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Geophysical interpretation for groundwater exploration around Hurghada area, Egypt

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ABSTRACT

This study aims to investigate the aquifer in the Northern part of the Red Sea, Egypt. The RTP magnetic data were used to interpret of magnetic data, which was used to illustrate the depth of the basement rocks and subsurface structures. The major structural trends have the directions NE-SW, NW-SE, NNE-SSW, N-E, NNW-SSE and E-W, while the depth of the basement rocks ranges from 1000 m at the eastern part to 3500 m at the western part. The geoelectrical survey is represented through measuring 24 VESes which were collected by using Schlumberger configuration of AB/2 ranged (from 1.5 to 300 m). The results of quantitative interpretation refer to the subsurface sequence consists of four geoelectrical units. The first unit consists of alluvium with high resistivity and thin thickness. While the second one consists of sand and gravel with thickness ranging from 1 to 17 m of moderate to high resistivity. The third one consists of sandstone of low resistivity ranging from 0.32 to125 ohm. m and thickness ranging from 6 to 45 m; this unit represents the aquifer of the study area. The last geoelectrical unit consists of limestone with high resistivity. These units represent the post-Zeit formation of Quaternary (Pliocene-Pleistocene).

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Resistivity; magnetic; Hurghada; groundwater aquifer

1. Introduction

Some authors used different geophysical tools such as magnetic and resistivity for groundwater exploration (Araffa et al. 2015a; Araffa et al, 2015b, 2017. Dahab et al. 2003) studied the infiltration capacity and groundwater potentiality of Hurghada area; and they conclude that the groundwater in this area accumulated in the Quaternary, Middle Miocene and fractured basement column. The Red Sea is significant as the principle prolific province in Egypt. It was saving the main energy supply for the country and is still contestation the petroleum companies. The investigated area of Hurghada is located on the Northern part of the Red Sea, Egypt. Its coordinates are latitude from 27° 12` to 27° 25`N and longitude 33° 36` to 33° 48`E (Figure 1). The magnetic survey in the present study is used for delineating the subsurface structure in the investigated area and the thickness of the sedimentary cover, while geoelectrical method is applied for explaining the geology of subsurface and aquifer.

In this study, the quantitative and qualitative interpretation of VES data led to the analysis of hydrogeological and geological information. The interpretation of VES data refers to the aquifer of the study area represents by third geoelectrical unit of sandstone of Zeit Formation.

1.1. Geology of the study area

1.1.1. Surface geology

The surface geology of the investigated area has been described through a geological map of Hurghada after geological survey of Egypt (2005) (Figure 2). Gharamul Formation of marl and marly limestone at northwestern part (Early Miocene). Gabir Formation of yellow to brown calcareous sandstone, limestone, girt and gravels with oyster fossils at northwestern part (Pliocene). Pleistocene deposits of coralline limestone at northeastern and southeastern parts. Alluvial wadi deposits of sands, silts and conglomerates are distributed in the most of study area (Holocene). Sabkhah deposits of fine sands, silts, silty clay and evaporates on the margin of the Red Sea (Holocene). Resent wadi deposits are distributed in all the area: detrital of sands, silts and gravels (Holocene). Coral reefs of Holocene are on the coast of the Red Sea.

1.1.2. Subsurface geology

The subsurface succession of the investigated area was collected from a well after El Naggar et al, (2017) (Figure 3). This well is situated in the Hurghada area of latitude 27° 15`and longitude 33° 45`and depth more than 3500 m. The subsurface stratigraphic column is distinguished into the following rock units from base to top as follows: Basement

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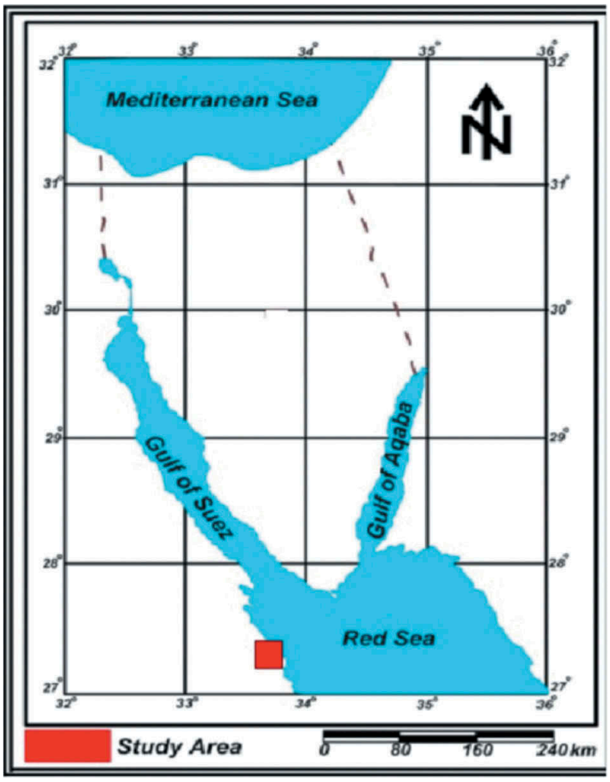

Figure 1. Location map of the study area.

