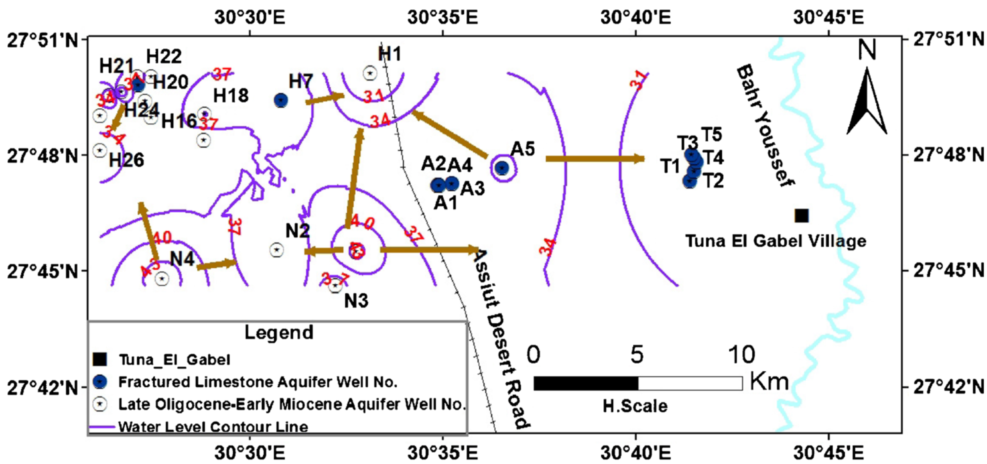


Fig. 9 Static water level contour map (as sea level)

and pumping test of 21 wells carried out by the author in the field. The water samples were collected from well pumps after a pumping period at least 1 h and transferred into pre-cleaned polyethylene bottles. Hydrogen ion concentration (pH), total dissolved solids (TDS), and electrical conductivity (EC) for the collected water samples were measured in the field immediately after sampling using a pH-meter, a portable EC-meter, and a TDS meter. Complete chemical analyses were carried out during winter season at the Ministry of water resources and irrigation laboratories, Cairo, Egypt. Analysis methods which used for the samples are essentially the same as given by American Public Health Association (APHA 2005). Calcium and magnesium concentration were determined by atomic absorption where the flame photometry is used for sodium and potassium. The concentrations of bicarbonate and chloride were determined by titration, and sulfate was measured by colorimetric method. Arc GIS 10.2.2 (ArcMap) are used to prepared the maps which used in our work. The technique of inverse distance weighted (IDW) is used to generate the spatial interpolation maps for different parameters. The analytical data of the collected water samples has been interpreted by plotting different graphical representation such as Piper (1953) and Wilcox (1995), to define the classification of groundwater and its suitability for different purposes. Based on the physico-chemical analyses, irrigation quality parameters, i.e., sodium absorption ratio (SAR), noncarbonated hardness (TH), and residual sodium carbonate (RSC), were calculated. The suitability of the collected groundwater samples for drinking, domestic, and irrigation purposes was evaluated by comparing the values of different water quality parameters with water quality guidelines for human drinking and domestic uses (Egyptian Higher Committee for water 2007) and those of the World Health Organization (2011). Two geoelectrical well logging chart representing both aquifers were measured in the area under investigation.

Results and discussion

Well logging of the study area The resistivity log of the fractured limestone aquifer (Fig. 5) shows a high value of long normal resistivity due to the presence of dolomite characterized by massive texture of high resistance to the electrical current (the resistivity value reaches 8000 Ω in the first 100 m and then reduces to about 500 Ω in the saturated thickness). The gamma ray curve has a low value reflecting a clean formation of clay or shale deposits. (10 c.p.s).

The resistivity log of the late Oligocene–early Miocene aquifer (Fig. 6) indicates a moderate value of long normal resistivity, reaching 30 Ω from a depth of 85 m to the end of the well (which represents the saturated thickness). The gamma ray curve has a low value (about 10 c.p.s., except at some depths 50, 85, and160 m), reflecting a clean formation from clay or shale deposits.

