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ARTICLE

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# Application of Time Domain Electromagnetic survey to detect fractured limestone aquifer in desert fringes, West Assiut, Egypt

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**ABSTRACT**

New agriculture projects in the desert fringes along the western side of the Nile Valley of Egypt need exploring new groundwater resources. Time Domain Electromagnetic (TDEM) technique was used to acquire the field data. This technique is focusing on two main objectives. The first objective is to test the availability of applying TDEM in areas where other DC resistivity methods can't be applied due to the presence of a high resistive layer on the ground surface such as in the investigated area. The second objective is detecting the geoelectrical succession, emphasising on the water-bearing layer, which is represented by the fractured Eocene limestone layers. Results obtained from TDEM soundings were represented in the forms of cross sections and maps to illustrate the aerial distribution of the different geoelectrical layers and pay attention on the water-bearing layer. These results show up a good agreement with the data obtained from the drilled wells in the study areas.

Accordingly, TDEM method is a suitable choice when other DC resistivity tools were failed to acquire field data. Moreover, this technique helped to determine the parameters of the water-bearing layer such as resistivity, thickness, and extension. Also, it gives an idea about the hydrogeological setting of the study area where the water-bearing the fractured limestone layer overlays the low resistivity shale beds. New sites were recommended to drill productive wells in the western and southern parts of the study area based on the resistivity values and the thicknesses of the water-bearing layer.

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## 1. Introduction

### 1.1. Overview

Creating new communities in the desert fringes need decent information about the groundwater aquifer, its ability, and geometry. Economically, these new communities are based on agricultural activities that depend mainly on the groundwater due to the shortage in the surface water supplies and the low rainfall precipitation. The area under consideration lies in west Assiut governorate, Egypt. It extends along the western side of the Nile Valley in the western desert between Dairout and Manfalout. It pounded by latitudes 27° 12′ 00” and 27° 30′ 00” N and longitudes 30° 35′ 00” and 30° 51′ 00” E (Figure 1).

The study area is characterised by extremely arid conditions, long hot summer and short cold winter, low and erratic rainfall, and high evaporation. Air temperature attains its maximum value during June (45.3° C), and it attains its minimum value during January (1.3° C). The annual mean rainfall intensity reaches 38.5 mm, while the annual mean evaporation intensity reaches 76.2 mm/day (EMA, 2015).

Groundwater in the area under investigation is extracted from the Lower Eocene aquifer; it is composed mainly of the fractured limestone beds. The depths to the water of this aquifer range from 55 to 163 m and its salinities range from 440 mg/l to about 1010 mg/l (El Abd et al. 2011). Many works were established in the study area and its vicinities to determine the geomorphologic, geologic, and hydrogeologic settings. Some geophysical investigations were carried out to the north of the study area to investigate groundwater occurrences (El Sayed 1993; RIGW 1994; El Miligy 2004; Mahmoud and Kotb 2017; Abdel Hafeez et al., 2018).

The present work aims to use Time Domain Electromagnetic Sounding (TDEM) to acquire field data instead of ordinary Vertical Electrical Sounding (VES). Vertical Electrical Sounding method failed to be applied in the study area due to the presence of the high resistive layers on the ground surface. Also, this work aims to study and notating the Lower Eocene aquifer and to determine its characteristics as depth to the water-bearing layer, the thickness of the aquifer suitable for exploitation, its extension along with the study, and to locate the proper sites to drill new wells.

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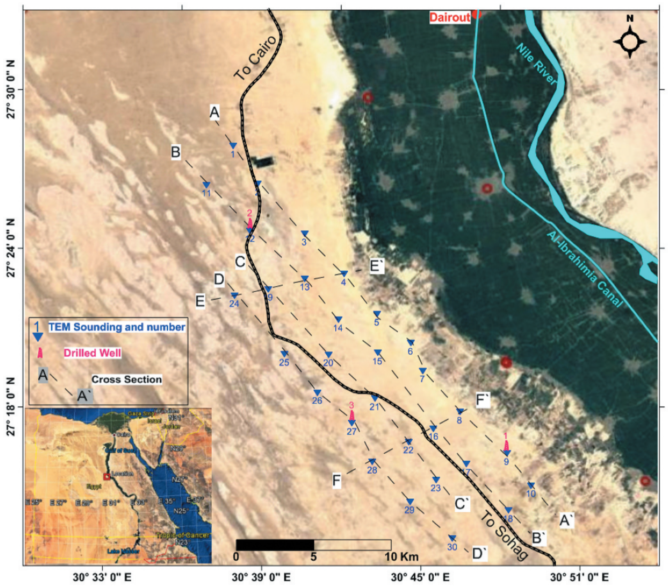


