



Application of electrical resistivity for groundwater exploration in Wadi Rahaba, Shalateen, Egypt



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ABSTRACT

Shalateen area is located on the Red Sea coast at the southeastern part of the Eastern Desert. It is suffering from shortage in fresh water, where the main source of water is the rain water. Desalinated water is another source but it is more expensive. So, groundwater is the alternative solution to face the gap between the water demand and available water in this area. Vertical electrical sounding (VES) is considered as one of the most common methods in groundwater exploration. Twenty Schlumberger VES's with maximum current electrode spacing of 400 m were carried out in the coastal zone of Shalateen area at the alluvial fan of Wadi Rahaba. The obtained data were processed and interpreted qualitatively and quantitatively. The geoelectric layers that were detected in the study area are Quaternary dry alluvial sediments, Quaternary alluvial deposits and Miocene sandstone aquifer, clay lens, sill, fractured basement, non-fractured basement. The Quaternary alluvial deposits and Miocene sandstone represent the main shallow aquifer in the study area. The salt water appears at the eastern part while fresh water is concentrated at the western part. Resistivity values of the fresh to slightly brackish water ranges between 38.6 and 98.4 $\Omega\cdot\text{m}$ with thickness varies from 1.18 to 24.4 m and depth range between 1.31 and 19 m. Clay lenses appear in the alluvial fan channel with resistivity values ranges between 1.3 and 9.1 $\Omega\cdot\text{m}$ and thickness varies from 2.1 to 13.7 m. The fresh coastal aquifers are affected by set of faults. These faults appear in all profiles distributed orthogonally through the study area. In the study area, a fractured sill intrusion is intruding the groundwater aquifer. It is located near a granodiorite-tonalite exposure with resistivity values (230–315 $\Omega\cdot\text{m}$) at (5.6–16.4 m) depth. Basement is also detected at shallow depths especially in the western part of the study area.

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1. Introduction

Egypt has a lot of promising areas which are not developed yet. Shalateen area is considered as one of these areas which suffer from lack of development vision or serious research activities. It is located on the Red Sea coast at the southeastern part of the Eastern Desert. Shalateen lies to the north of Halayeb Triangle and about 520 km to the south of Hurghada. The study area (Fig. 1) lies

between latitude 23.116111° N and 23.231667° N and Longitude 35.605000° E and 35.450833° E.

The study area is a part of the Red Sea coastal plain strip which extends northwest-southeast parallel to the Red Sea coast. The elevation of the coastal strip varies between 20 and 196 m above sea level (Shawky et al., 2012). The study area is also a part of Rahaba basin which is a sub-catchment of wadi Hodein (Soussa et al., 2012). Wadi Rahaba is responsible for supplying the study area with the Quaternary alluvial sediments that drains from west towards the Red Sea (Abdel Moneim, 2005; Soussa et al., 2012).

The climate of the area is arid where the temperature reaches its maximum in the summer and ranges between 45 °C and 50 °C (Ageeb et al., 2007). The rainfall plays an important role as it is considered as the main source of aquifer recharge. The annual rainfall is less than 150 mm/year (Khalil, 2014), while the relative humidity ranges between 28% and 52% (Hassanein et al., 2004).

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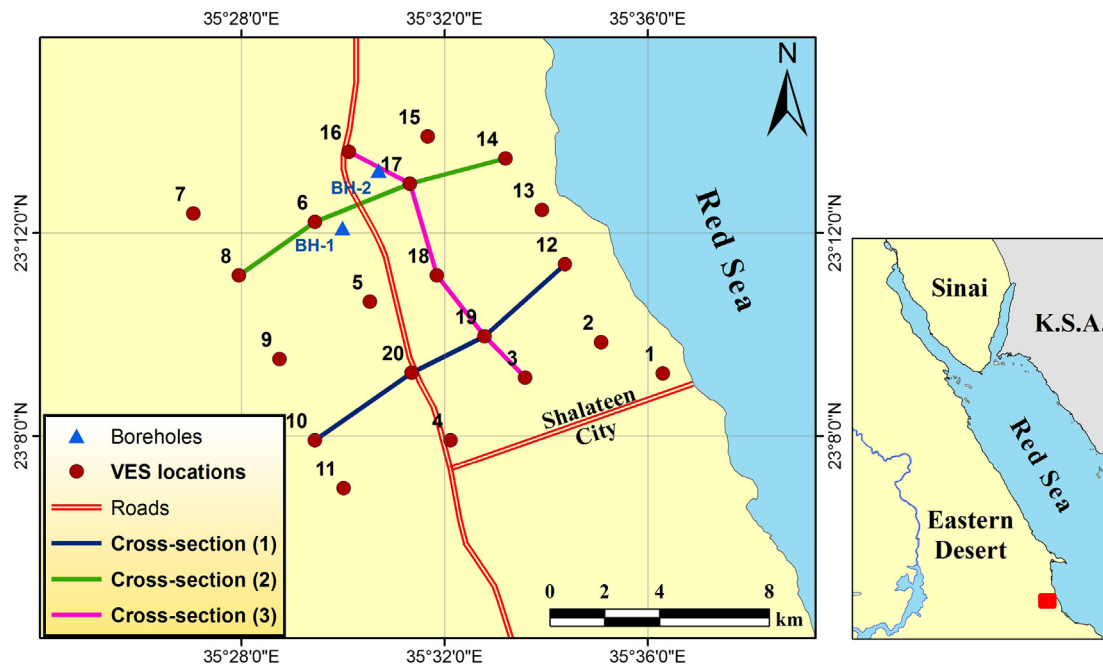


Fig. 1. Location map of the study area showing VES's and profiles distribution.