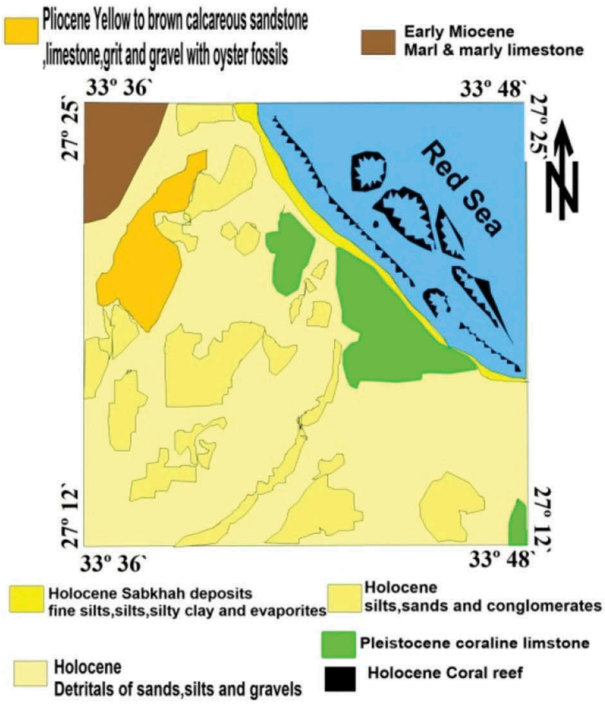

Figure 2. Geologic map after geological survey of Egypt (2005).

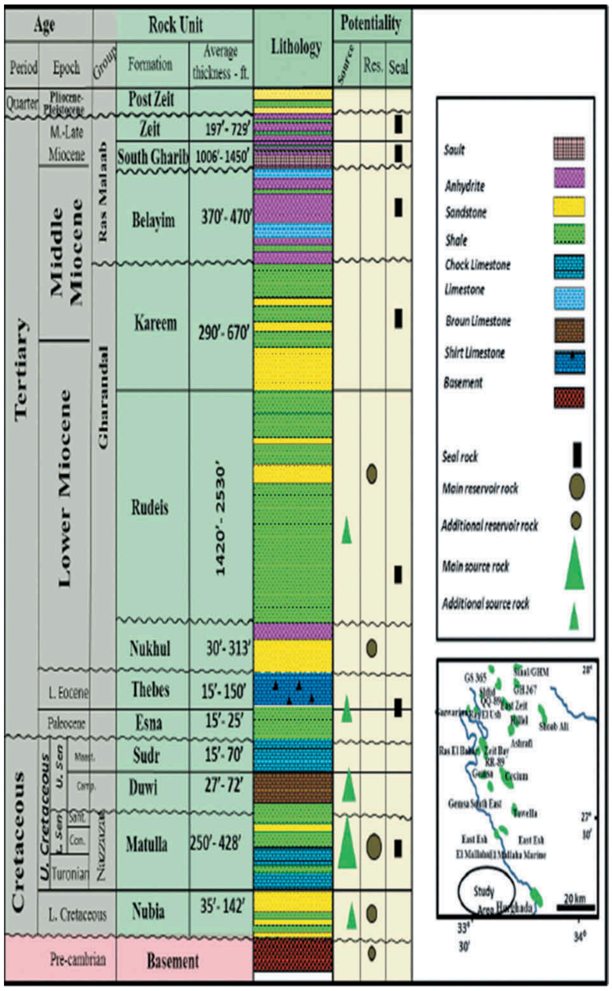

Figure 3. Stratigraphic section of Hurghada area after El El Naggar (2017).

complex of Precambrian is represented by granites and metamorphic rocks. Nubia Formation (L. Cretaceous) consists of carbonates and alternating clastics of 45to142 feet thickness. Matulla Formation (Lower Senonian) consists of shale and marl with sandstone and carbonates of 250- to 450-ft. thickness. Duwi Formation (Campanian) is composed of limestone which is partially dolomites and highly phosphates with thickness ranging from 10 to 70 feet. Sudr Formation (Maastrichtian) is composed of a chalky white limestone of 30- to 75ft. thickness. Esna Formation (Paleocene) consists of limestone and calcareous shale of 25- to 210-ft. thickness. Thebes Formation (Early Eocene) is composed of calcareous shale and chalky limestone with abundant chert bands of 20- to 150-ft. thickness. Nukhul Formation (Early Miocene) is composed of anhydrite, sandstone, limestone and shale of 80- to 390-ft. thickness; the age of Nukhul Formation (Aquitanian – Early Burdigalian). Rudeis Formation (Lower Miocene) is mainly composed of sandstone, siltstone, limestone, and shale of 1420- to 2530-ft. thickness. Kareem Formation (Middle Miocene) is mainly composed of sandstones with anhydrite and shale interbeds of 290- to 670-ft. thickness. Balayim Formation (Middle Miocene) consists of limestone, anhydrite, and shale beds of 370- to 470-ft. thickness. South Gharib Formation (Middle to Upper Miocene) is composed of thick salt bodies with minor anhydrite and shale intercalations of the lagoonal environment of 1000- to 1450-ft. thickness. Zeit Formation (Upper

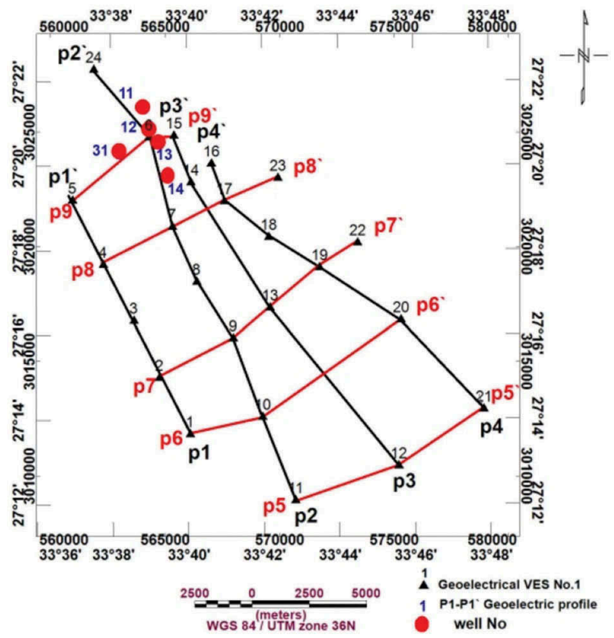

Figure 4. Location map showing the VES stations, directions of studied resistivity profiles and hand-dug wells in the investigated area.

