

## Sea Water Intrusion: A Case Study, Gargub Port, Egypt

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### Abstract

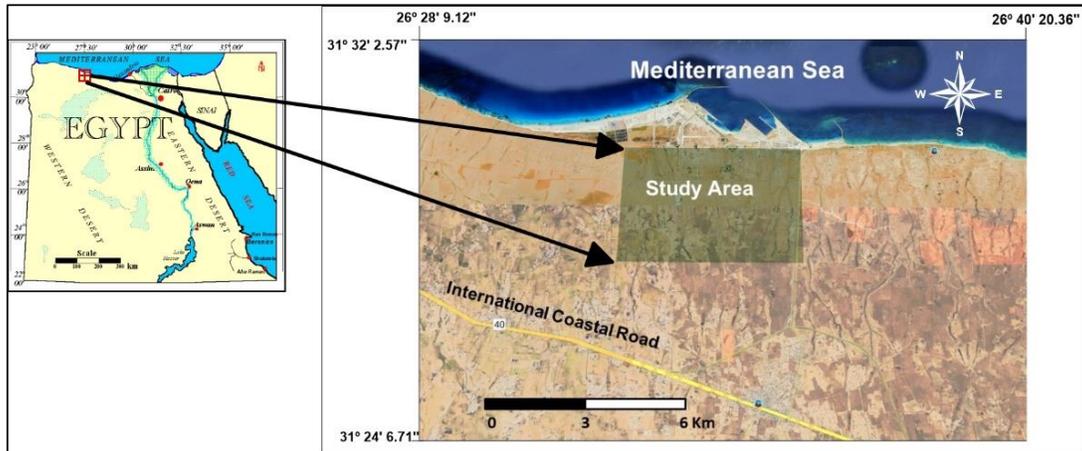
The study area is located at the western coastal zone of the Mediterranean Sea, Egypt between Wadi Abu Emera and Abu-Hesha. It has a general slope towards the sea which occupies coastal plain, piedmont plain and southern tableland. The general stratigraphic succession consists of Middle Miocene to Quaternary deposits. The groundwater aquifers consist of marine limestone and clay intercalations of Miocene age. The objective of this research is to study the effect of sea water intrusion on groundwater quality, using geo-electrical techniques including the vertical electrical resistivity soundings (VES) and the time domain electromagnetic methods (TEM). Ten Schlumberger VES with a current electrodes distance of as high as 600m and twenty TEM soundings with a single loop of 200\*200 meters were carried out during this study. Processing and interpretation of the field data concluded that the geo-electrical succession of the area consists of three layers of which the bottom layer is the water bearing formation. Also, the resistivity values decrease seriously with depth and towards the Mediterranean Sea because of the sea water intrusion. This intrusion occurs along faults and fractures of limestone formation which act as conduits to bring the sea water inland. However, the southern part of the study area is suitable for drilling shallow wells as the resistivity decreases to as low as 3000 ppm. Some precautions should be considered to maintain the safe yield of these wells.

**Keywords:** Mediterranean Sea, Egypt, VES, TEM, Fractured Limestone, Groundwater Aquifers

### 1. Introduction

The study area occupies a portion of the Mediterranean coastal zone, Egypt and covers an area of about 24 Km<sup>2</sup> (Fig.1). It is very suitable for reclamation and tourism projects if water resources are available. The primary supply of water for agricultural activities in this area is the rainwater, but this source is not enough. Accordingly, groundwater could emerge as the most practical complementary resource to supply the area with the necessary amount of water, but the intrusion of the sea water is the common pollutant in the area. This phenomenon usually occurs in the coastal aquifers and can lead to a severe deterioration of the quality of fresh groundwater

resources. Accordingly, a fresh-saline water interface in the coastal regions needs an intensive geophysical study and monitoring for the assessment of the hydrological and hydro-chemical parameters which are relevant to sea water intrusion. For this, geo-electrical exploration techniques are of great help to study the groundwater conditions, including sea water intrusion and to locate suitable sites for drilling water wells. Additionally, the study area suffers from environmental issues due to progressive loss of freshwater and increases in water salinity. Several attempts were suggested to save water such as rainwater harvesting but the quantity was insufficient [1].