Hydrogeology According to lithology, saturated thickness, hydraulic parameters, and chemical composition, two main aquifer systems have been identified in the study area, namely, fractured limestone aquifer and late Oligocene–early Miocene aquifer. The characteristics of each aquifer well are discussed in the following:

A fractured limestone aquifer covers a large area around the western desert road and most of the reclaimed land and composed of fractured limestone sediments, the lithiology of the wells taping this aquifer different from east to west in the thickness of wadi deposits and its nature (Fig. 7). In the west area, this layer reaches 100 m in thickness, which may represent a big load on the fractured limestone aquifer. This aquifer characterized as an unconfined aquifer in the east near to the old valley. The depth to water of this aquifer varies from 79.95 to113.62 m from the ground surface (Fig. 8); the static water level ranges between 21 and 37.4 m above mean sea level. Figure 9 showing that the groundwater flow of

Table 1 Result of pumping test of the studied area

Well no.	Aquifer type	*X*	*Y*	Elevation (m)	Total depth of drilling (m)	Total screen (m)	Static water level (as sea level)	Dynamic water depth (as sea level)	Depth to water (m)	*Q* (m^3/h)	Saturated thickness	Transmasivity
T1	Fractured limestone aquifer	27 47 20.8	30 41 26.9	111	200	70	31.05	80.55	79.95	185	120.05	11,607
T2		27 47 35.7	30 41 32.4	113	194	62	27.25	86.69	85.75	170	108.25	34,566
T3		27 47 49.1	30 41 34.9	116	192	60	29.94	86.83	86.06	160	105.94	15,276
T4		27 47 55.7	30 41 31.9	115	200	60	29.3	90.98	85.7	170	114.3	11,593
T5		27 48 1.6	30 41 27.7	113	192	60	31.4	86.22	81.6	170	110.4	5597
A1		27 47 14.5	30 34 54.7	135	211	81	33	117	102	135	109	1720
A2		27 47 16.8	30 35 15.1	140	265	96	36.8	117.2	103.2	120	161.8	1500
A3		27 47 16.6	30 35 14.6	140	203	76	35	116	105	110	98	1520
A4		27 47 14.5	30 34 54.7	135	200	89	37	110	98	120	102	1550
A5		27 47 39.9	30 36 32.6	151	205	94	37.38	128	113.62	120	91.38	1440
H15	Late Oligocene–early Miocene aquifer	27 50 3.6	30 27 26.7	129	217.2	45.46	35	114	94	120	123.3	1233
H19		27 48 59.9	30 27 27.1	116	214	60	36	92	80	200	134	3263
H22		27 50 3.4	30 27 6.4	131	201.45	51.5	39	117	92	167	109.45	528
H25		27 49 1.65	30 26 7.63	116	192.5	40	36	93	80	200	112.5	2673
H26		27 48 8.85	30 26 8.1	115	191	50.2	31	101	84	200	107	6473
N1		27 45 31.2	30 32 45.9	122	202	70	43.47	100	85.53	158	116.47	6800
N2		27 45 32.8	30 30 42.3	133	205	58	34.4	105	92.6	190	112.4	2680
N3		27 44 37.8	30 32 14.4	126	180	62	36.51	100	88.49	195	91.51	1800
N4		27 44 49.1	30 27 43.7	122	182	65	44	120	87	200	95	1140
H21		27 49 49.1	30 27 7.4	122	382	75	36	106	86	200	296	6895
H23		27 49 33.3	30 26 22.5	112	192	50.5	28	115	84	200	108	577

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Fig. 10 Transmissivity contour map of the study area