Miocene) consists of anhydrite and intercalations of shale with salt and sandstones bodies of 197- to 729-ft. thickness. Post Zeit Formation (Pliocene-Recent) is mainly composed of coarse-grained sand and gypsum streaks in the marginal areas, with the gravels and lesser Ostrea-pecten, coquinas and marls which are only broadly Pliocene to Pleistocene in age.

2. Methodology

2.1. Measurements and interpretation of geoelectrical data

2.1.1. Measurements of geoelectrical data

For the selected study area, we obtained the geoelectrical data represented by 24 Vertical Electrical Soundings using the Schlumberger configuration with an AB/2 spacing ranging from 1.5 to 300 m (Figure 4). The main aim is to detect the Quaternary aquifer and the different subsurface successions.

2.1.2. Quantitative interpretation of VES

Quantitative interpretation of geoelectrical data aims to delineate the true resistivity values and thicknesses of the sequential strata of subsurface section; the measured field data that represented by plotting the AB/2 spacing against apparent resistivity values. There are two techniques of quantitative interpretation. The first one is the manual interpretation, which includes two methods and depends on using two

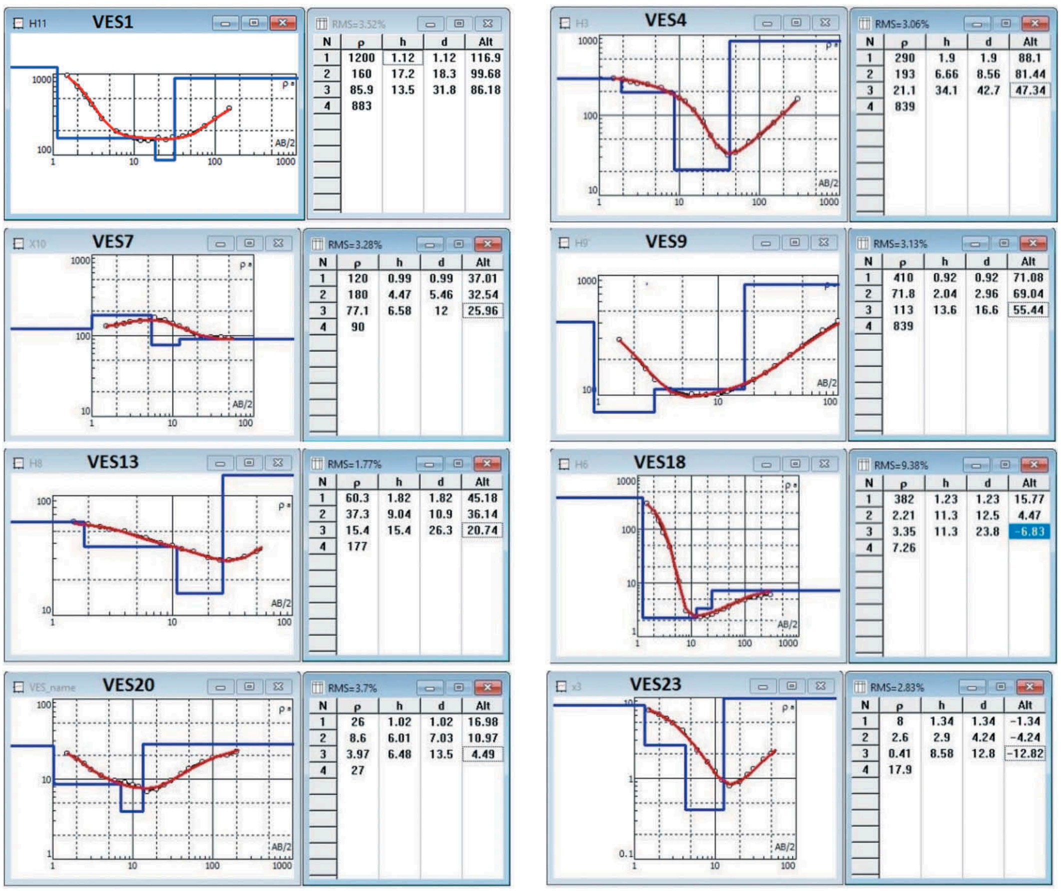

Figure 5. Interpretation of some VES (1, 4, 7, 9, 13, 18, 20 and 23) using IPI2WIN Program.