Figure 1. Spatial location map of the TDEM soundings in the study area.

### 1.1. Geomorphologic setting

The area under consideration forms a long stripe parallel to the western desert road between Dirout and Manfalout. Its Geomorphologic setting (Figure 2) was classified into three main units named the young alluvial plain, the old alluvial plain and the calcareous plateau (El Abd et al. 2011; Abdel Moneim et al. 2016; El Aassar et al. 2016). The young alluvial plain unit is located adjacent to the western side of the Nile valley; this unite becomes narrow toward the south and its slope is undefined because it is a cultivated area (Figure 2e). The second unit lies spatially and topographically between the young alluvial plain and the calcareous plateau, this unit named the old alluvial plain, its size shrinking toward the north (Figure 2b and 2c) and its surface is occupied by old terraces formed mainly of travertine conglomerate with gravel, sandstone, clay and elongated sand dunes. The third unit (western unit) is named the calcareous plateau, it represented by the Eocene limestone plateau. It is wrapped by float sands, carbonate flints, and boulders. This unit has a higher elevation other than the other units (Figure 2d); its elevation is about 200 m above the main sea level. The maximum highest of this unit reach 285 m, and it gradually decreases from the south to the north.

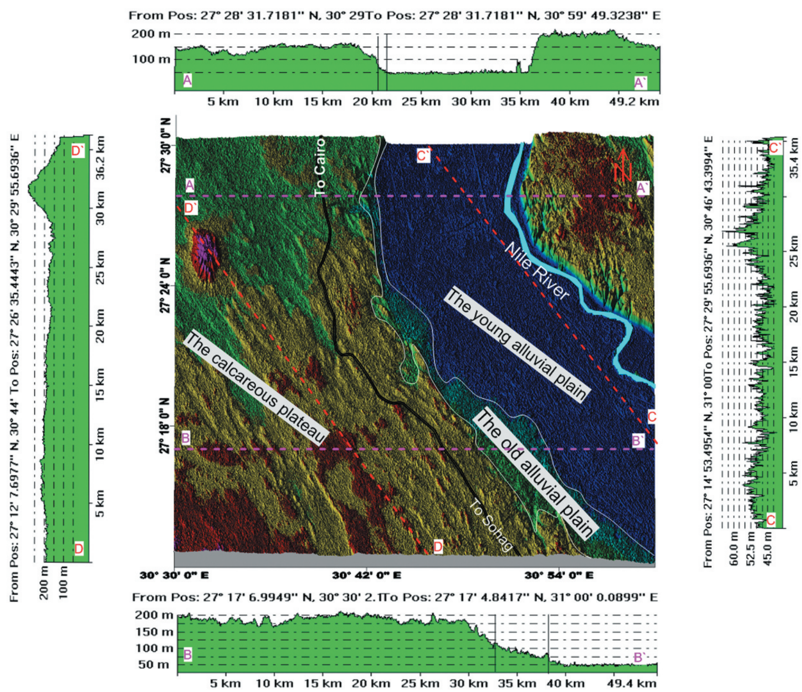


Figure 2. Classed topographic units and their elevation distribution.