Lack of the fresh water is the main problem affecting the development plans in Shalateen. The water supply to the Red Sea coast towns is either from the Nile River through pipes or sea water desalinization (Abdel Moneim, 2005). Groundwater is considered as a preferable alternative solution to face that type of problems. The study area attracted many authors such as Abdel Moneim (2005), Yousef et al. (2009), Shawky et al. (2012), Soussa et al. (2012) and Khalil (2014). The main objective of this study is to identify the shallow aquifer and salt/fresh water zone distribution in the study area using geophysical technique represented by electrical resistivity method. As, the electrical resistivity method is considered as one of the most powerful techniques in the groundwater exploration (Zohdy, 1974; Telford et al., 1990; Reynolds, 2011).

2. Geological and structural settings

The shallow formation is represented by the Quaternary alluvial deposits. The age of these deposits ranges from Pleistocene to the recent ages. Its thickness ranges between 2 and 20 m as it increases towards the Red Sea coast (Abdel Moneim, 2005). The Quaternary deposits are composed of beach sand and gravel in the western part while they are converted to clayey sand toward the east direction. They also contained rock fragments of basement origin (Abdel Moneim, 2005; Yousef et al., 2009; Shawky et al., 2012). Along the Red Sea coast, Quaternary deposits are described as a highly productive aquifer (Abdel Moneim, 2005).

The exposure of Neogene sediments are found in the Red Sea coastal belt which belongs to Miocene succession. The Oligo-Miocene sandstone formation (Abu Ghusun Formation) is extended along the Red Sea coastal plain. This Miocene aquifer represents a good source of water (Abdel Moneim, 2005; Soussa et al., 2012).

Pre-Cambrian basement rocks are parts of the Arabo-Nubian Shield (Sabet, 1972). The southern part of the Eastern Desert composed of ophiolitic melange rocks accompanied by extensive metasediments of oceanic character (Greiling et al., 1994), calc-alkaline metavolcanics, metamorphic and intrusive assemblages (Kroner et al., 1987).

They are classified into fractured and non-fractured basement. The fractured basement is the deeper aquifer in Shalateen and

characterized by its moderate salinity (Shawky et al., 2012). The fractured basement aquifer is detected at very shallow depth (started from around 10 m) in some wadis along the Red Sea coast (EGSMA, 1995).

Both Quaternary alluvial deposits and Miocene sandstone formations represent the main shallow aquifer in this area. The deeper fractured basement aquifer is not highly recommended to be used as a source of water, as the supplement of groundwater from the aquifer is very limited (Abdel Moneim, 2005; Khalil, 2014).

The extension of the Quaternary alluvial deposits and Miocene sandstone aquifer is not large and its conditions changes geographically and seasonally. Although that, the aquifer is considered to be of good quality due to its high storage capacity of water. The aquifer is mainly recharged from the occasional rainfall. Although the rainfall is intermittent, it plays an important role as a recharge source as the bifurcation ratio of the wadi is high and the stream frequency is low. The deep fractured basement aquifer also could be another source of recharge. Sea water intrusion has a significant effect on the aquifer along the Red Sea coast which explains the presence of saline water within the aquifer (Abdel Moneim, 2005).

Structurally, the creation of both the Gulf of Suez and Red Sea are the main causes of the subsurface geologic structures at the study area. These structures affect both the sedimentary sequence and basement rocks (El-Bayoumi and Greiling, 1984). Trends of the fault systems present in the area are the following: The Syrian Arc trend (ENE-WSW), Trans-African trend (NE-SW), the Aqaba trend (NNE-SSW), the Najd trend (WNW-ESE), the Gulf of Suez -Red Sea trend (NW-SE), the Mediterranean Sea trend (E-W) and the Meridional trend (N-S) (Nano et al., 2002) (Fig. 2). It is also found that the fresh coastal aquifer is affected by deep and shallow faults associated with dykes and/or dyke swarms. Sill igneous intrusion also is detected in the study area at shallow depths (Khalil, 2014). Hydro-geophysicists consider these types of structures as challenging and confusing during interpretation (Durasiwami, 2005).

3. Methodology

The electrical resistivity technique is a preferable geophysical technique for groundwater exploration. As, the water content

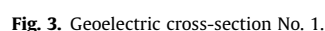


In this method, the apparent resistivity measurements of the subsurface layers are obtained during the field survey. In the present study, Syscal Pro instrument was used to perform twenty Vertical electrical soundings by applying the Schlumberger configuration with maximum current electrodes (AB) 400 m. The measured data were used to estimate the subsurface models

Khalil (2014) described two boreholes, BH-1 and BH-2 in the study area (Fig. 1). He detected the groundwater surface at 21 m depth in BH-1 while at BH-2 he detected a dyke at shallow depth (11 m). This information besides the available geological data was used for determining the different geoelectric units and calibrating the estimated models (Khalil, 2006). InterpexIX1D-v.2 software was used for data processing and interpretation. Finally, the data were represented in geoelectrical cross-sections and contour maps.