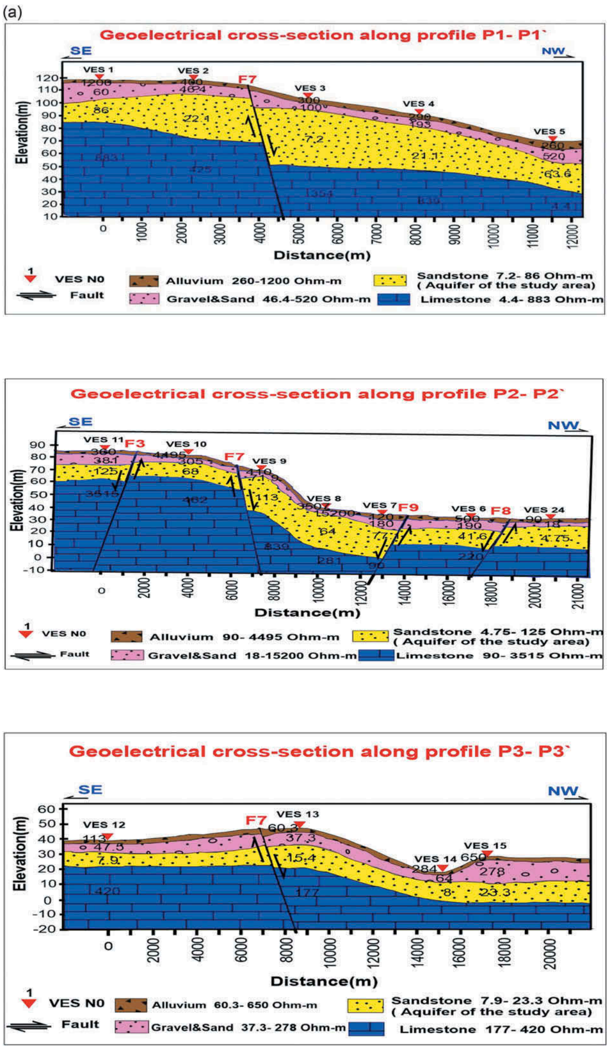

Figure 6. (a) Geoelectrical cross-sections along profiles 1, 2 and 3. (b) Geoelectrical cross-sections along profiles 4, 5 and 6. (c) Geoelectrical cross-sections along profiles 7, 8 and 9.

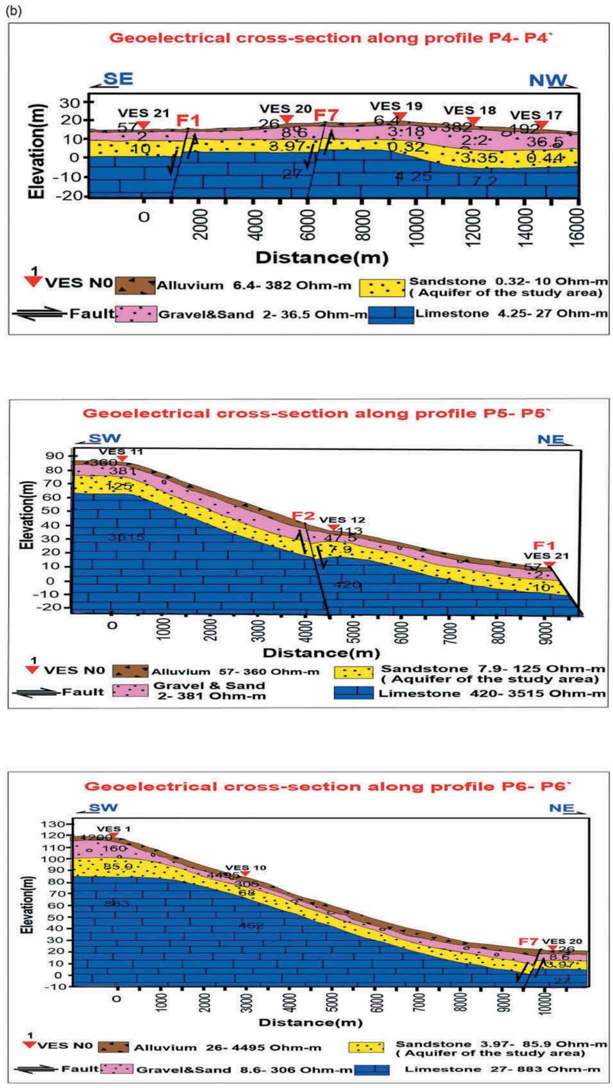

Figure 6. (Continued)

layers standard curves and generalised Cagniard graphs (Koefoed 1960; Orellana and Mony, 1966). While the second one is the analytical interpretation; this technique depends on using the results of manual interpretation as an initial model to compute the true resistivity values and thicknesses by using IPI2WIN program (2000) final results. This program deals with VES curves in a man–computer interacted regime and draws theoretical and field curves on a display screen together with a Rho (z) model curve (Figure 5). The latter results of VES interpretation were used for the constrictive of geoelectrical cross-sections which show the different geological units finding in the investigated area (Electrical sounding 1992).

2.1.3. Geoelectrical cross-section

The geoelectrical cross-sections along profiles (1–9) (Figure 6(a–c)) indicate four geoelectric units. The first unit consists of Alluvium (surface wadi deposits) with high resistivity ranging from 6.5 to 3500 ohm.m and thickness ranging from 1 to 2 m. While the second unit consists of sand and gravel with thickness ranging from 1 to 17 m and resistivity ranging from 1.2 to 15200 ohm.m. The third unit consists of sandstone with low resistivity ranging from 0.32 to 125 ohm.m (this low resistivity value is because of presence VES next to the Red Sea) and thickness ranging from 6 to 45 m. This unit represents the aquifer with freshwater of the study area. The last geoelectrical unit composed of limestone with high resistivity ranging from 4.2 to 3515 ohm. m. These four geoelectric units represent the Zafarana-Wardan Formation of Resent-Pliocene, after Darwish and El Araby (1993) and McClay et at, (1998); and represent the post-Zeit Formation of Quaternary (Pliocene-Pleistocene) after El Naggar (2017).

