# Delineation of groundwater aquifer and salt front in coastal areas (case study Delta Wadi El-Arish, Sinai, Egypt)

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Abstract: The Sinai area attracted the government to set a national plan for its sustainable development. Since the major problem facing the construction of new communities in Sinai generally, and in El Arish, is the source of water. This work represents a part of extensive field program for groundwater evaluation that was planned and executed by WRRI since 1982. The objective of this work is to develop the area to become attractive for population and reclamation.

This study includes geological and hydrogeological studies besides forty eight vertical electrical sounding (using the Schlumberger arrangement) that were measured in the north part of El Arish, in order to investigate the Quaternary groundwater aquifer systems. A special care was directed towards groundwater investigations, to be used later for domestic and irrigation purposes. The present work is selected to show the drawbacks of the effect of saltwater intrusion on the groundwater potentiality.

These VESes have been interpreted both qualitatively and quantitatively using geoelectrical cross-sections. Correlation of the deduced geoelectric and hydrogeological parameters with the available geological information helped in establishing the specific resistivities of the formations. The results revealed that there are three main geoelectrical units. The second and third geoelectric layers represent is water bearing formations, but they are not connected under all VES. The third geoelectrical unit is affected by salt-water intrusion.

**Key words:** resistivity, hydrogeological, VES, salt-water intrusion

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## 1. Introduction

The area of study is one of the promising areas in the Sinai Peninsula regarding its possible integrated development, based mainly on local groundwater resources. The main objective of the present work is to recognize the hydrogeologic characteristics of the Quaternary aquifer, which is the main groundwater resource in the area. The area of study is located between Lat: 31° 00′ 00″, 31° 11′ 00″ E, and Long: 33° 45′ 00″, 33° 56′ 30″ N as shown in Fig. 1, between Lehfen in the south, El Karrouba in the east, El-Masaeid in the west, and the Mediterranean Sea in the north.

This area possesses good quality land that could be reclaimed and cul-

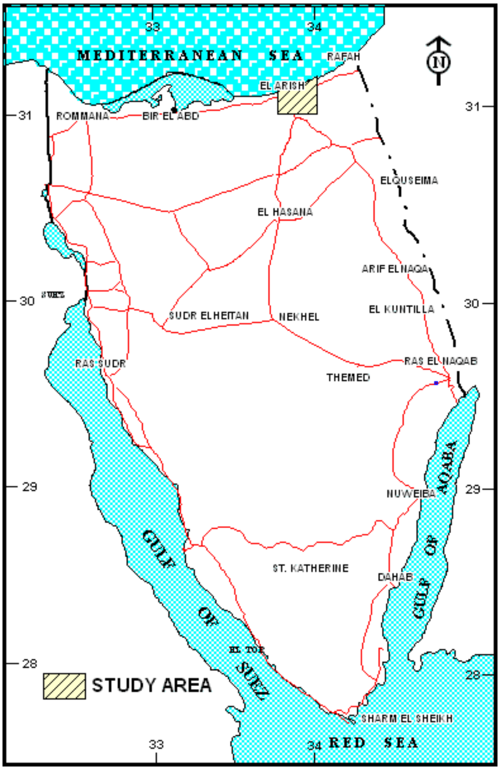


Fig. 1. Location map of the study area.

tivated. The main problem of this area is that it is polluted by salt water intrusion. The question is to what extent does this phenomenon spread. The resistivity methods have proven to be the most successful of the electrical methods for obtaining information about the substrata of the earth. According to *Ball (1939)* and *Shata (1992)* the study area is classified as a coastal plain that is characterized by a thick succession of Quaternary sediments, varying between beach deposits to the north, deltaic deposits in the west and dune sand deposits to the south and east. Interference between these sedimental environments is possible.

As the geoelectrical method was found to be useful to detect the fresh water/saline water in coastal aquifers (*Patra and Mallick, 1980; Bhattacharya and Patra, 1968*), forty eight vertical electrical soundings (VESes) were observed in the field. The Schlumberger four symmetrical electrode configurations were used. The quantitative interpretation of the field geoelectrical measurements are discussed by several authors; among them *Koefoed (1965)* and *(1979)*, *Kunetz and Rocroi (1970)*, *Gosh (1971)*. The interpretation of each measured field curve by using the software prepared by *Zohdy (1989)* and *Van Der Velpen (1988)* and IPI2WIN software (2001) were used. Four boreholes were drilled and one of them was completed as an excavation well to be used further for monitoring purposes.