4. Results

Three profiles were chosen to be representative to the area (Fig. 1). Two profiles are chosen to be perpendicular to the shoreline to illustrate the effect of salt water intrusion. The third



is parallel to the shoreline to show the lateral variation in the area. Processing and interpreting all the obtained data revealed eight geoelectric units in the study area.

The first unit is the surface layer which is Quaternary dry alluvial sediments. It is composed of a mixture of gravel boulders besides silt and sand. This heterogeneous nature causes wide variation in resistivity values (khalil, 2014) (4–4777 $\Omega\cdot\text{m}$) and thickness ranging between 1 and 9.7 m.

The second geoelectric unit is the Quaternary and Miocene sandstone aquifer which is the main shallow aquifer. It represents the fresh to slightly brackish water bearing formation that is

mainly composed of sand and gravel with resistivity values varying from 38.6 to 98.4 $\Omega\cdot\text{m}$ and thickness ranging between 1.2 and 24.4 m. The resistivity values increase towards the west direction (Figs. 3–5).

The third geoelectric unit is the brackish water bearing formation of Quaternary and Miocene sediments with resistivity values varying from 11.3 to 25 $\Omega\cdot\text{m}$ and thickness ranging between 1.6 and 52 m.

The fourth geoelectric unit is the salt water bearing formation of Quaternary and Miocene sediments which are composed of silt and sandstone as the lithology tend to be fining downward

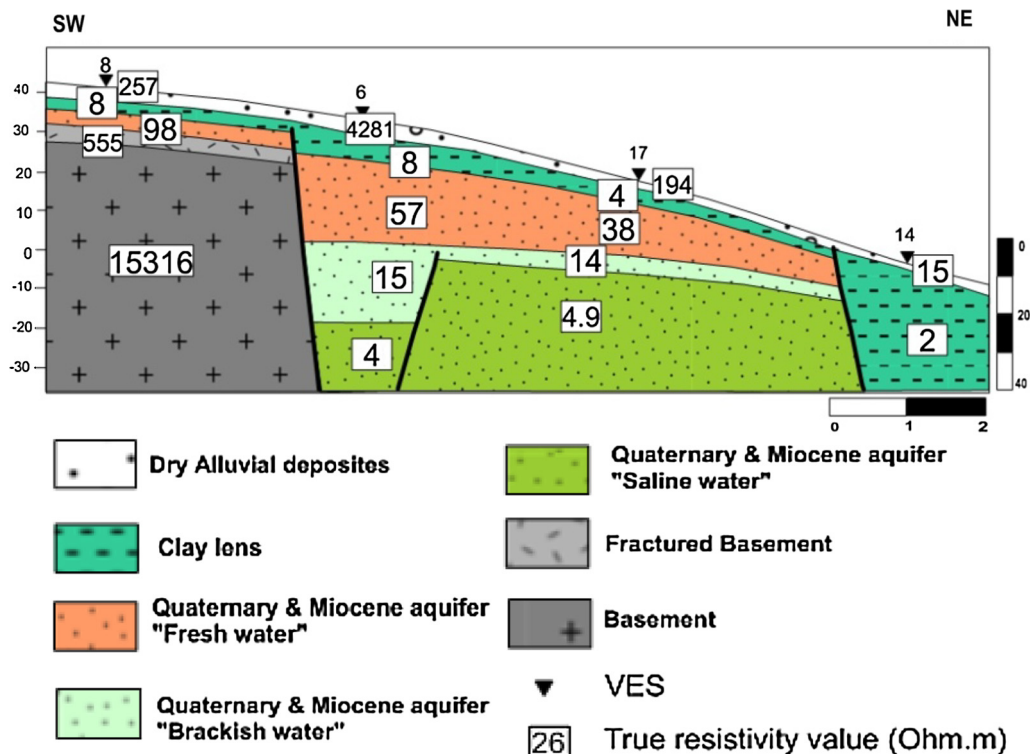


Fig. 4. Geoelectric cross-section No. 2.