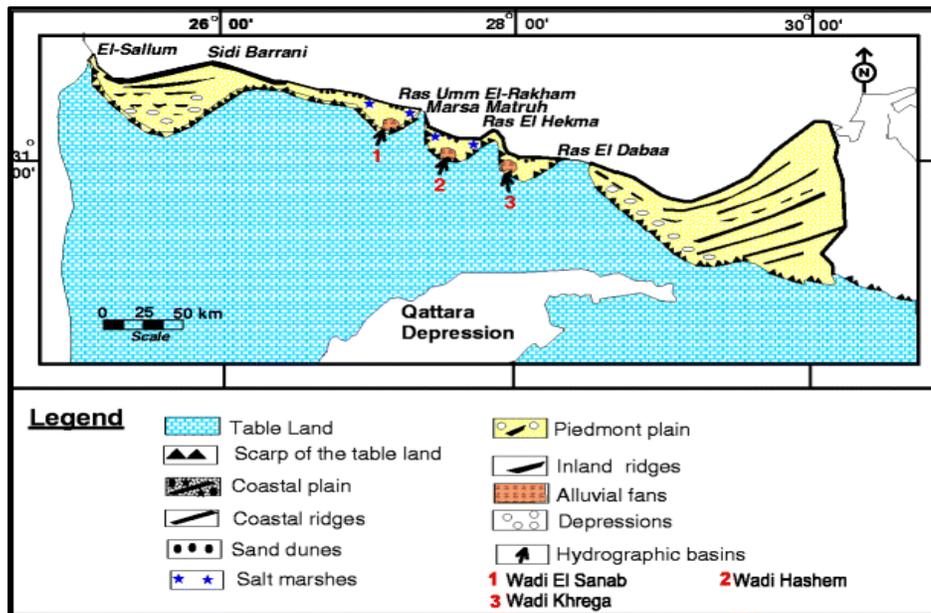
**Figure 1:** Location Map of the Study Area (Gargub Port)

Twenty TEM soundings, in the form of a grid with a single loop of 200\*200 meters, and ten Schlumberger VES, with a distance between the current electrodes of as much as 600m, were measured in the area. The objectives of these field measurements are to get more information about the suitable subsurface conditions for drilling water wells and try to understand the sea water intrusion and its effect on the quality of the groundwater.

## 2. Geomorphological, Geological and hydrogeological settings

The study area is close to the coastal plain (Fig. 2), where different geomorphological and geological studies were carried out (Shata 1953, 1955 & 1971; Said 1962; Abdallah 1966a; & 1966b; Sayed 1967; Selim 1969; Taha 1973; Moussa 1976; Raslan 1995; Yousif

and Bubenzer 2013a & 2013b). These studies concluded that the region is characterized by a sub-arid climate where the average monthly temperature ranged from 14.4 to 26.8oC and the average yearly rainfall ranged from 100 to 190 mm (DRC internal report, 2010). Various geomorphological units were reported in the area (i.e. the coastal plain, the piedmont plain, and the tableland, Fig. 2). The width of the coastal plain ranges from few meters to several kilometers and its altitude ranges from sea level to almost 100 meters. The piedmont plain consists of thick, fine calcareous soil with depressions, alluvial fans, and inland ridges. Whereas the tableland consists of fractured limestone which can recharge the groundwater aquifers with rainwater.



**Figure 2:** Geomorphologic Units of the Northwestern Coastal Zone [9].

Generally, the stratigraphic sequences of the northwestern coastal zone (Figure 3) are mainly covered by sedimentary strata that range in age from Middle Miocene to Quaternary [7,10]. The middle Miocene deposits are represented by marine limestone with clay intercalations. Folds and faults are common structures in

the northwest coastal zone. In certain locations, fractures affect all the wadies which have different directions such as NE–SW, E–W, and N–E. Pleistocene, Middle Miocene, and Holocene aquifers exist in the study area [11].