## 2. Geomorphology

Geomorphologically the area is flat in general with a little slope from south to north. Delta Wadi El-Arish is the main geomorphologic feature, where the wadi width attains one kilometer in the outlet to more than three kilometers in the middle part due to sand dunes accumulations from east and west directions with elevation ranges from 40-50 m, and it increases gradually towards the west till El-Arish city. The main stream of the wadi is covered by vegetation cover. The northern coastal belt area can be classified into the following units:

1. Coastal and continental sand dunes.
2. Flood plains.
3. Raised beaches.
4. Modern beaches.

## 3. Geology

Many authors studied the Sinai in detail *(Said, 1980; 1990; Jenkins, 1980; Issawi and Hux, 1982).* As shown in Figs. 2, 3 the geology of the area can be classified into the following lithostratigraphic units from younger to older as follows.

### 3.1. Holocene deposits

These deposits include:

- Sand dunes accumulations: which cover the most area of study in the form of beach sand dunes with ripple marks shape, sand sheets and scattered lenses intercalated within the wadi deposits.
- Beach deposits: it extends along the coastal shore line from El-Arish to Rafah to beyond Gaza in the form of friable sands to consolidated sandstone as a result of interferences of calcareous material as calcium carbonate.
- Recent wadi deposits: known as wadi fill the main stream of wadi El-Arish and its tributaries, are composed of sand, clay and silt with thickness varying from 4 to 28 m.

### 3.2. Pleistocene deposits

These deposits cover the most area of eastern coast of Sinai Peninsula, and it can be classified as:

- Wadi deposits of delta wadi El-Arish, which cover the most area of the main stream of wadi El-Arish with thickness ranging from 47 to 144 m and are composed mainly of sand, silt, clay and gravel.
- Calcareous sandstone: It occurs in the form of continuous or discontinues layers underneath the wadi deposits or intercalated with it in El-Arish area and underneath, or intercalated with old beach deposits in the area from west El-Sheikh Zuwyed to Rafah and composed of two layers, the upper one is continental, while the other is marine sediments with different thickness.

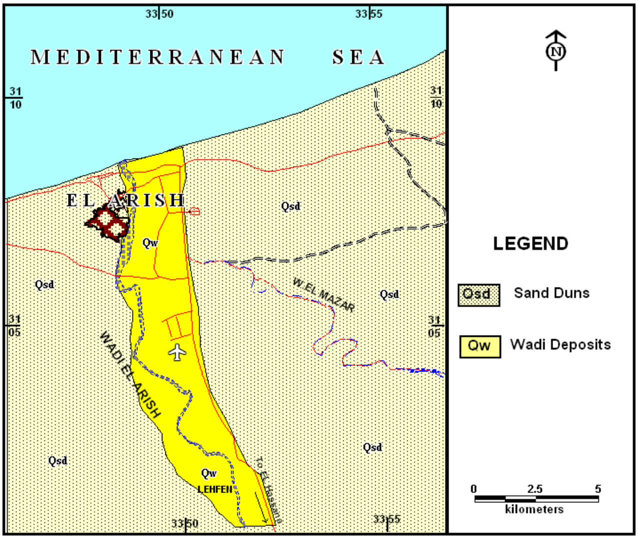


Fig. 2. Simplified geological map of the study area *(UNSECO Cairo Office, 2005).*

### 3.3. Miocene deposits

These deposits are not outcropping on the surface of the area of study, but they occurs underneath the Quaternary sediments in the form of clay to the south of El-Arish airport.

### 3.4. Eocene deposits

The Eocene deposits were found in the form of sandy clay, marl and marly limestone to the north of Lehfen, and in the form of clay and gypsum near the coastal belt of El-Arish.