(Modified after ASTER Global Digital Elevation Model 2009)

### 1.1. Geologic setting

Geologic setting and classification of the sedimentary rocks exposed along the study area and its vicinities were described by many authors (Figure 3). These rocks belong to different ages, they extend from the Tertiary to the Quaternary ages (Conoco 1987). The oldest rocks exposed in the study area belong to the Tertiary age, they are represented by Drunka Formation. This formation is characterised by the fractured and cavernous limestone, its age is Lower Eocene, and its thickness reaches 134 m (El Naggar, 1970). This formation is followed by Minia Formation with maximum thickness of about 140 m (Said 1990). Minia Formation covers the middle part of the calcareous plateau and it is composed of grey to white limestone with thin intercalations of dolomite and sandy limestone; its age is Middle Eocene. Samalut Formation overlies Minia Formation with 160 m thickness (Said 1990); it occupies the northwestern corner of the study area and it composes mainly from white Nummulitic limestone; its age is Middle Eocene. Minia and Samalut Formations represent the most explored water-bearing formations at El Minia fringes. The new reclamation processes are based on water supplies from groundwater sources, which may be extracted from the cracked Eocene limestone beds. This aquifer is influenced by a system of network of faulting and fractured systems (Said 1981; Tantawy, 1992; Fitzner et al. 2002; Abou-Heleika and Niesner, 2009; El Kashouty 2010). Small patches in the study area were covered by the gravel and sand deposits of the Pliocene age. Quaternary sediments are represented by linear stripes from fanglomerate and Nile deposits in addition to gravel plains that covered the northern part of the study area.

Faulting and fracturing represent the main structural framework in the study area. The faults belong to normal type with two main trends, the first trend parallel to the Gulf of Suez (NW-SE) while the other trend parallel to the Gulf of Aqaba (NE-SW). Structural elements generally play important roles in the groundwater recharge, accumulation, and transportation (Shaban, 2010; Mahmoud and Kotb 2017).

## 2. Materials and methods

The electrical properties of rocks are very important guide for exploring and evaluating the groundwater occurrences and quality (Loke et al. 2013). The rocks material are high resistive or insulator and roughly the differences in electrical properties caused by formation fluids in addition to the degree of salt concentration (John 2003; Tawfik and Mahmoud 2017; Metwally et al. 2018). To achieve the main targets of the present work, thirty electromagnetic soundings were constructed. Time Domain Electromagnetic Sounding technique (TDEM) was applied because it has many advantages over the conventional DC resistivity methods; it does not require electrodes hammering into the ground and therefore, it does not require long electrode separations for deep investigations, less sensitive to lateral changes in formations resistivity, in addition it has better depth resolution and overcomes the contact resistance between the ground and the electrodes as in this case, where the ground surface is covered by resistive beds.

Time Domain Electromagnetic sounding technique (TDEM) was utilised for mapping water-bearing layers where the conductivity of the water-bearing layer is more than that of the dry layers. This method

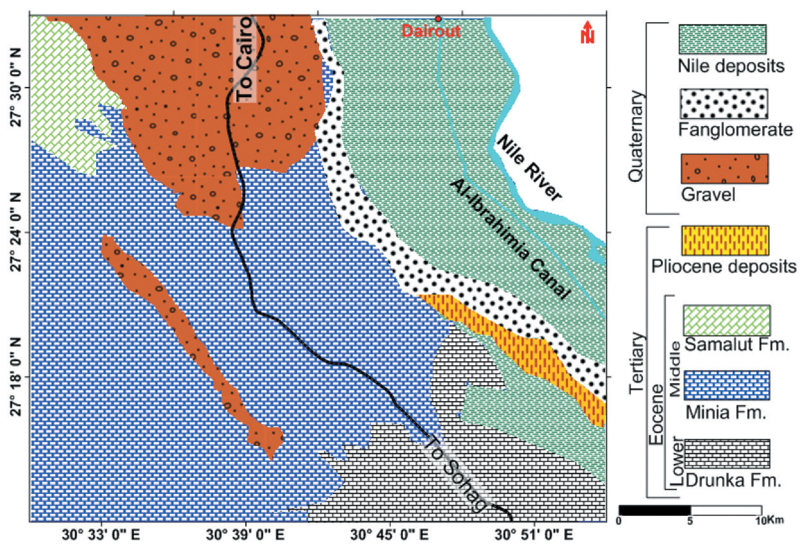


Figure 3. Surface distribution map of the lithological units on the study area (Modified after CONOCO, 1978).