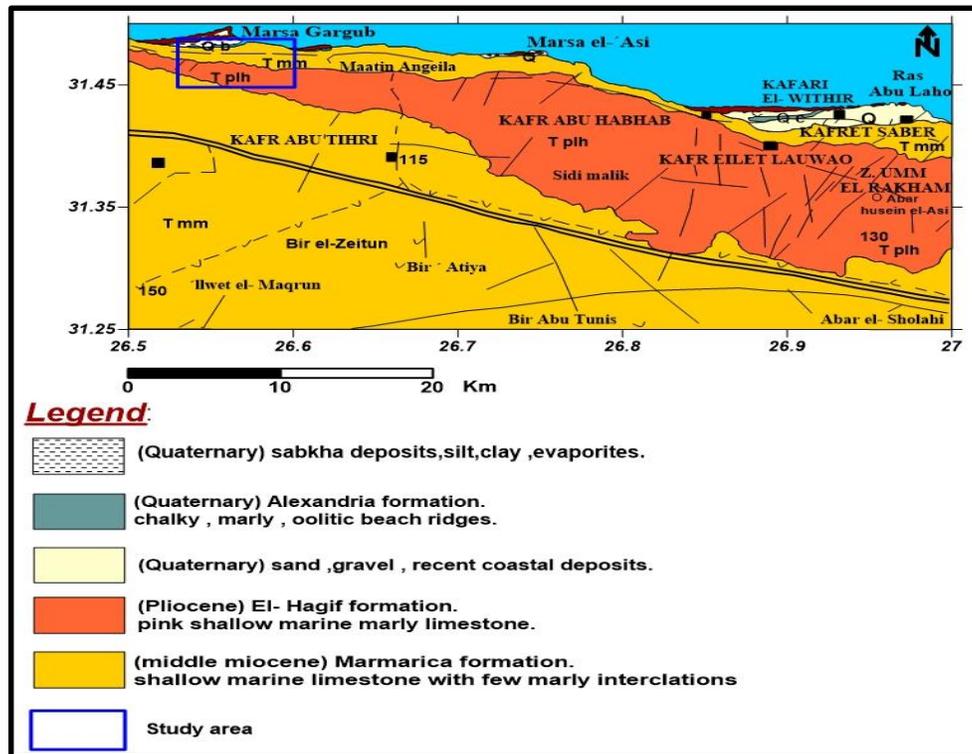


Figure 3: Geologic Map of the Study Area and Surroundings [13].

### 3. Materials and Methods

#### 3.1. Transient Electromagnetic Method (TEM)

This method is a quick and economical way to get depths, ranging from a few meters to hundreds of meters. It may be used in a variety of configurations and does not require direct electrical contact with the ground. It is an inductive method which works by passing a high current through a squared loop placed on the ground. This current produces a time varying primary magnetic field which penetrates the ground and causes eddy currents. These currents produce a secondary magnetic field. When the current is abruptly stopped, there will be an electromagnetic induction according to Faraday’s law. The intensity of the eddy currents depends on the resistivity of the ground at a given depth and time [14]. In this study, the field TEM measurements were acquired by setting the time range of transient characteristics to 7 or 9. The induced current was set to 4A and the frequency of the filter was set to 50

Hz to improve the quality of the collected measurements. Twenty TEM soundings were acquired in the study area (Figure 4) using TEM-FAST 48HPC instrument with a loop size of 200\*200 m. The acquired TEM data, in the form of apparent resistivity versus time, were processed and inversed using ZONDTEM1D software.

#### 3.2. Vertical Electrical Sounding (VES)

Ten Soundings were measured in this study, along profiles perpendicular to the sea coast (Figure 4). Some of these soundings were measured close to water wells in order to estimate the resistivity spectrum of the area and to facilitate the interpretation of the other soundings. Also, some other soundings were measured near TEM soundings for the sake of correlation and confirmation of the results. Schlumberger array was used where the current electrodes distance reaches up to 600 m. The device which was used to collect the field data is SYSCALJONIUR resistivity meter.