2.1.4. Isopach map of third geoelectrical unit

The isopach map of third geoelectrical unit shows that the thickness increases at the western part, reaches to 45 m and decreases at the eastern part,

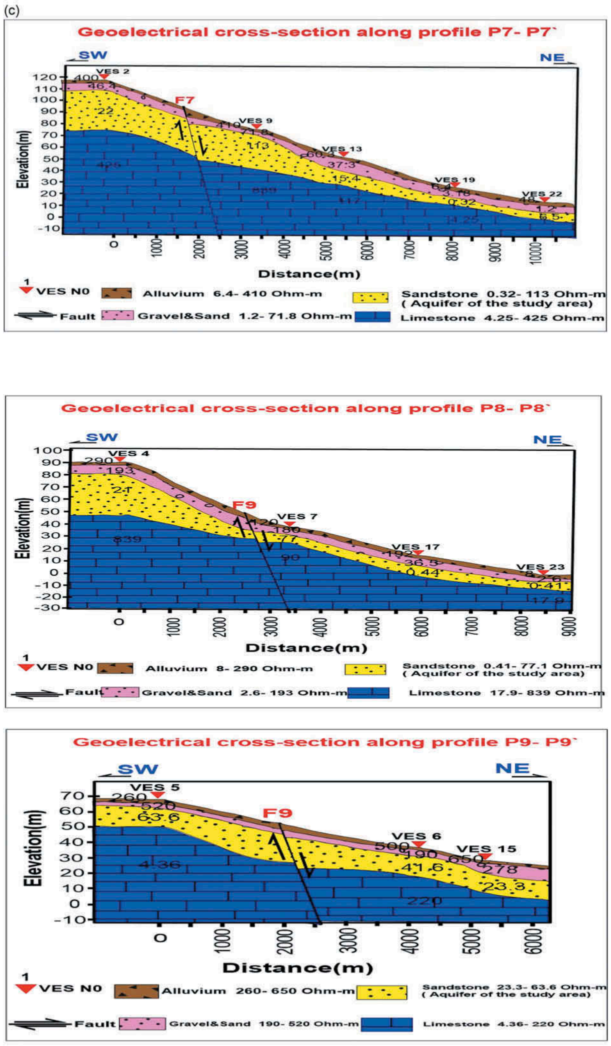

Figure 6. (Continued).

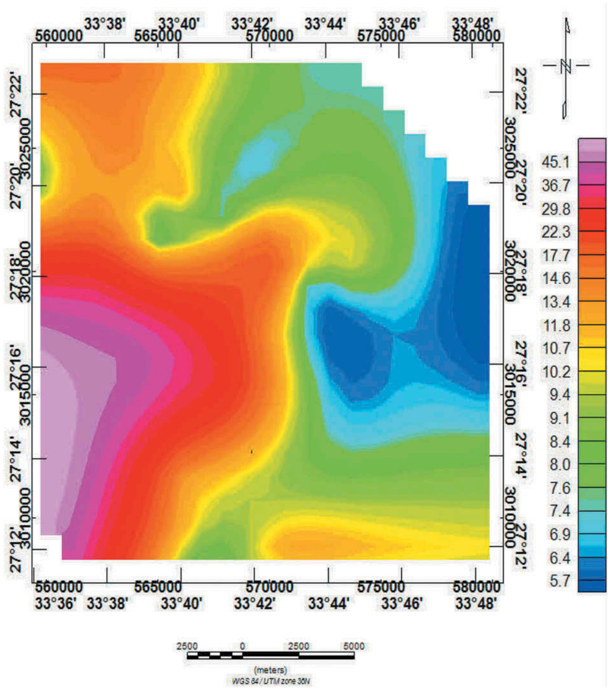

Figure 7. Isopach map of third geoelectrical unit.

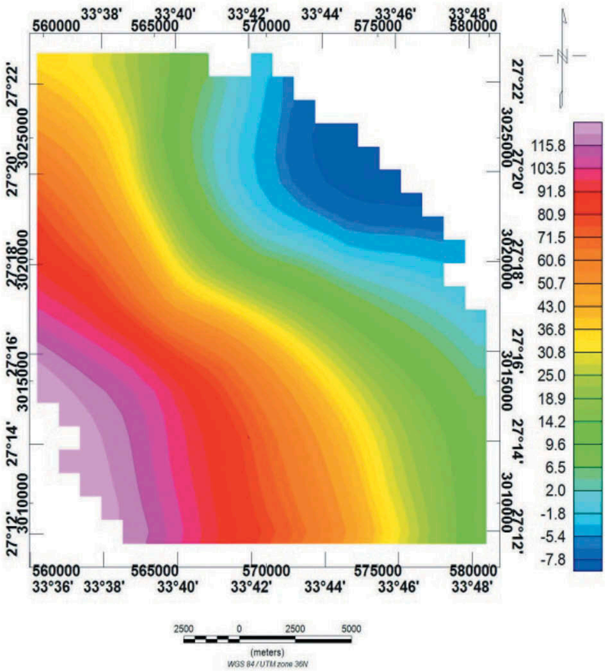

Figure 8. Depth map of third geoelectrical unit.

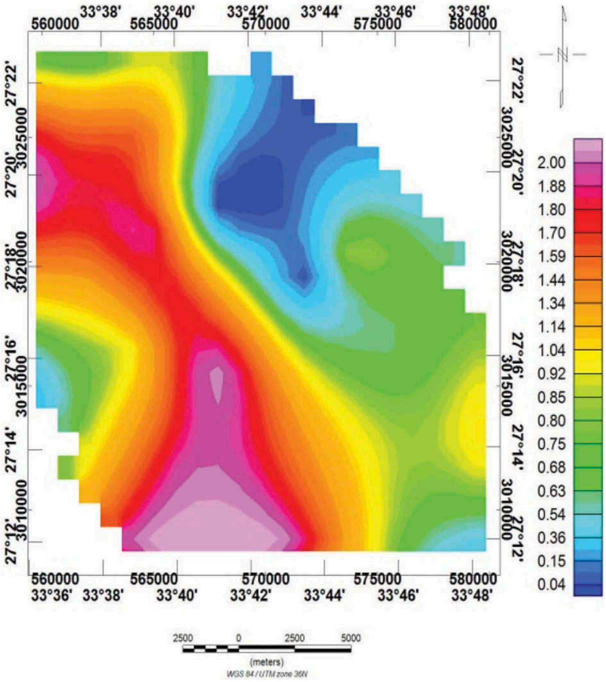

Figure 9. Iso-resistivity map of third geoelectrical unit.

reaches to 6 m of the study area (Figure 7). This unit represents the aquifer with freshwater and is composed of sandstone.