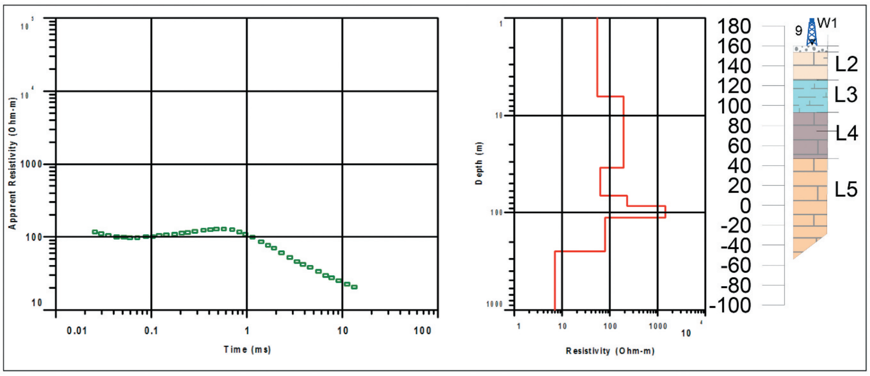


Figure 4. TDEM sounding no. 9 with the lithological log of well 1.

is utilised to identify the vertical resistivity changes due to its better vertical resolution and its lower sensitivity to geologic noise. In this geophysical tool, electrical pulses are passed through the transmitter loop laid on the ground surface, after disconnecting the power cord, the rapid deterioration of the current at the end of each pulse generates a magnetic field spreading into the stratified earth. Eddy currents