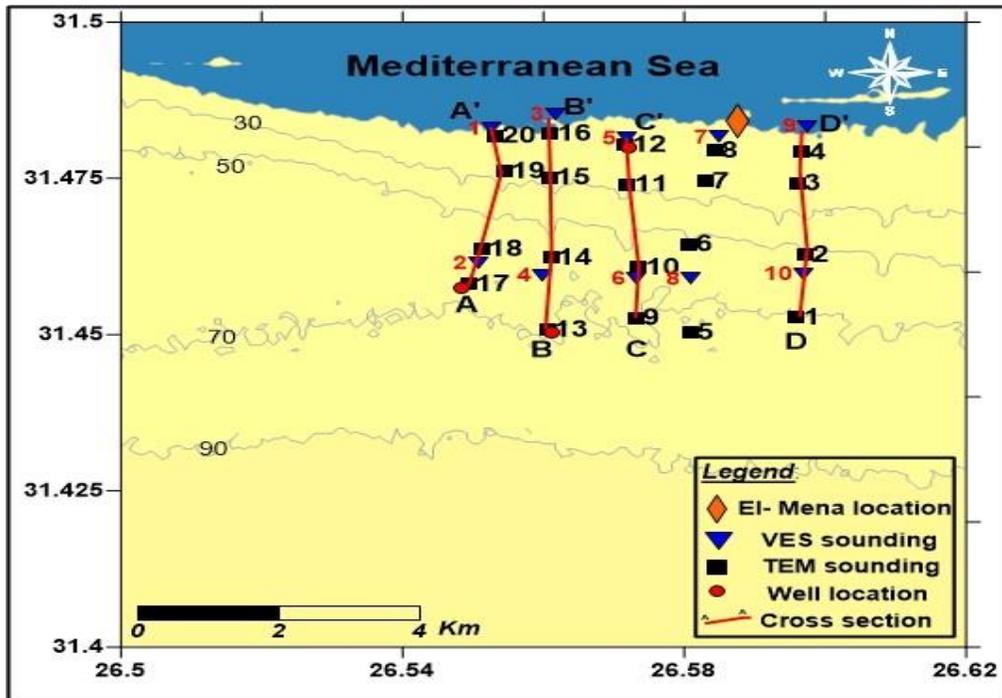


Figure 4: Location Map of TEM and VES Soundings, Water wells and Cross-Sections

#### 4. Results

The field data of the Transient Electromagnetic (TEM) soundings were filtered, smoothed and converted to apparent resistivity versus time ( $\rho$  and  $t$ ) prior to inversion process. Also, the VES curves represent the variation of resistivity with depth. Figure 5 shows TEM and VES curves close to water well as an example,

showing the variation of resistivity with depth. There is a great similarity between the two curves. They both indicate a decrease in the value of electrical resistivity with depth which may confirm the idea of sea water intrusion. Table (1) contains the obtained VES and TEM results in the study area.