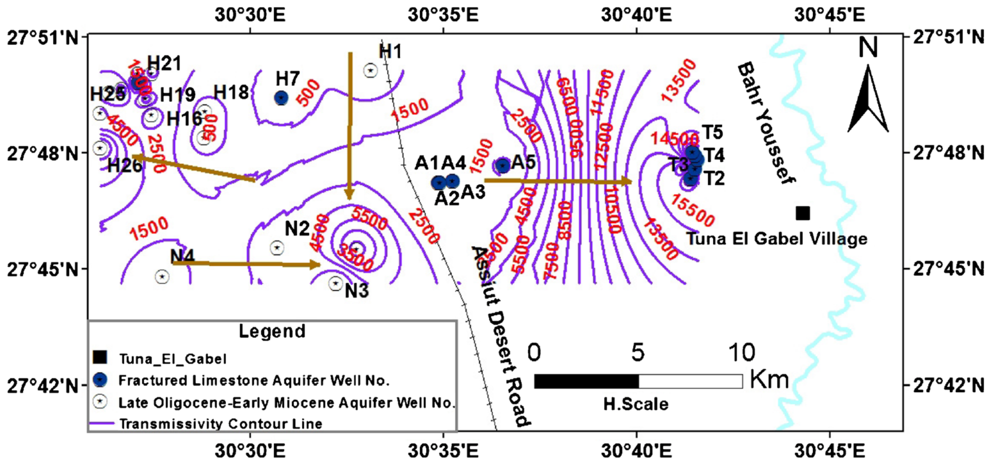
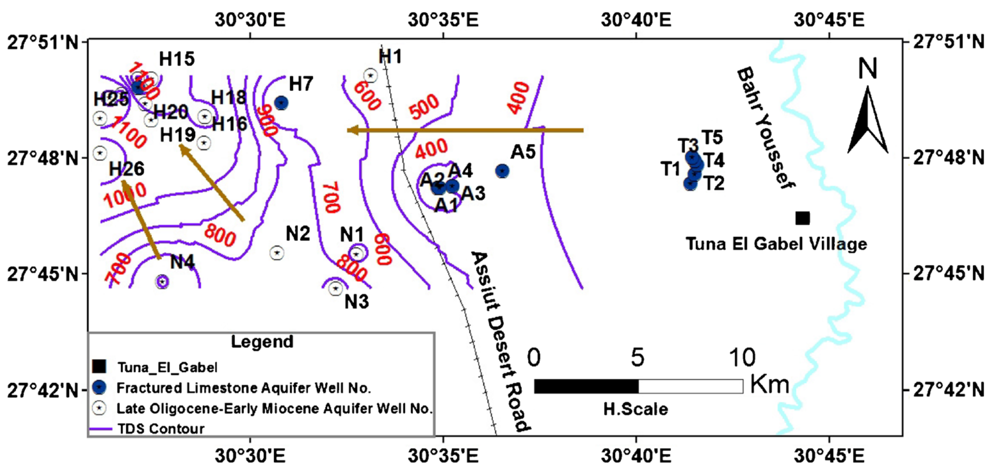


Fig. 11 Salinity distribution contour map

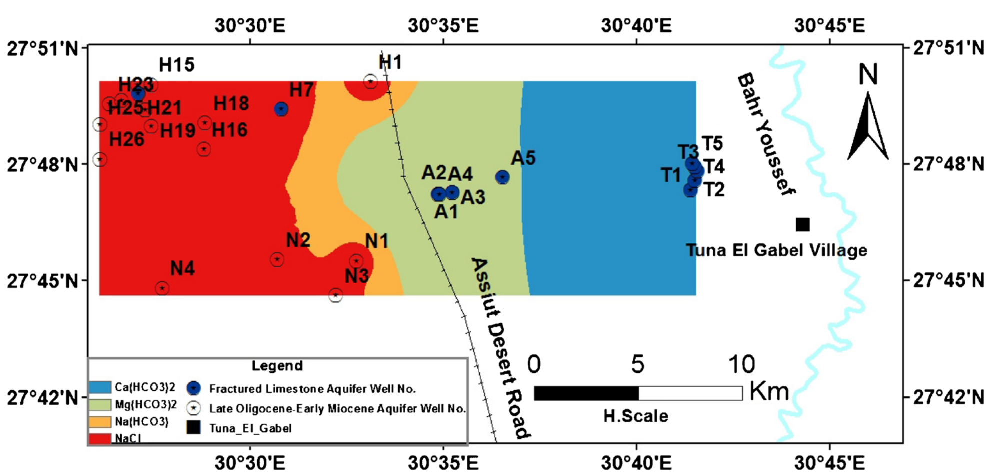


the study area has two directions in both east and west toward which may be revered to presence of water divide along geological structure (fault plain). The partial recharge of the studied aquifers takes place from the upward leakage of deep aquifers, as well as the Nile water.