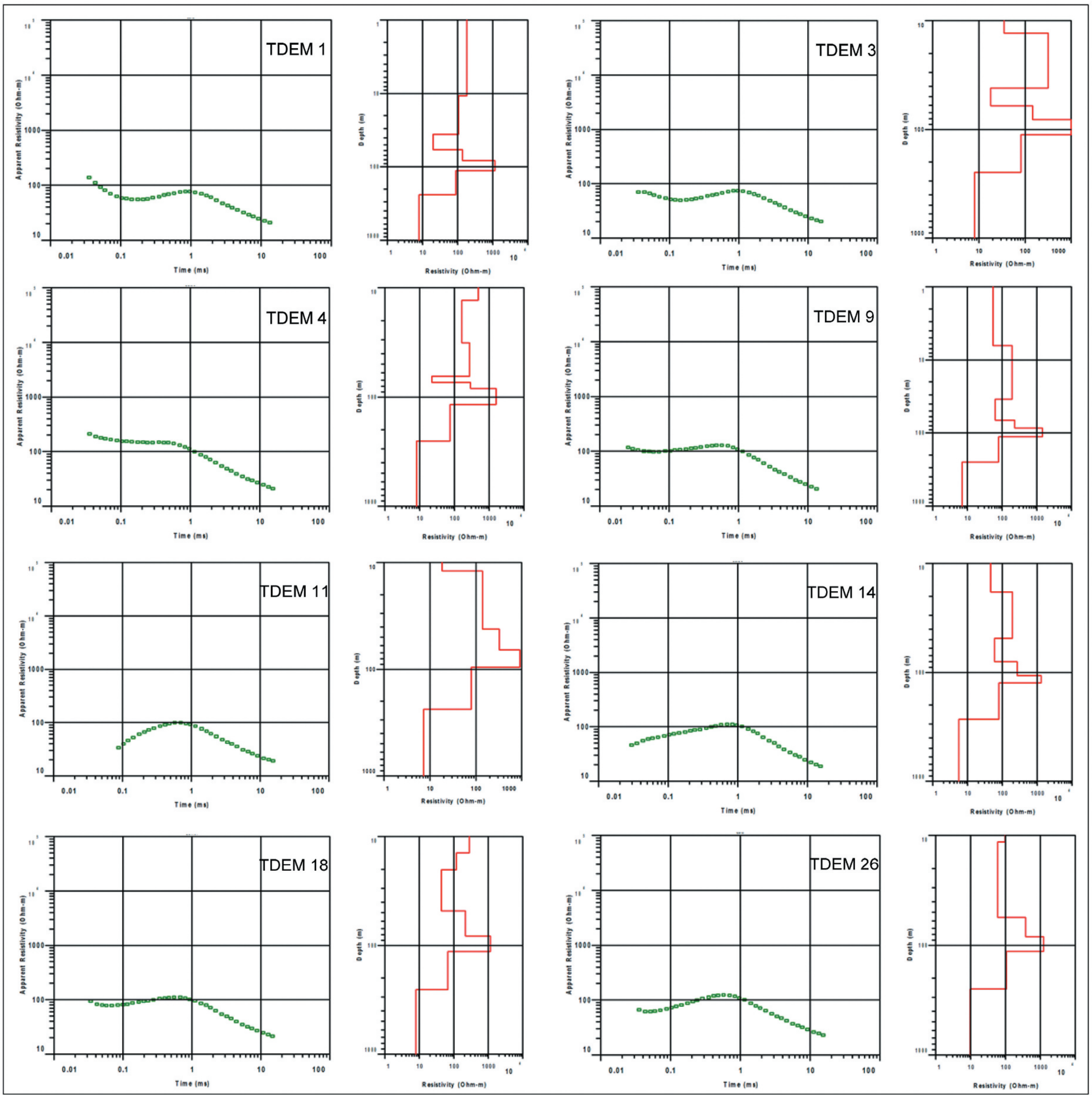


Figure 5. Examples of some TDEM sounding interpretation.

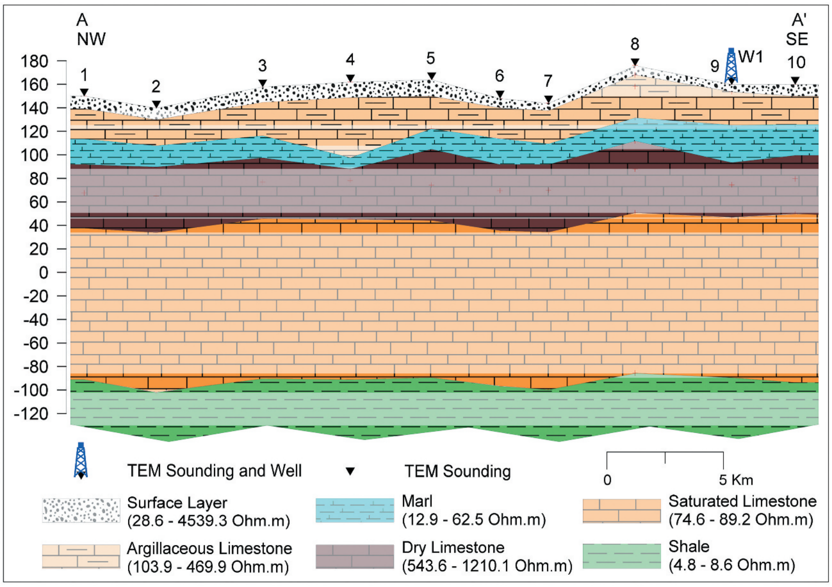


Figure 6. Geoelectrical cross section AA′.