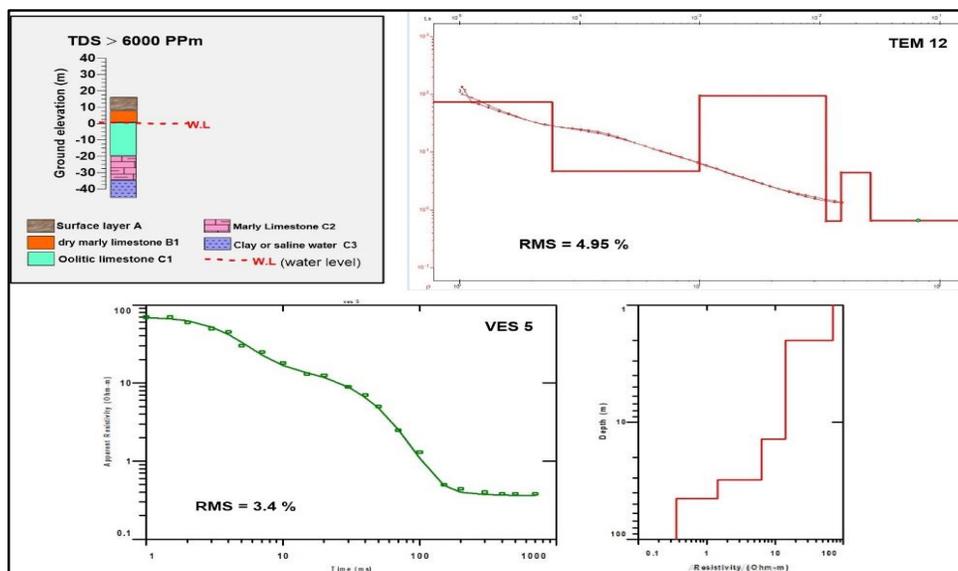


Figure 5: Example of VES and TEM Soundings Close to Water Well in the Study Area

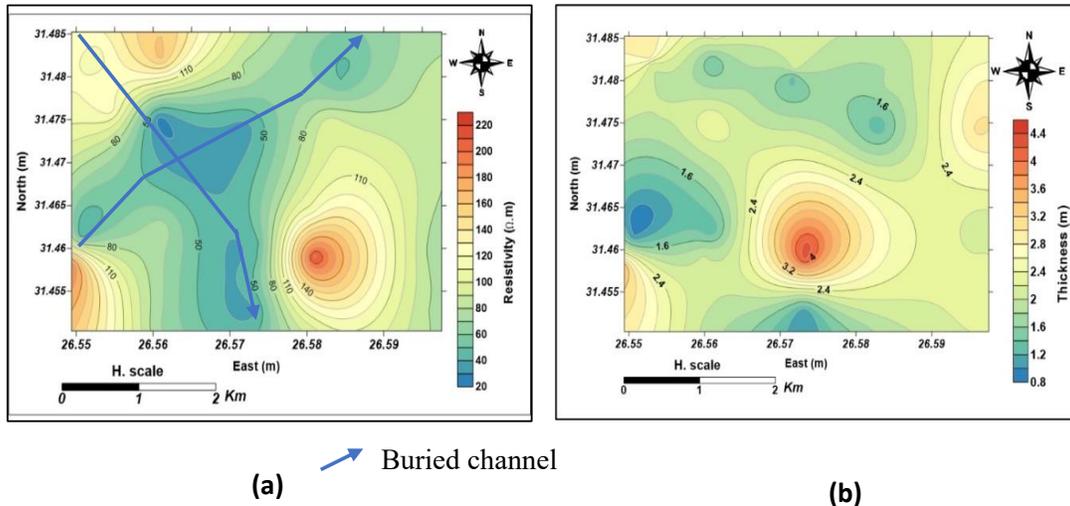
Section	Goelectrical layers, resistivity and thickness					
	Surface layer (A)	Layer "B"		Layer "C"		
		Zone "B1"	Zone "B2"	Zone "C1"	Zone "C2"	Zone "C3"
A-A'	43.8-195 $\Omega$ .m 1-3 m	6.5 -121.5 $\Omega$ .m 2-9 m	9.9-95.13 $\Omega$ .m 15-61 m	7.25-16.23 $\Omega$ .m 3-5 m	1.81-5.25 $\Omega$ .m 21 m	0.29-2.48 $\Omega$ .m -----
B-B'	25.3-162.2 $\Omega$ .m 1-2 m	2.1-25.9 $\Omega$ .m 4 -5 m	12.1 -46.27 $\Omega$ .m 3 - 63 m	9-16.14 $\Omega$ .m 13-40 m	1.47-3.34 $\Omega$ .m 22 m	0.6-0.73 $\Omega$ .m -----
C-C'	34.1-81.5 $\Omega$ .m 2-4 m	4.7-41 $\Omega$ .m 2 - 7 m	10.9 - 355 $\Omega$ .m 5-60 m	6.27-13.7 $\Omega$ .m 17-43 m	1.43-4.28 $\Omega$ .m 11 m	0.36-4.2 $\Omega$ .m -----
D-D'	75-84.5 $\Omega$ .m 2-3 m	13.2-26.6 $\Omega$ .m 7 -16 m	24.01 -72.2 $\Omega$ .m 38 - 57 m	6.2-10.8 $\Omega$ .m 16-30 m	1-3.6 $\Omega$ .m 29 m	0.6-0.68 $\Omega$ .m -----

**Table 1: Goelectrical Data of the Study Area**

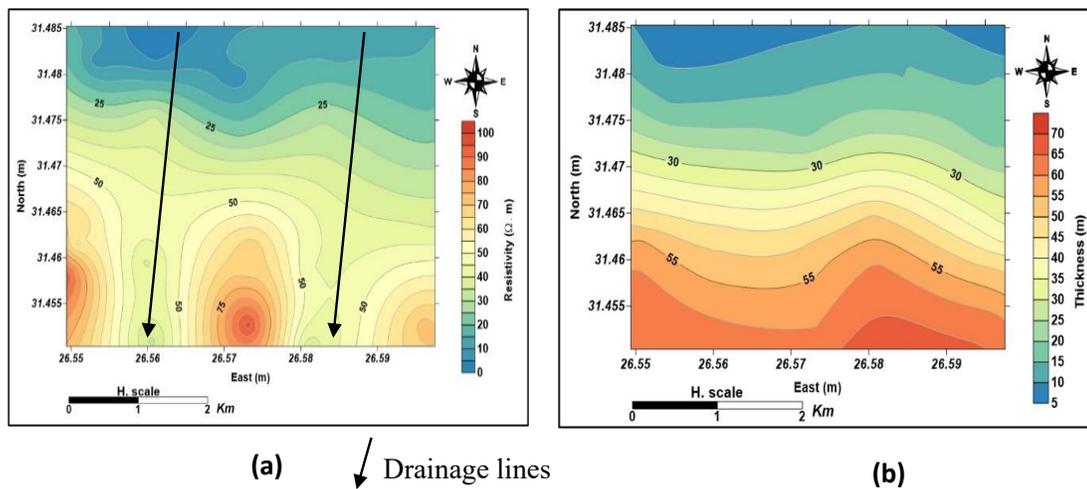
## 5. Discussion

Interpretation of the TEM and VES data includes comparison of the relative changes in the apparent resistivity and thickness of the different layers. It gives information about the number of the geoelectrical layers, their continuity throughout the area or in a certain direction and their degree of homogeneity or heterogeneity. It also gives information about the areal distribution and the lateral and vertical variations of resistivity values all over the study area, the thicknesses of the subsurface geo-electrical layers and their apparent resistivities. Interpretation of both TEM and VES soundings of the study area was carried out by using several softwares such as ATO software (Zohdy 1989), RESIST software [16-19]. The VES curves of the study area are of QQQ and HKQ types (Figure 5, as an example). Generally, the resistivity of the first and second cycles of the VES curves reflects the heterogeneity of the surface and the near surface sediments which are composed of dry gravel and sand. Whereas the third cycle reflects homogeneity of the bottom layer which consists of fractured limestone of different types. However, all the VES curves are terminated by Q-type, indicating that the resistivity values decrease seriously with depth which can be interpreted as sea water intrusion. The quantitative Interpretation of the VES curves, in the light of the available water wells data, indicates subsurface geo-electrical section consisting