The fractured limestone aquifer has a high potentiality values (Table 1 and Fig. 10).

Late Oligocene-early Miocene *aquifer*; this aquifer has been detected for the first time in the present work. Many drilled wells taping this formation and explored

Fig. 12 Chemical water type zonation map of the studied water samples



for data collection and analysis, including description of rock samples, pumping test (step test and constant test), well logging, and chemical analysis. The collected data indicate the wide area coverage of the aquifer, which may be considered the extension of Moghra formation. The aquifer is mainly composed of sand and gravels with shale and limestone fragment intercalation and characterized by its great thickness reaching about 382 m (well no. H21). The saturated thickness in this aquifer ranges between 84 and 296 m while depth to water ranges from 80 to 97.2 m (Fig. 8) and the static water level from 28 to 44 m above mean sea level (Fig. 9). The transmissivity value of these aquifers ranges between 1140 and 6800 m^2/day (Fig. 10), and the hydraulic conductivity ranges from 13.57 to 30 m/day (Table 1) that referring high potentiality of late Oligocene–early Miocene aquifer.

Hydrogeochemically TDS values of fractured limestone aquifer range between 318 and 497 ppm (so it can be classified as freshwater) while in the late Oligocene–early Miocene aquifer ranges from 555 to 1210 ppm (it can be classified as fresh to slightly saline water). Figure 11 shows the salinity contour map; this map refer that the collected groundwater samples from the west part of the study area have a salinity values higher than the samples of the eastern one. This is due to the groundwater in the eastern part are connected with surface water which represented by (River Nile and irrigation canals) while the western part are far away from the surface water. The hydrogen ion concentration of fractured limestone aquifer ranges between 8.2 and 8.4 (reflecting natural groundwater, slightly alkaline) while in the late Oligocene–early Miocene aquifer, it ranges between 7.6 and 7.83 (slightly alkaline character type). The water type of fractured limestone aquifer is bicarbonate (magnesium bicarbonate, sodium bicarbonate, and calcium bicarbonate) while in late Oligocene–early Miocene aquifer is sodium chloride (Fig. 12).

Piper diagram 1953 is a graphical representation of the water sample chemistry and used to define the chemical character of water. By plotting the chemical data of the groundwater samples on piper diagram (Fig. 13), we classify the sample points to six fields.