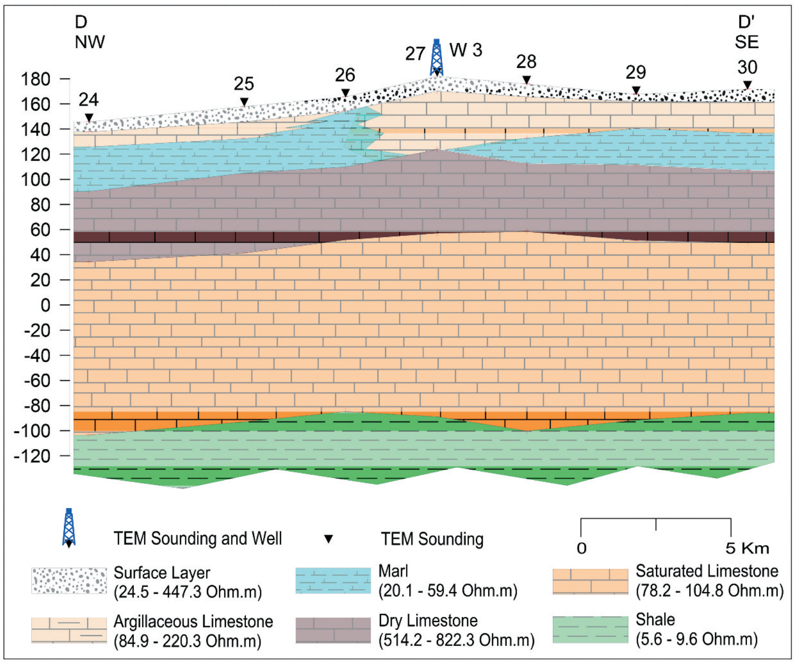


Figure 7. Geoelectrical cross section DD′.

prompted by the Variable magnetic field over time generate, per contra, secondary magnetic field in the electrically conductive stratified earth. The amplitude and degradation rate of these secondary fields on the receiving loop are measured and analysed in terms of variance in electrical resistivity with depth (Kontar and Ozorovich 2006).

Thirty TDEM soundings (Refer to Figure 1) were acquired with TEM-FAST 48HPC instrument with the usage of ungrounded horizontal magnetic antennas in a single loop configuration (square loop with 100 m or 200 m side length), one loop combines functions of the transmitter and receiver. The measurements were repeated repeatedly at every single site to acquiring the best field curve (enhanced signal-to-noise ratio) adequate for processing and interpretation. Some TDEM soundings were measured adjacent to existing wells to aid in correlation and reduce the ambiguity during the interpretation of the collected data. Based on Occam's inversion principle (Constable et al. 1987),

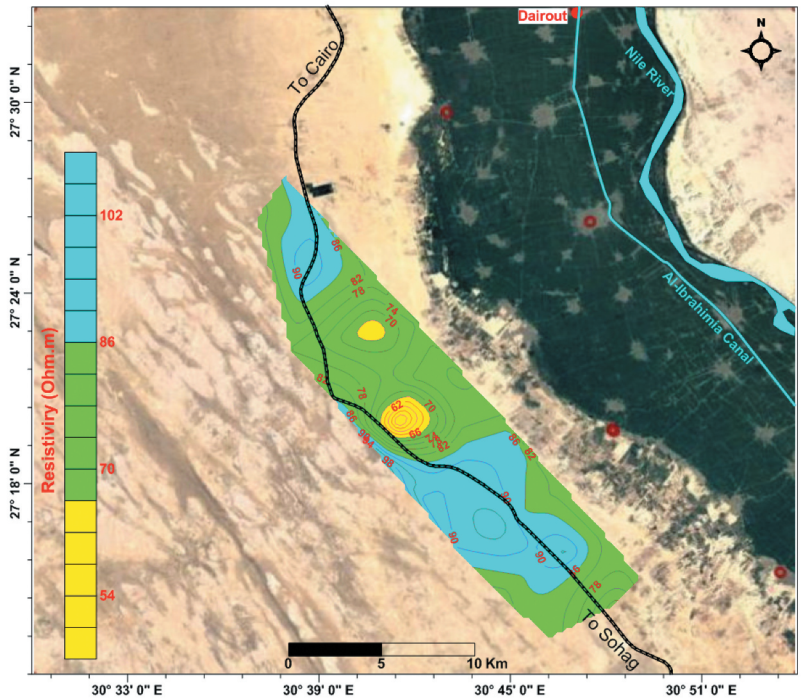


Figure 8. Explored aquifer iso-resistivity contour map.