of three layers. The near surface two layers (i.e. layers A & B) are composed of dry alluvial sediments whereas the bottom layer (i.e. layer C) is the water bearing formation of Miocene deposits (i.e. different types of limestone). A detailed description of these layers indicates that layer (A) is composed of dry sand, gravel and clay of recent age. This layer has resistivity values range from 25 to 195 Ohm.m and a thickness varies from 1 to 4 m (Figure 6 and Table 1). This variation in resistivity is mainly due to lithological changes. This map also shows low resistivity zones run both in the NE-SW and NW-SE directions. These zones may represent buried drainage lines of shallow depths which should be considered during the drilling program of shallow water wells. Layer (B) has resistivity values reach up to 100  $\Omega$ .m and its thickness records as high as 63 m (Figure 7). In general, the resistivity and thickness values of this layer decrease towards the Mediterranean Sea and vice versa. This map also shows low resistivity zones run nearly in the NE-SW directions. These zones may represent buried drainage lines passing through faults and managing the sea water intrusion. The locations of these faults should be avoided during the drilling of water wells unless these wells are drilled for desalinization process. In this case, these faults act as conduits of sea water to the desalinization wells.



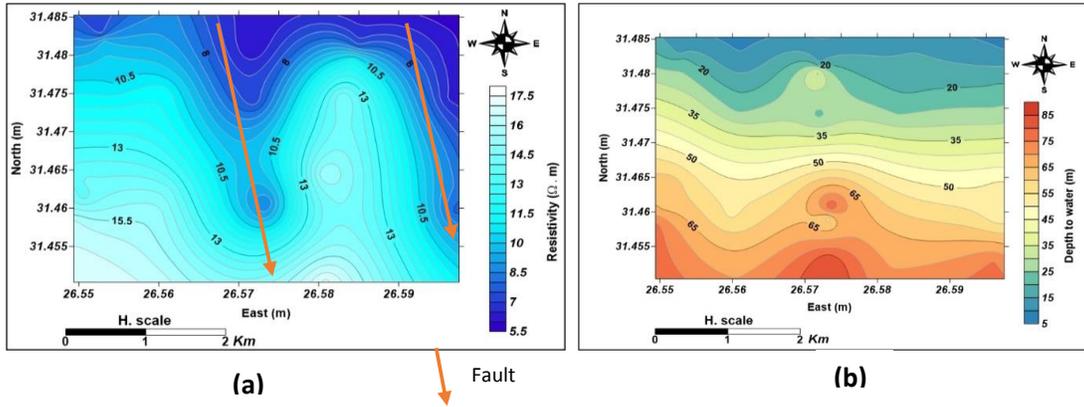
**Figure 6:** Iso-Resistivity Map (a) and Thickness Map (b) of the Surface Layer (A)



**Figure 7:** Iso-Resistivity Map (a) and Thickness Map (b) of the Layer (B)

Layer (C) represents the water bearing formation in the study area. Its resistivity decreases seriously towards the Mediterranean Sea with some parallel very low resistivity zones extend inland in the NW-SE direction (Figure 8). It is believed that these zones represent fault zones which may act as conduits for sea water intrusion. These zones should be avoided while drilling water