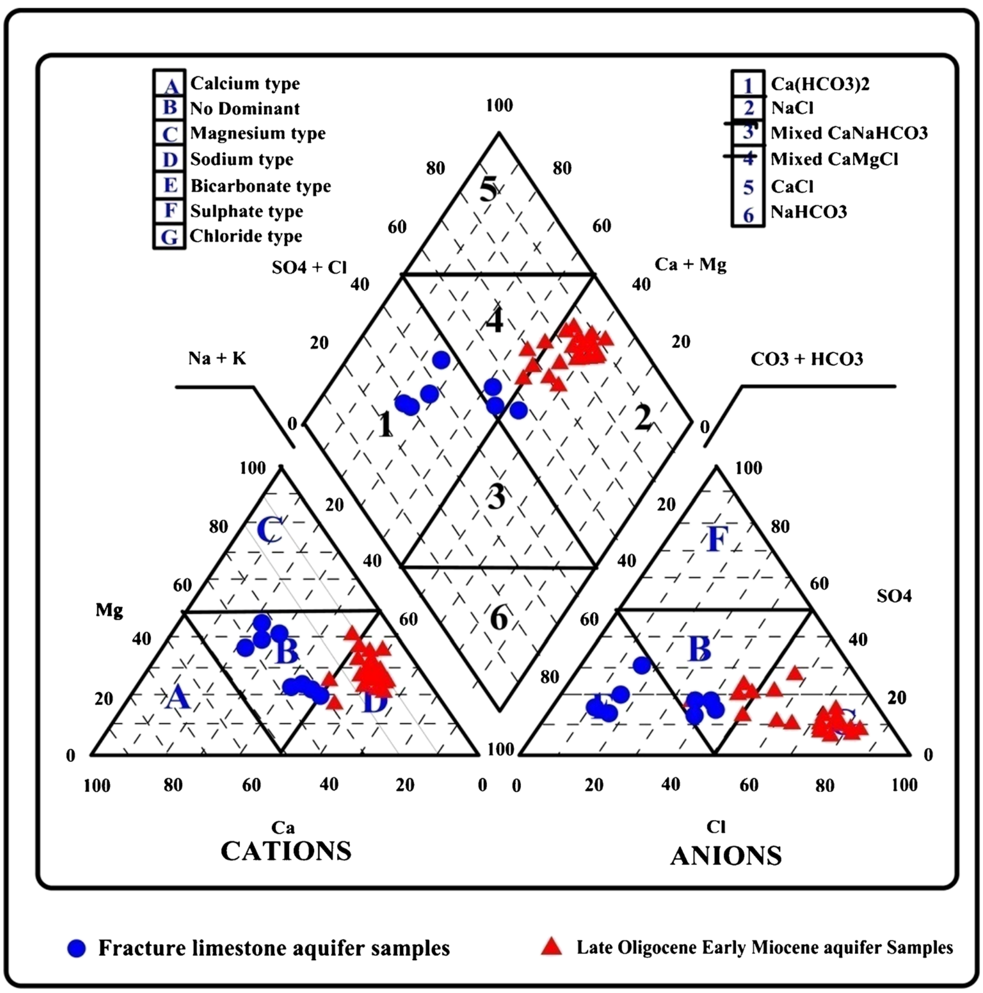


Fig. 13 Piper diagram of the studied water samples

Table 2 Water quality guidelines for human drinking and domestic uses

Elements	WHO limit (mg/l)	Egypt limit (mg/l)
pH	6.5–8.5	7–8.5
Electrical conductivity (EC) (μS/cm)	1500	–
Total dissolved solids (TDS) (mg/l)	500	500.0
Calcium (Ca^{2+}) (mg/l)	75	75
Magnesium (Mg^{2+}) (mg/l)	30	50
Sodium (Na^{+}) (mg/l)	200	200
Potassium (K^{+}) (mg/l)	10	–
Bicarbonate (HCO_3^{-}) (mg/l)	100	–
Chloride (Cl^{-}) (mg/l)	200	200
Sulfate ($SO4^{2-}$) (mg/l)	200	400
Iron (Fe^{-}) (mg/l)	0.3	0.3
Total Hardness (TH) (mg/l)	300	500.0

They are (Ca-HCO3, Na-Cl, Ca-Na-HCO_3, Ca-Mg-Cl, Ca-Cl, $NaHCO_3$). In the present study, the studied ground water samples of late Oligocene–early Miocene aquifer are located in the Na-Cl field while the water samples of fractured limestone aquifer are located in Na-Cl and Ca-Na-HCO_3 field. Evaluation of the water types using piper plot suggests that there is a clear indication of the presence of ancient sea water (pale water), dissolution of halite and related minerals in evaporate deposits in the study area.