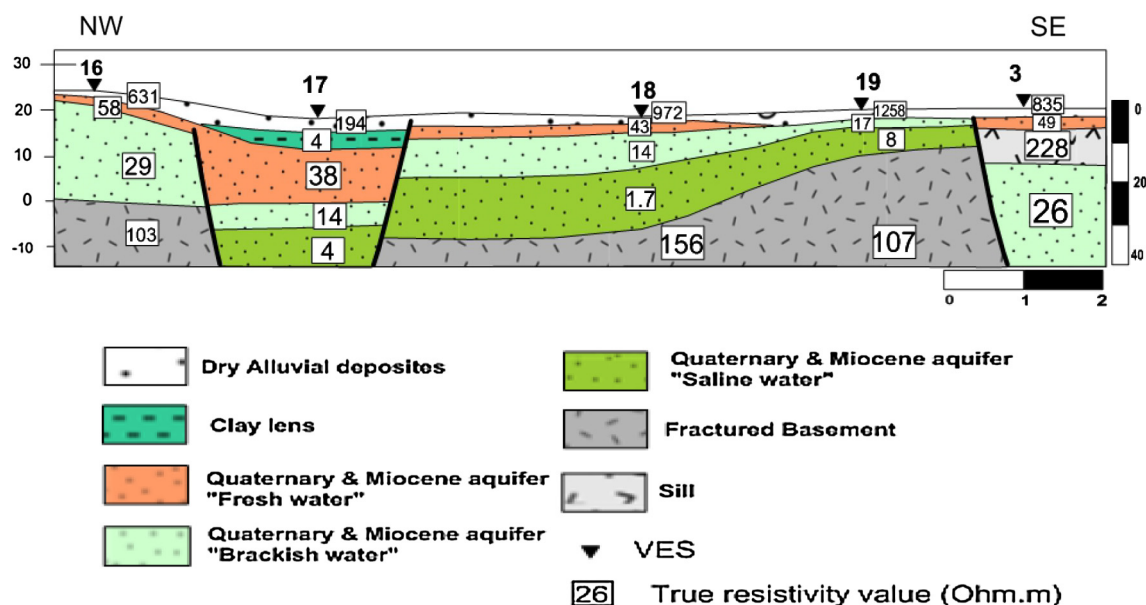


Fig. 5. Geoelectric cross-section No. 3.

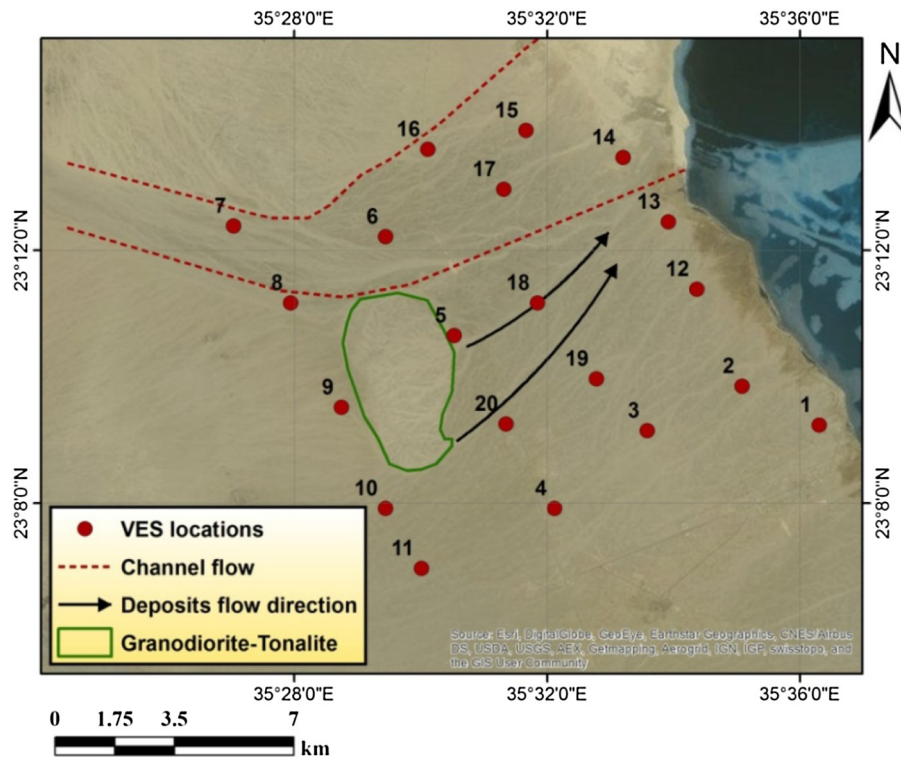


Fig. 6. Location map showing some surface features in the study area.

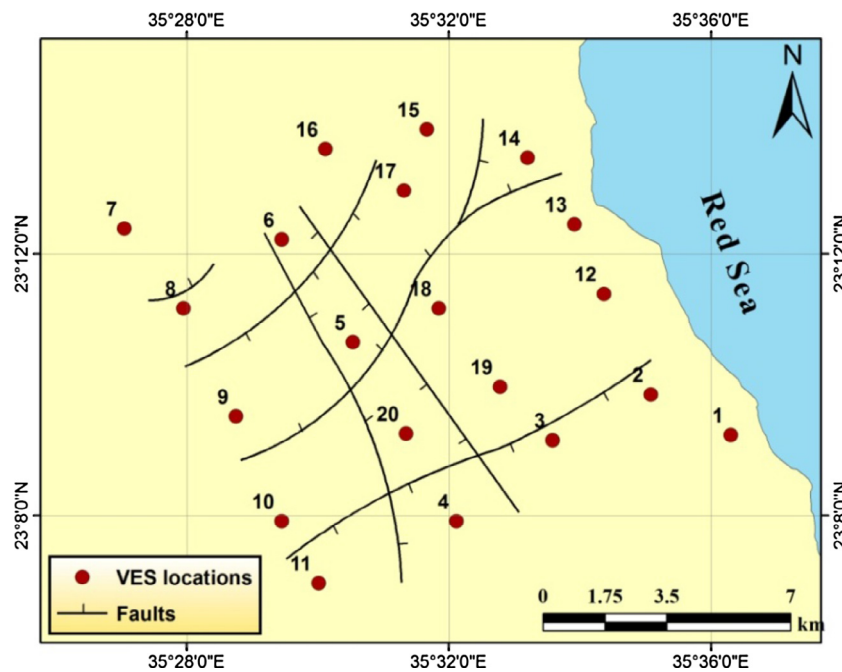


Fig. 7. Distribution of the detected structures in the study area.