2.1.5. Depth map of third geoelectrical unit

The depth to the top of third geoelectrical unit varies from place to another (Figure 8) where the eastern and north-northwestern parts reveal shallow depths,

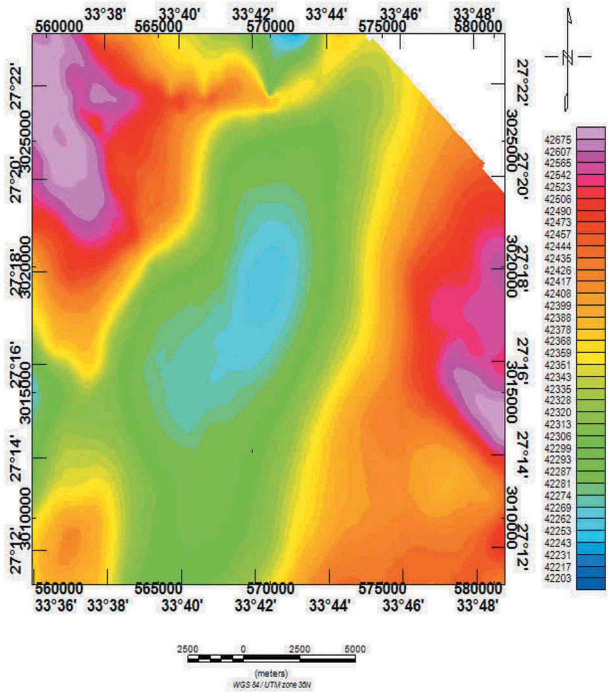

Figure 10. The RTP aeromagnetic map.

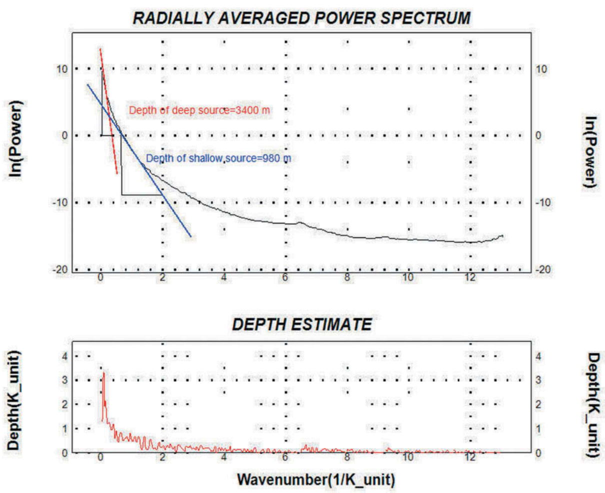

Figure 11. Power spectrum showing the mean.

while the western and southwestern parts reflect deep depths.

2.1.6. Isoresistivity map of third geoelectrical unit

The resistivity values of third geoelectrical unit range from 0.32 to125 ohm.m, in which the minimum resistivity is represented at the eastern and northeastern parts, while the maximum resistivity is displayed at the western and southwestern parts (Figure 9).

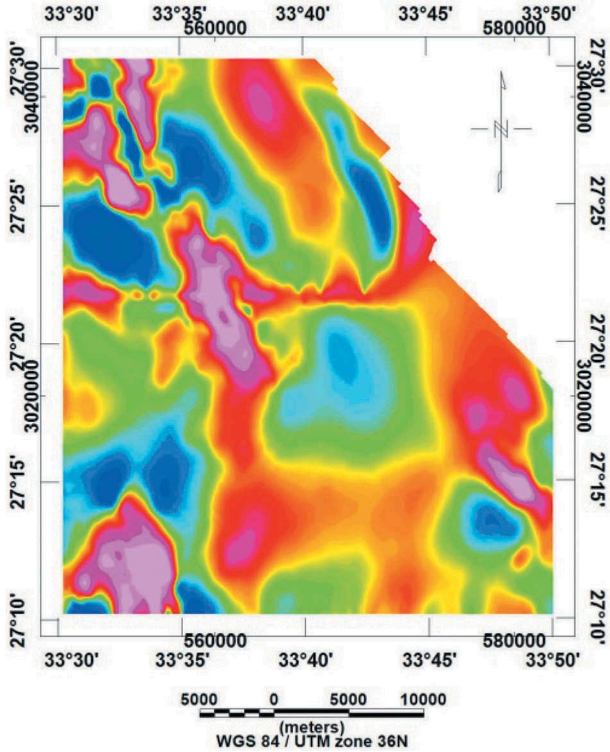

Figure 12. Residual aeromagnetic map depth to the basement rock in the area.

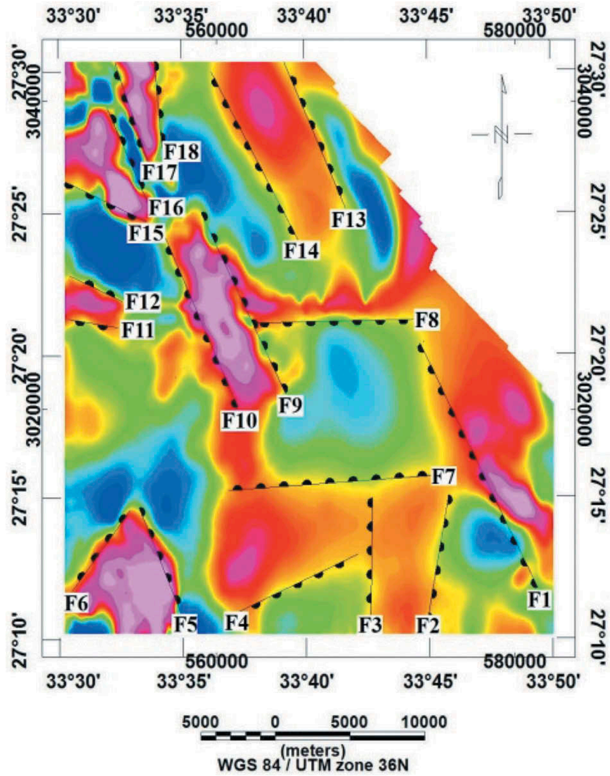

Figure 13. Fault elements dissecting the study area.