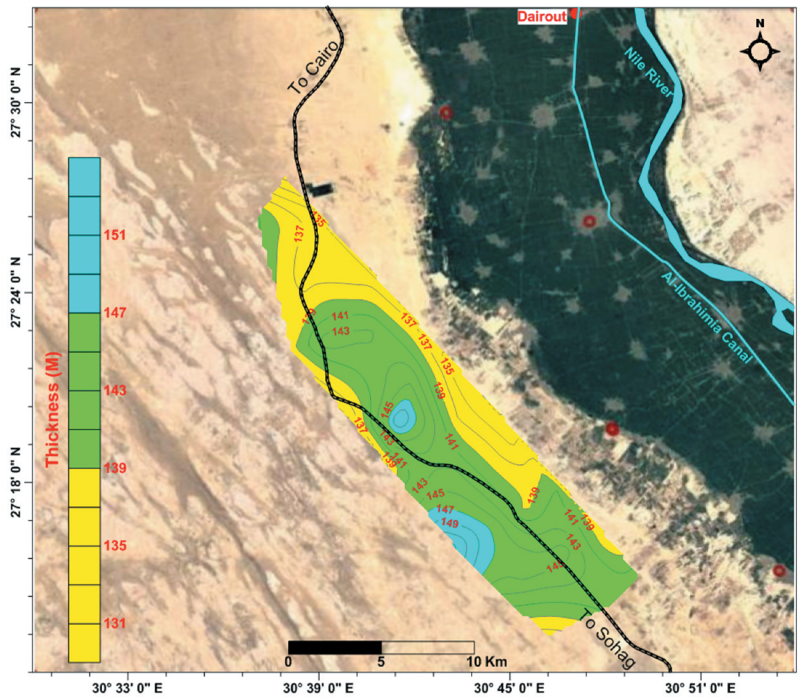


Figure 9. The explored aquifer thickness contour map.

the acquired TDEM data in the form of apparent resistivity versus time were processed and inversed using 1X1D software (Interpex 2008).

## 3. Results and discussion

The initial model used during the interpretation of the TDEM soundings is based on all information about the study area; surface and subsurface available geological and hydrogeological data collected from published manuscripts in addition to that obtained from the existing wells (Figure 4). The aim of this interpretation is constructing a model to form the best fit with the smoothed data. The obtained results from these TDEM soundings (Figure 5) were used to construct a group of geoelectric cross-sections that reveal that the vertical resistivity stratification in the study area composed of five to six layers (Figures 6 & 7). The

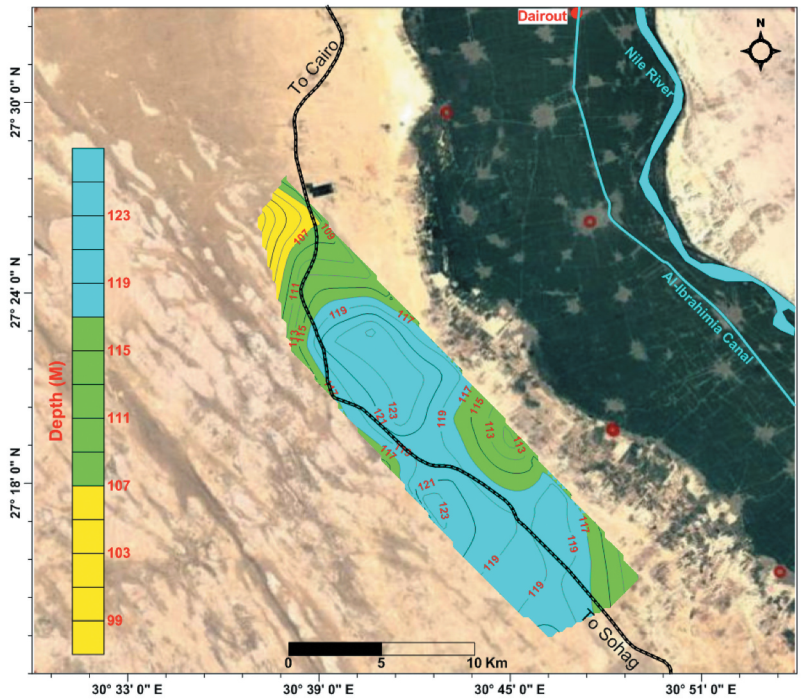


**Figure 10.** Profundity contour map for the explored aquifer.

first geoelectric layer is represented by the surface layer, it forms the uppermost part of the dry zone; it has resistivity values range from 18.4 Ohm.m at sounding 11 to 4539.3 Ohm.m at sounding 6. The great variations between its resistivity values are due to the variations in the exposed sediments on the ground surface that vary from fine sediments to compact rock fragments derived from the western plateau. The thickness of this layer varies from 4.2 m at sounding 15 to 24.8 m at sounding 12. This layer is composed mainly of gravel, sand, silt, and occasionally from limestone.