in alluvial fans. The resistivity values vary from 0.2 to 8.8 $\Omega\cdot\text{m}$ and thickness ranges between 7.5 and 27.1 m. The ranges of the resistivity values of the water bearing formations are slightly similar to the ranges detected by Khalil (2014) at this area. These layers were detected by the help of the information provided from the borehole. For example in VES 6 which is near BH-1. Khalil (2014) also interpreted a VES near this borehole which was closer than VES 6. Geoelectric layers are highly

matched as he first detected the Quaternary dry alluvial sediments then the fresh to brackish water bearing formation at 20.7 m depth with resistivity 59 $\Omega\cdot\text{m}$ while in VES 6 at 14.5 m depth with resistivity 57 $\Omega\cdot\text{m}$, then the saline water bearing formation with resistivity 4.6 $\Omega\cdot\text{m}$ while at VES 6 the resistivity is 4.9 $\Omega\cdot\text{m}$.

The fifth geoelectric unit is the clay lens which is detected along the stream flow of the alluvial fan channel with resistivity values

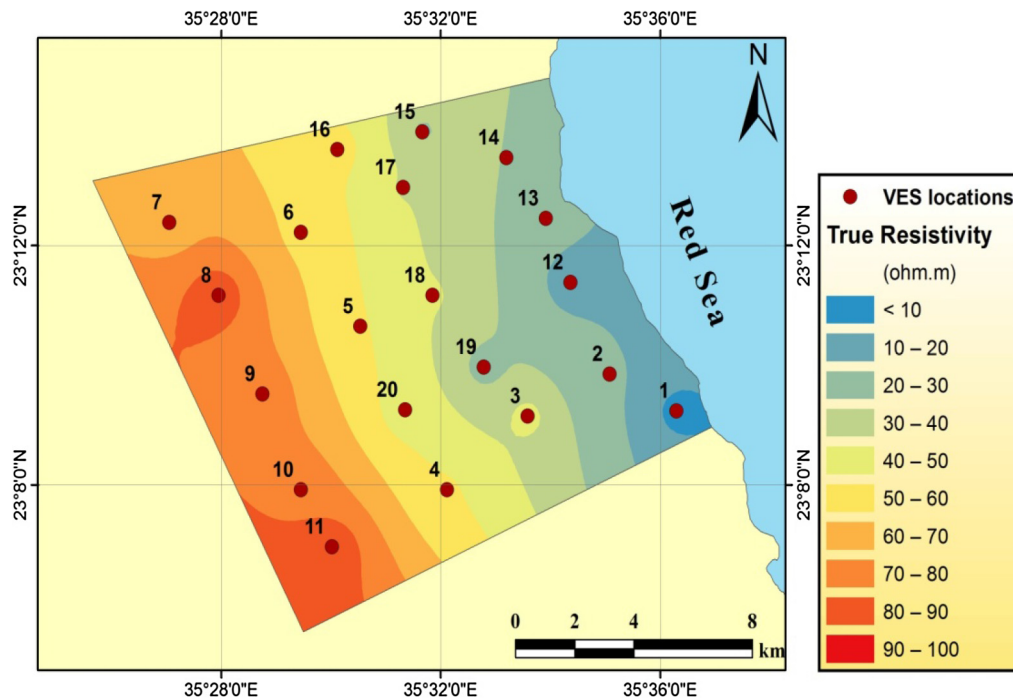


Fig. 8. True resistivity map of the aquifer.