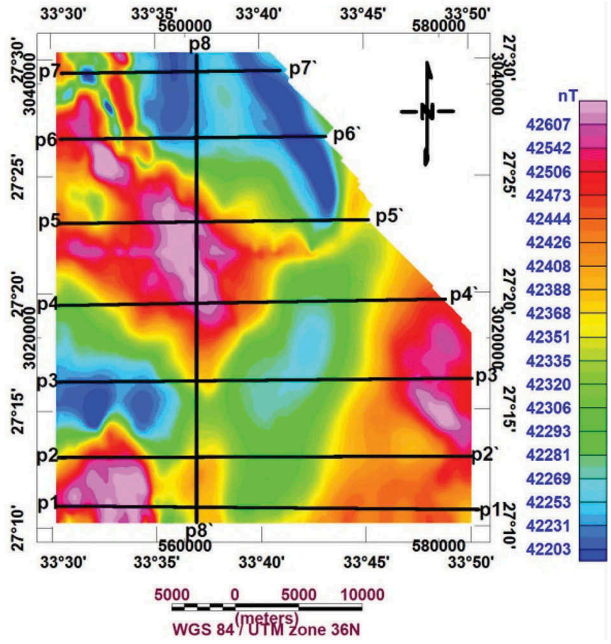

Figure 14. Location of the magnetic profiles used for 2D modelling.

2.2. Measurements and interpretation of magnetic data

2.2.1. Measurements and enhancement of magnetic data

The geophysical aeromagnetic surveys of the studied area were carried out by Geological survey of Egypt. The acquired aeromagnetic data were reduced to the north magnetic pole (RTP); assemblage and lastly presented in the form of (RTP) aeromagnetic map reduced to the pole (Figure 10). The RTP aeromagnetic map shows high magnetic anomaly at the southeastern, northwestern and eastern parts, whereas show low magnetic anomaly at the centre of the study area.

2.2.2. Interpretation of magnetic data

2.2.2.1. Filter of magnetic data. Based on wavenumber, the filter technique of high and low pass was applied on the RTP aeromagnetic map reduced to the pole data for discrete the regional and residual magnetic anomalies. Through the power spectrum technique at a wave number cut-off of 0.000153 (1/km) the separation has been carried (Figure 11), by using geosoft program (Oasis Montaj 1998), the high pass (residual) (Figure 12) and low pass (regional) magnetic anomaly maps represent two maps producing from RTP aeromagnetic. • **Quantitative interpretation of the RTP map**:

The RTP map shows that the high gradient zones are indicator of possible major fault zones; the major structural trends have the directions E-W, NW-SE, NNE-SSW, N-E, NNW-SSE, NE-SW and (Figure 13).

2.2.2.2. Modelling of magnetic data. Modelling of magnetic data was carried out by eight profiles crossing the magnetic anomalies in two directions (Figure 14); One magnetic profile in north-south direction and seven magnetic profiles in east-west direction. Through the use of measured magnetic susceptibly of 0.00757 cgs units for the basement rocks and using geosoft program (GM-sys program 1998), it was probable to quantify the shape of the basement surface and the sedimentary cover overlying it, Where the different locations have different depths to the surface of the basement rocks, as shown in (Figure 15).

2.2.2.3. Basement depth determination. The depths of the basement surface were found to be widely variable in the investigated area. It ranges from 1000 m at the eastern and western parts to 3500 m in the deepest area at southwestern, NNW and NNE parts (Figure 16).

3. Results and discussion

Through the interpretation of geoelectrical data of VESes, we obtained the following results: There are four geoelectrical units in the study area; The first unit with a thickness of about 2 m and is composed of Alluvium (surface wadi deposits) of high resistivity, while the second one with a thickness of about 17 m and consists of sand and gravel of moderate to high resistivity, the third geoelectrical unit with a thickness of about 45 m and represents the aquifer with freshwater in the investigated area, the last geoelectrical unit consists of limestone with high resistivity value. Two geophysical techniques are used to integrate geophysical interpretation for groundwater accumulations where the geoelectrical technique used to determine the depth and thickness of water-bearing zones and magnetic technique used for delineating subsurface structures which control the configuration of groundwater occurrences (Goldman and Neubauer 1994). There are chemical analyses for hand-dug wells in the investigated area (Figure 4) after Dahab et al. (2003) in which the Quaternary aquifer well number (11) has salinity (10,240 mg/l) and chemical analyses as following:

Hydrochemical parameters

T.D.S	Hydrochemical coefficiants (epm)					
9910	Na/cl	So4/cl	Ca/Mg	Cl-Na/Mg	Cl-Na/So4	Na-Cl/So4
	0.62	0.47	0.69	0.71	−0.8	0.38

Hypothetical Salts

NaCl	Na2so4	NaHCo3	MgCl2	MgHCo3	CaCl2	MgSo4	CaSo4	Ca(Hco3)2
41	0	0	24	0	0	11	20	4

Chemical analyses of minor elements (mg/l)

Silica	Iron	Boron	Bromide	Iodide	Nitrate	Phosphate
37	0.3	2	80.2	0.053	13	0.0

4. Summary and conclusion

According to the results of interpretation of the geoelectrical and aeromagnetic data in the present work, it can be concluded that:

(1) The depth of the basement surfaces at the southwestern and western parts is 3500 m and 1000 m at the eastern and southeastern parts in the study area.
(2) The investigated area is identified by the presence of structure trends such as: NE-SW, NW-SE, NNE-SSW, N-E, NNW-SSE and E-W.
(3) The study area has four geoelectrical units; they belong to Quaternary deposits.