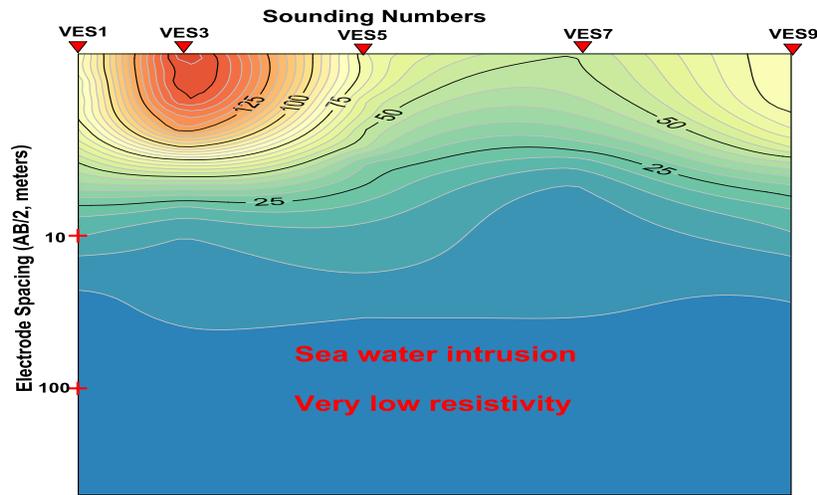
wells unless these wells are drilled for de-salinization operation. In this case, the fault zones are considered the best sites for drilling wells because they will facilitate the passage of sea water towards these wells. In general, the resistivity values of layer (C) starts from as low as 4  $\Omega\text{m}$  and reaches up to 20  $\Omega\text{m}$  and its thickness reaches up to 70 m (Figure 8).



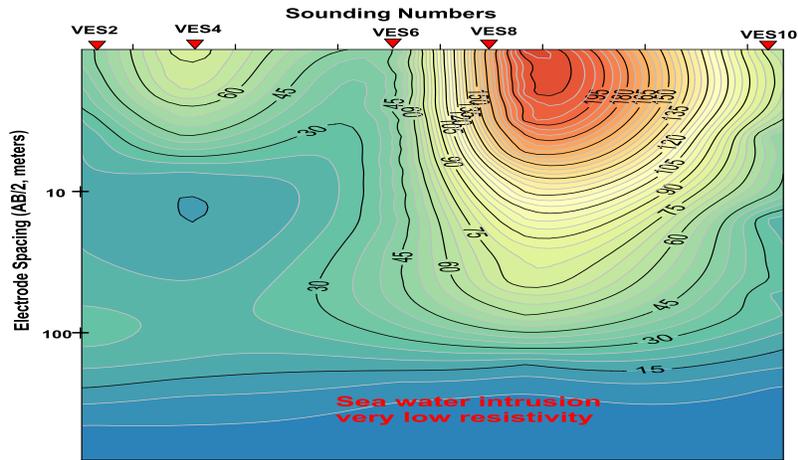
**Figure 8:** Iso-Resistivity Map (a) and Depth Map (b) of Layer (c)

Sometimes, preparation of apparent resistivity sections (pseudo-sections) can contribute valuable information about the sea water intrusion. These sections are constructed by plotting the apparent resistivity values along vertical lines, beneath the sounding locations and these values are then contoured. Two pseudo-sections are constructed in the study area, one parallel and close to the sea coast (Figure 9) and the other at a distance of about 2.5 km

(Figure 10). Figure (9) shows that the sea water intrusion occurs at shallow depth where the resistivity values are extremely low. On the other hand, the pseudo-section in Figure (10) shows that the sea water intrusion occurs at relatively deep depth, in comparison to the section which is close to the sea coast. However, the results of the two sections should be considered while drilling wells to avoid the negative impact of the salt water.