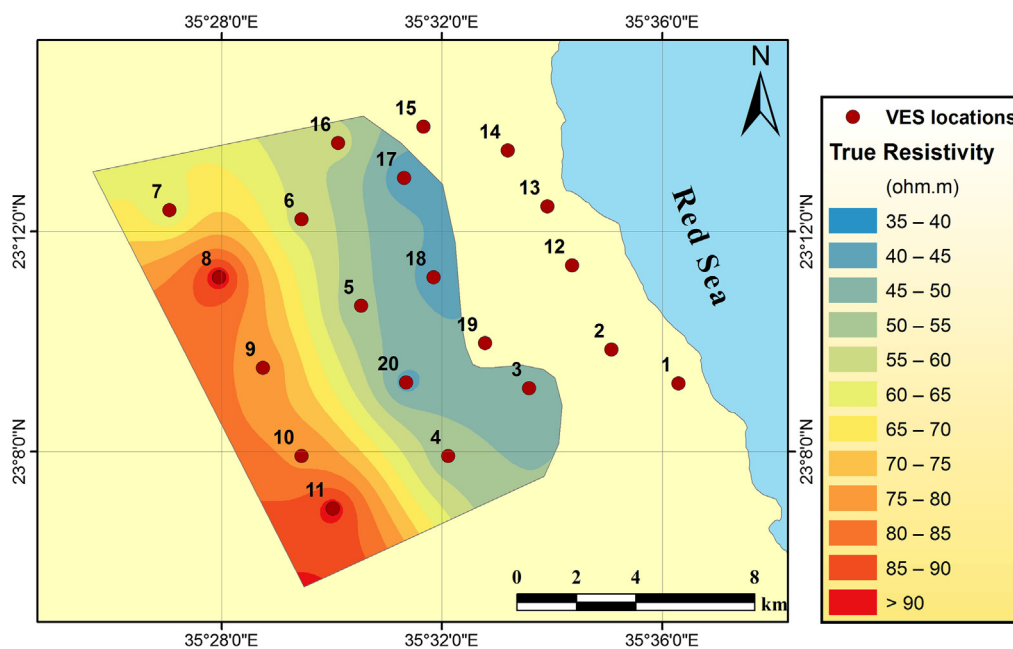


Fig. 9. True resistivity map of the fresh water aquifer.

(1.3–9.1 $\Omega\cdot\text{m}$) and thickness ranges between 2.1 and 13.7 m. The thickness of the clay in VES 14 is relatively large and this is mainly because of its position at the end of the alluvial fan channel (Figs. 4 and 6).

The sixth geoelectric unit is an igneous intrusion which is a fractured sill with resistivity values (230–315 $\Omega\cdot\text{m}$). This sill is detected in VES 5 and 3. Soussa et al. (2012) described the presence of granodiorite-tonalite intrusion near VES 5, which may explain

the presence of this sill (Figs. 2 and 6). The sill in VES 5 was detected at 16.4 m depth with 25.2 m thick while it becomes shallower (5.6 m) and thinner (8.6 m) in the south east direction towards VES 3 (Fig. 5). It intrudes the aquifer separating the fresh and the brackish water.

The seventh geoelectric unit is the fractured basement aquifer with resistivity values (69.9–371.4 $\Omega\cdot\text{m}$) and thickness ranges between 24.5 and 40.1 m.

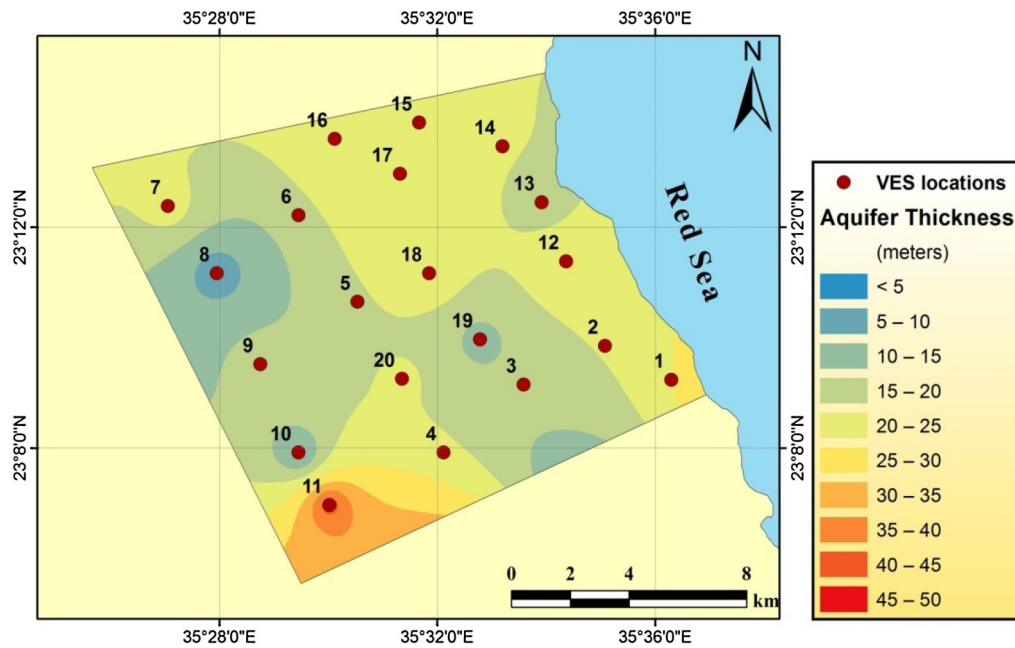


Fig. 10. Thickness map of the aquifer.