The second geoelectric layer has resistivity values range from 83.2 Ohm.m at sounding 23 to 559.9 Ohm.m at sounding 12; and its thickness varies from 6.0 m at sounding 18 to 57.9 m at sounding 13. It is correlated with the argillaceous limestone beds; this layer is missed at the location of sounding 26.

The third geoelectric layer represents the marl bed with resistivity values increase toward the central part of the study area. Its resistivity values range from 12.9 Ohm.m at sounding 2 to 76.9 Ohm.m at sounding 15. The thickness of this layer varies from 9.0 m at sounding 4 to 44.4 m at sounding 26, it gets thicker toward the southwest directions. This layer is not detected at the location of soundings 11, 20, 21, and 27 where it changed laterally to argillaceous limestone beds.

The fourth geoelectric layer is correlated with the dry limestone beds. In the most cases this layer is composed of two sub layers that combined into one layer to represent the dry limestone layer. Its average resistivity values range from 514.2 Ohm.m at sounding 27 to 1210.1 Ohm.m at sounding 2. Its resistivity values increase toward the northwestern part of the study area. The thickness of this layer varies from 30.1 m at sounding 11 to 80.8 m at sounding 21; it increases toward the southern part of the study area.

The fifth layer is the most important layer in this succession; it represents the saturated limestone layers. Its resistivity values range from 43 Ohm.m at sounding 20 to 104.8 Ohm.m at sounding 26. The low resistivity values of this layer can be attributed to the increase in the water salinity and/or the increase in the argillaceous materials. The thicknesses of this layer vary from 129.0 m at sounding 1 to 154.0 m at sounding 28. This layer rest over the sixth layer, which is described as an impervious shale bed and considered the base of the Eocene aquifer with resistivity range from 4.2 Ohm.m at sounding 20 to 9.6 Ohm.m at sounding 26; and its lower boundary was not detected.

In order to clarify the characteristic properties of the water-bearing layer in the area under consideration, three maps were constructed (Iso-resistivity map, Iso-pach map, and depth to the water-bearing layer map). The Iso-resistivity map (Figure 8) shows that; the resistivity values of the water-bearing layer tend to be increased toward the NW and the SE directions, whereas these values decrease in the central part around stations 13 and 20. It is noticed that the resistivity values of about 70 Ω.m were measured in the TDEM stations beside the exist wells with a good water quality. The iso-pach map (Figure 9) indicates that the saturated thickness of this aquifer increases in general toward the western side of the study area; and also it increases southward. Profundity to the upper surface of this aquifer (Figure 10) increases southward due to the increase in the ground elevation. Based on the resistivity values and thicknesses of the water-bearing layer, the best sites to exploit the groundwater from the fractured Eocene limestone aquifer exist at the western and southern parts of the study area.

## 4. Conclusion

TDEM method is convenient to carry out in areas where other ordinary DC resistivity methods were improper. It doesn't require electrodes to inject current through the ground; so that, the influence of the highly resistive surface layer can be neglected. This method was used successfully to study the groundwater occurrence in the fractured limestone aquifer belongs to the Middle Eocene in the desert fringes of Assiut area, Egypt. In such a way, results confirmed the great potential of TDEM technique in the hydrogeological studies in the desert areas. The interpreted results attained from the acquired TDEM soundings helped to determine the geoelectrical sequence in the study area which consists of six geoelectrical layers. These layers are correlated with surface, argillaceous limestone, marl, dry limestone, saturated limestone and shall bed layers. Iso-resistivity map, iso-pach map and depth to the aquifer map were constructed to clarify characteristic properties of the water-bearing layer in the area under consideration. From these maps it is clear that the resistivity values of the water-bearing layer tend to be increased toward the NW and the SE directions, whereas these values decrease in the central part; the saturated thickness of this aquifer and its depths increase in general toward the western and southern sides of the study area. Based on the resistivity values and the thicknesses of the water-bearing layer, the best sites to exploit the groundwater from the fractured Eocene limestone aquifer exist at the western and southern parts of the study area; where the aquifer has suitable resistivity values and good thicknesses.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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