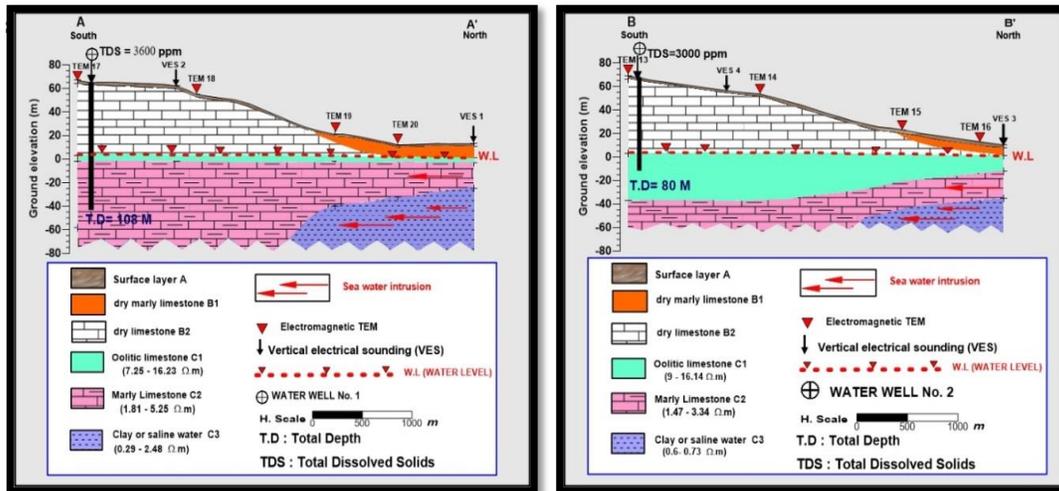


**Figure 9:** Pseudo-Section Close to the Sea Coast Passing through VES Numbers 1,3,5,7,9.



**Figure 10:** Pseudo-Section at the South of the Study area between VES Numbers 2,4,6,8,10.

Moreover, the VES and TEM results were used to construct four 2-D geo-electrical sections in the study area (i.e. A – A/, B - B/, C – C/ and D – D/, Figure 4 for locations), in the light of the subsurface geological information. These sections run from north to south to show the sea water intrusion. It can be concluded that the sea water intrusion appears on the four sections as the resistivity values are seriously decreasing with depth (Figures. 11 & 12). The water salinity of well no.3 confirms this conclusion where its T.D.S value reaches as high as 6000 ppm. This value decreases southwards to record about 3000 ppm at wells numbers 1 & 2 (Figure 11). Accordingly, precautions should be taken during drilling water wells close to the sea coast.



**Figure 11:** Geo-electrical Sections AA' and BB'

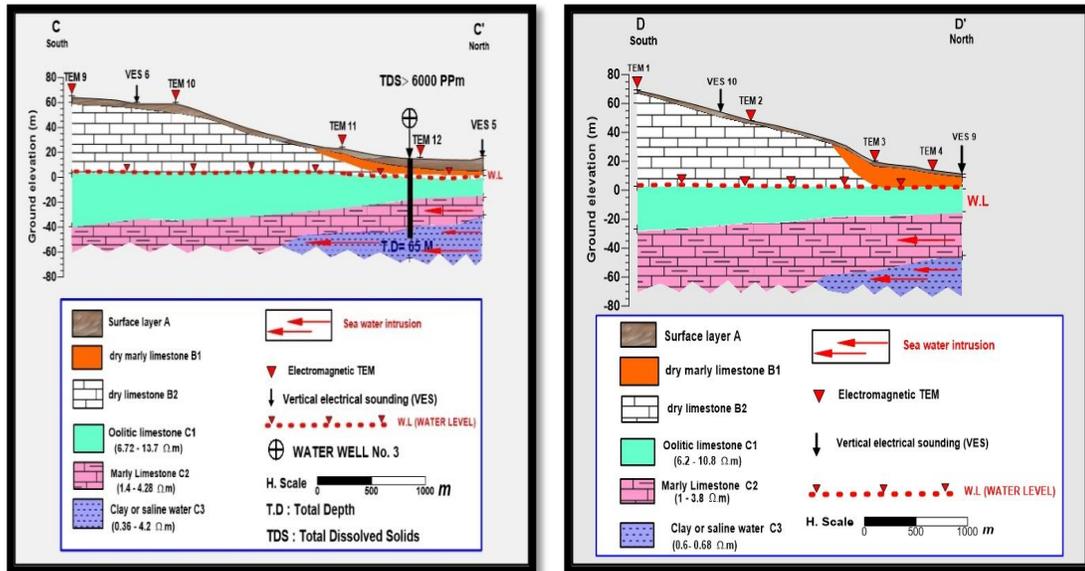


Figure 12: Geo-electrical Sections CC' and DD'

## 6. Conclusion

Geophysical studies have been conducted in the study area, which is located close to the western coast of the Mediterranean Sea, Egypt. The main target of these studies is to evaluate the groundwater aquifers and the possibility of sea water intrusion. Ten Vertical Electrical Soundings (VES), by Schlumberger array with a current electrodes distance of as much as 600m and Twenty Transient Electromagnetic Soundings (TEM) with a single loop of 200\*200m, have been measured in the area. Processing and interpretation of the field data concluded that the subsurface section of the area consists of three geo-electrical layers. The upper two layers are composed of dry gravel, sand and clay deposits. Whereas the bottom layer is the water bearing and consists of fractured limestone. This layer has a suitable saturated thickness reaching up to 25meters and its resistivity decreases with depth. Accordingly, precautions should be considered when drilling wells to consume the water of this layer to avoid the negative impact of the deep salt water. The salinity of water of this layer increases towards the Mediterranean Sea which may confirm the effect of sea water intrusion. This intrusion occurs along a system of faults which facilitates the movement of sea water inland. It is recommended to avoid these faults while drilling wells unless they are drilled for the purpose of the desalinization process. In this case, the faults act as conduits for sea water to the de-salinization wells. However, the southern part of the area is suitable for drilling wells as the water salinity decreases to as low as 3000 ppm.

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