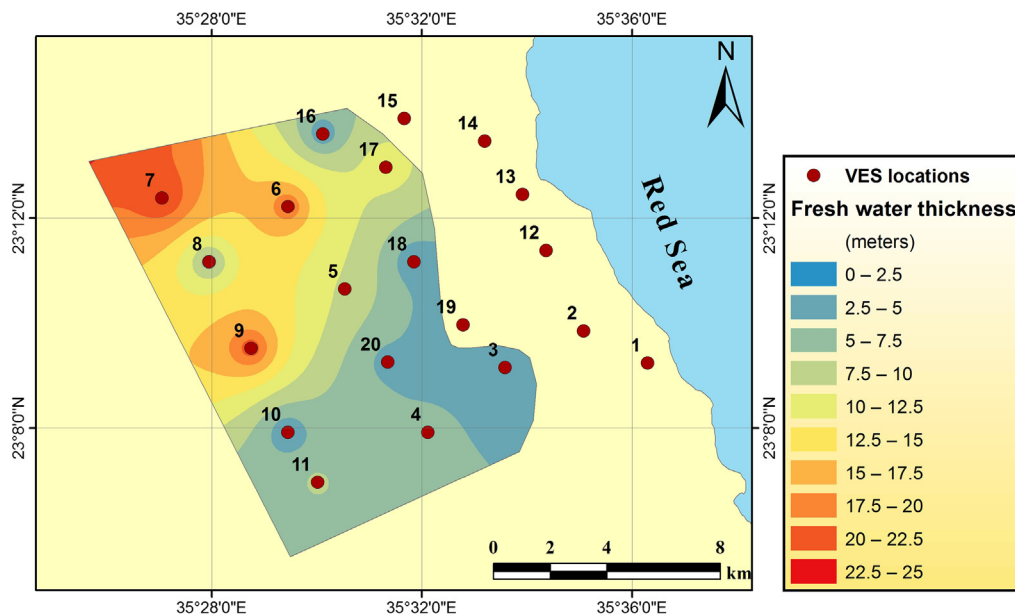


Fig. 11. Thickness map of the fresh water aquifer.

Finally, the eighth geoelectric unit is the non-fractured basement rocks which are detected in the western part with resistivity values (555.8–15,316 $\Omega \cdot m$).

The study area is affected by several tectonic movements which caused complex faults system. As shown in geoelectric cross-sections No. 1 & 2 (Figs. 3 and 4), the fresh water and non-fractured basement are found in the west direction. Horst structures are found in the western part followed by graben faults (Fig. 7). The basement in VES 8 appears at very shallow depth (10.6 m) (Fig. 4) indicating the end of the canyons of the alluvial fan. In contrast, the graben at VES's 7, 14 and 17 (Fig. 7) in addition to the large thickness of the fresh water bearing formation and the

aquifer in VESs 6, 15 and 16 indicate the subsidence of that area which mainly explains the flow of the alluvial fan channel in that direction (Fig. 6). In general, the deposits flow towards the subsidence part which is located in the north east direction (Fig. 6). This feature is obviously shown in the geoelectric cross-section No. 3 (Fig. 5) represented by the graben at VES 17. All the detected faults are shown in the structure map (Fig. 7).

5. Discussion and conclusion

The true resistivity map of the aquifer shows that the resistivity values decrease towards the east direction due to the effect of salt

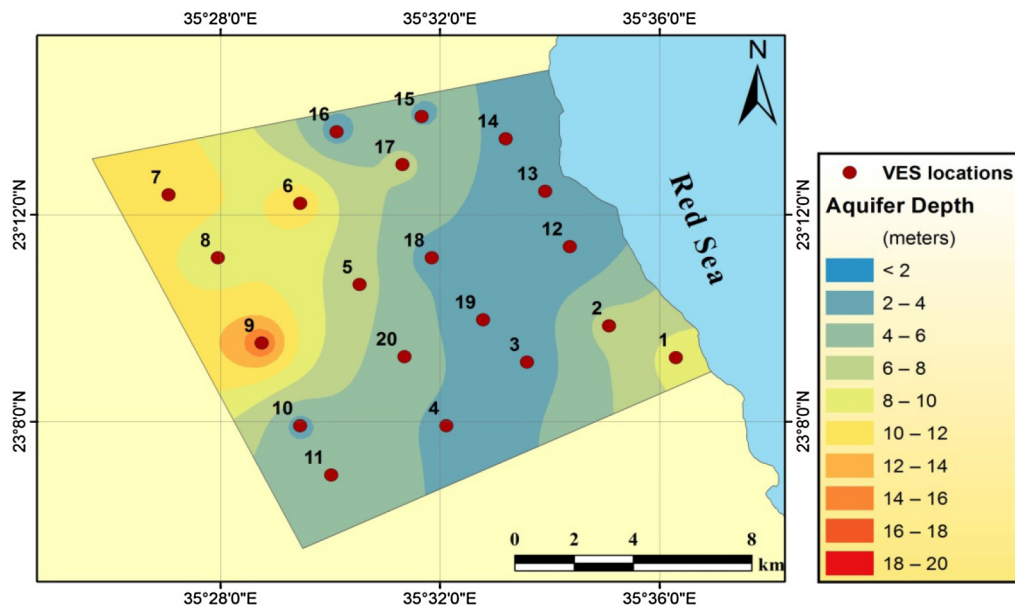


Fig. 12. Depth map of the aquifer.