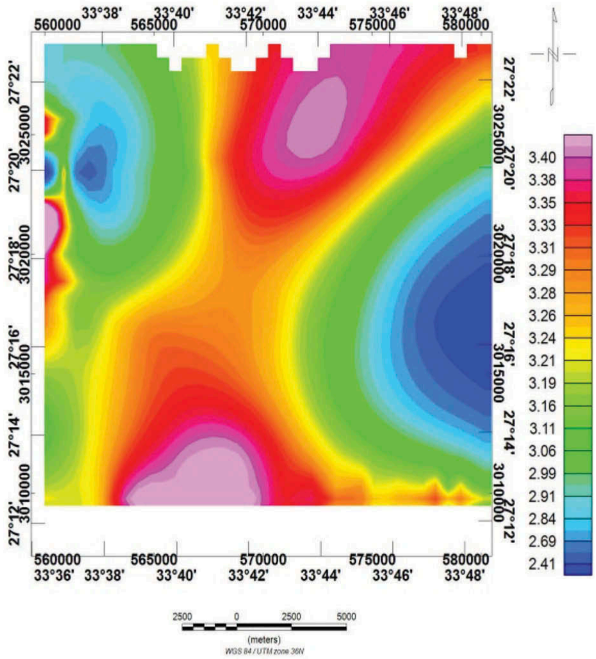

Figure 16. Magnetic depth map of the study area.

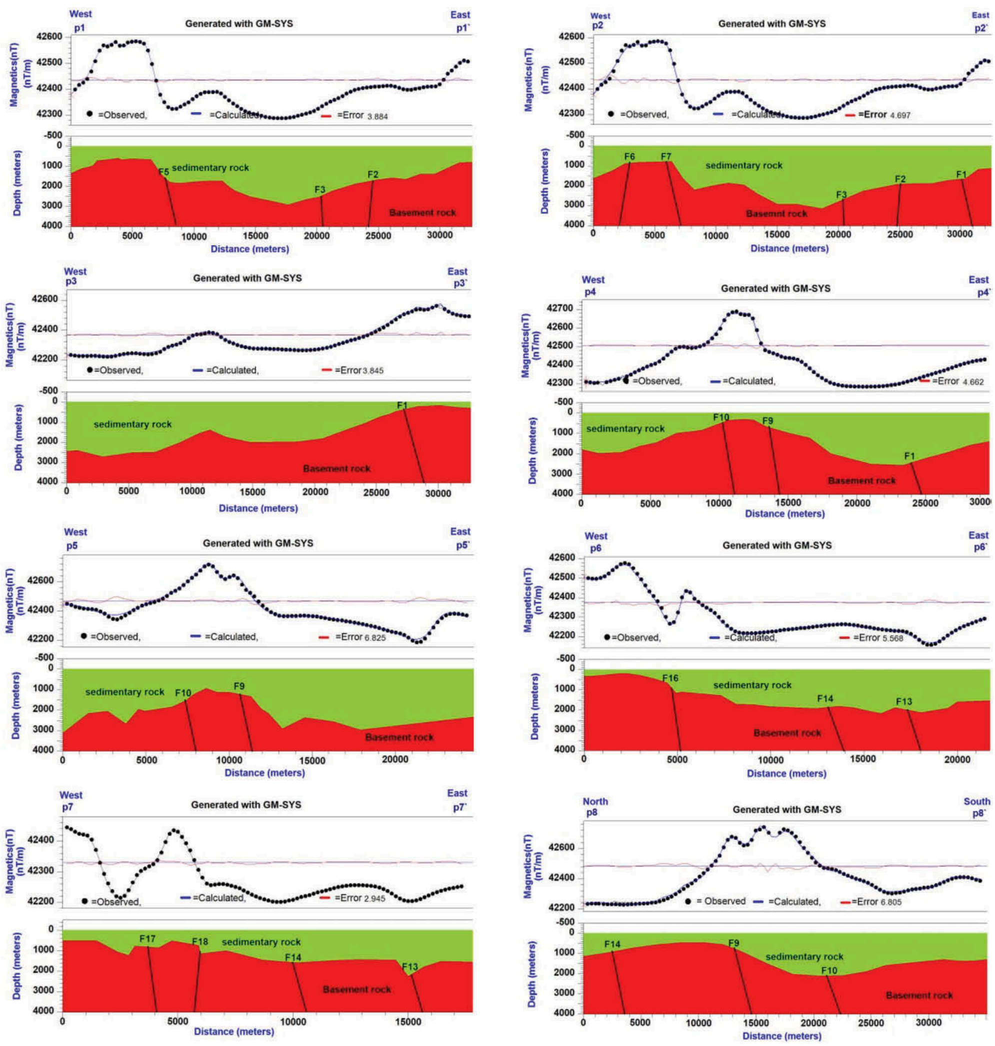

Figure 15. 2 D Magnetic Modeling along profiles (1:1`– 8:8`).

(4) In the investigated area the groundwater (aquifer) is accumulated in the third geoelectrical unit (sandstone unit) of thickness about 45 m and the depth from the earth's surface ranges from 3 to 18 m.
(5) The best locations for drilling wells are found in western part of the study area.

Disclosure statement

No potential conflict of interest was reported by the authors.

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