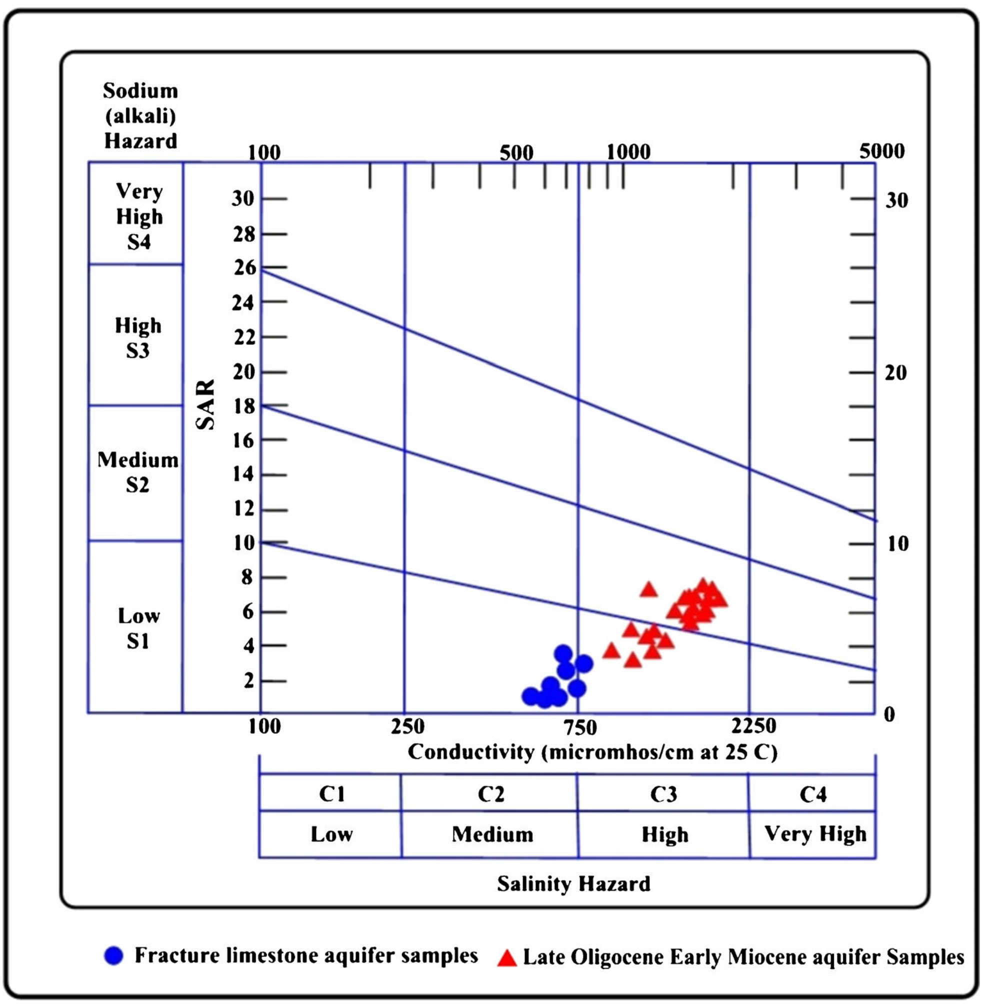


Fig. 14 Wilcox diagram for the studied water samples

Evaluation of water quality for different uses

By comparing the collected groundwater samples with the international standards for human drinking water (WHO 2011) and the Egyptian standards 2007 (Table 2), we found that all the water samples of fractured limestone aquifer and 67% of late Oligocene–early Miocene aquifer are suitable for drinking due to their low salinity (< 1000 ppm) while 33% of late Oligocene–early Miocene aquifer unsuitable due to their high levels of salinity (> 1000 ppm) and also the major ions are more than the permissible limits.

For industrial and domestic uses Majority of the collected groundwater samples of fractured limestone and late Oligocene–early Miocene aquifer are unsuitable for industrial purposes due to high level of hardness (90% hard to very hard).

For irrigation purposes According to Salinity index or salinity hazard (Bauder et al. 2007), all the studied water samples are categorized under good quality to permissible for irrigation. Based on US Salinity Laboratory Staff (1954), all the studied groundwater samples of fractured limestone and late Oligocene–early Miocene aquifers are suitable for irrigation due to low salinity and values of SAR (Fig. 14).

According to RSC, all of the collected water samples of fractured limestone aquifer and 24% late Oligocene–early Miocene aquifer are suitable for irrigation purposes while 76% of late Oligocene–pre-Miocene aquifer are unsuitable for irrigation.

Conclusions

Two water-bearing units are detected in the area under study, namely, Eocene fractured limestone water-bearing formation and late Oligocene–early Miocene aquifer. The groundwater flow is toward the north and east directions. There is a hydraulic connection between both aquifers through the structural pattern affected the area under investigation. The partial recharge of both aquifers takes place from the upward leakage from deep aquifers and the Nile water. The chemical properties of the collected groundwater of the study area show a general decreasing of total salinity from west to east due to the effect of irrigation and surface water. Salinity of the study area raged between fresh to slightly saline. Most of the collected water is unsuitable to domestic and industrial uses due to high level of hardness while these are suitable for drinking and irrigation uses.

Recommendations

The authors recommended that, it is advisable, as a follow-up of this work, to simulate the hydrogeological conditions and test the impacts of long-term development of groundwater in the aquifers, make the roles which control the different aquifers in the study area to save the groundwater aquifers in the area.

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