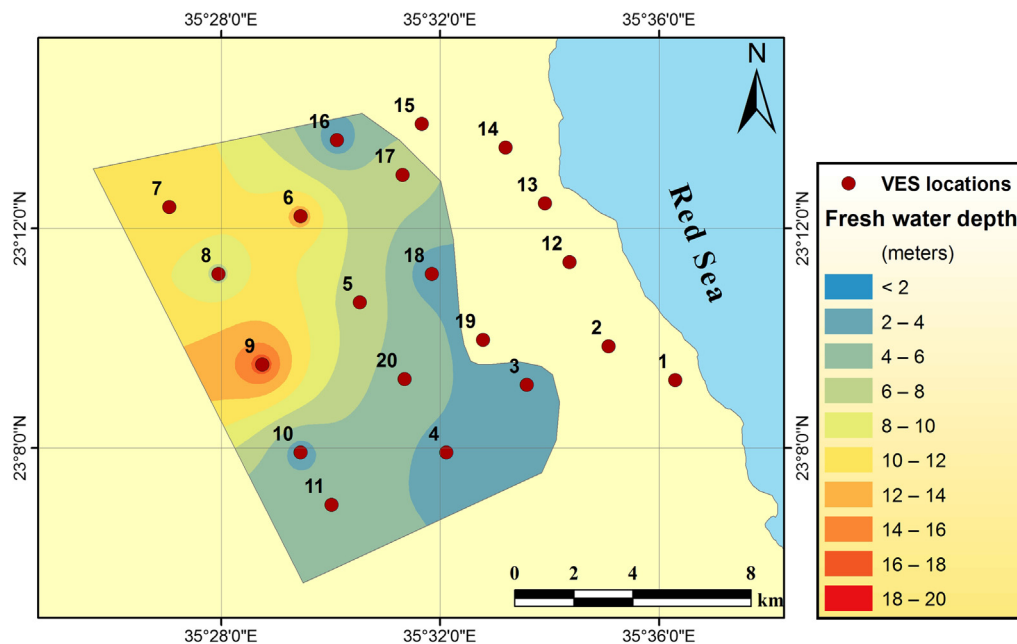


Fig. 13. Depth map of the fresh water aquifer.

water intrusion (Fig. 8). The resistivity values of the fresh water bearing formation of the Quaternary and Miocene sandstone aquifer ranges between 38.6 and 98.4 $\Omega\cdot\text{m}$ (Fig. 9).

The thickness map of the aquifer (Fig. 10) illustrates that areas with horst structure are characterized by smaller thickness units than the surrounding areas.

The thickness of the fresh bearing formation of the Quaternary and Miocene sandstone aquifer varies from 1.2 to 24.4 m (Fig. 11).

In the western part; the aquifer is found at higher depth than the eastern part as it gradually becomes shallower towards the

eastern part (Fig. 12). Then the fresh water is detected at depths ranging between 1.3 and 19 m (Fig. 13).

It is recommended to drill in the areas characterized by high resistivity values besides the high thickness of the aquifer. This makes the western part is preferable for drilling new groundwater wells except some locations that should be avoided; such as locations where horst structures are detected which reflects small aquifer thickness like in VES's 8 and 10. Drilling near VES's 3 and 5 where sill structure is detected should be also avoided (Fig. 14).

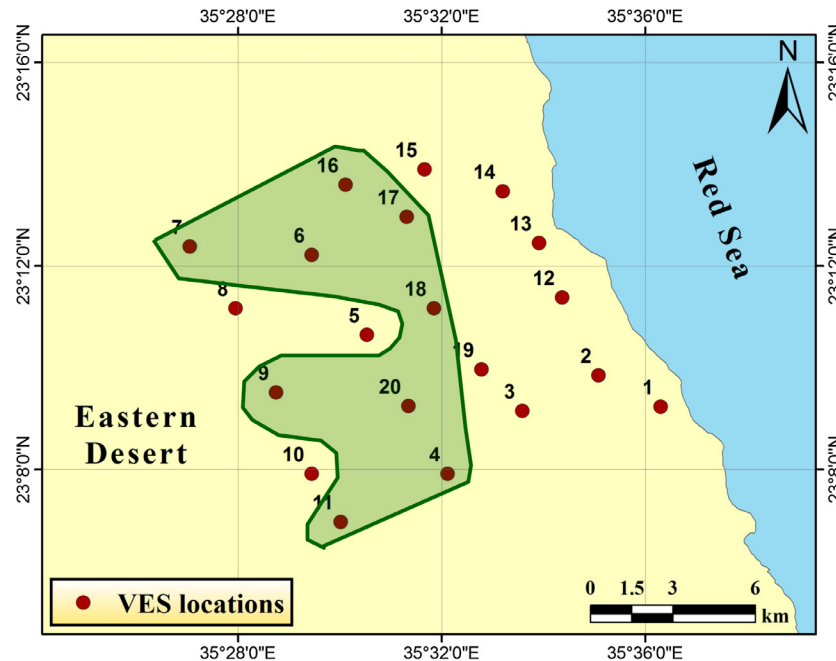


Fig. 14. Recommended locations for drilling new groundwater wells.

It is recommended to use different geophysical tools to determine the exact locations of the shallow structures such as dykes, sills and faults which are highly affecting the study area.

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