## 4. Hydrogeology

In the area of study one hydrogeological cross-section is constructed in the north and south direction to show the geometry of the Quaternary aquifer, as shown in Fig. 4. The area of study is located in Delta wadi

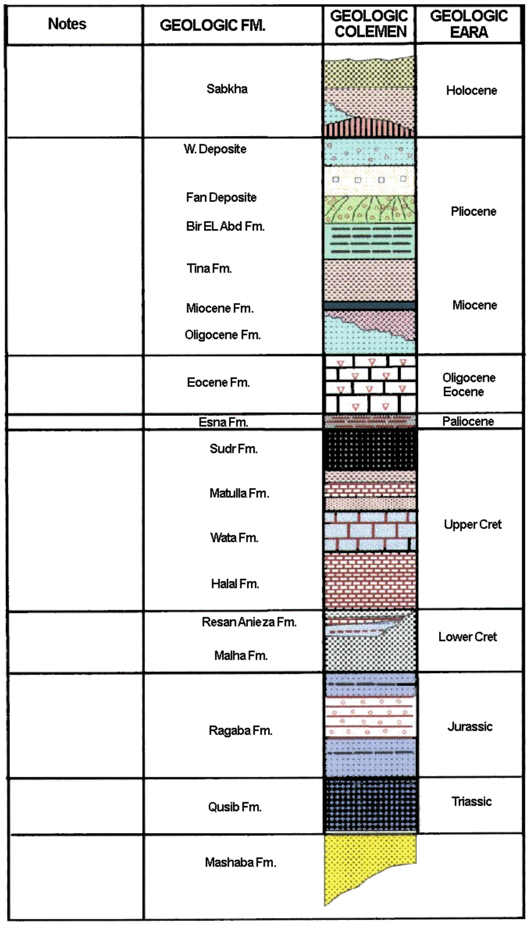


Fig. 3. Stratigraphy of North Sinai.

El-Arish and covered by sand dunes with irregular thickness. The sand dunes are forming an aquifer system of good quality. This aquifer system is underlain by alluvial layer that consists mainly of sand and gravel, as shown in Fig. 3. Most of El-Arish wells were installed through the alluvium aquifer system. The deepest aquifer system is the Kurkar which consists mainly of calcareous sandstone with shell fragments. This aquifer system contains water of low quality compared to the two overlying aquifer systems.

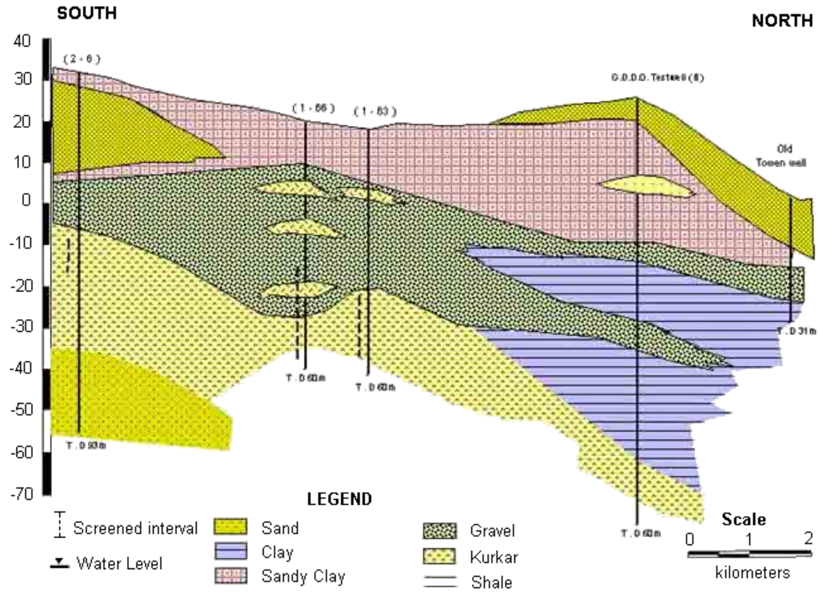


Fig. 4. Hydrogeological cross section in the area of study *(Mekhemer and Maryam Mostafa, 2007)*.

Table 1. Volumetric budget for the quaternary aquifer in Delta Wadi El-Arish

| Flow Items | Flow Rates For Year 2006 ($m^3$/day) |
|---|---|
| **Inflow:** | |
| Storage | 1057.7019 |
| Constant Head | 18935.6914 |
| Wells | 1350 |
| Recharge | 33641.4453 |
| Total | 54984.8359 |
| **Outflow:** | |
| Storage | 0 |
| Constant Head | 2778.397 |
| Wells | 52206.4414 |
| Recharge | 0 |
| Total | 54984.8359 |

Generally the water is flowing from south to north. The calculated values of transmissivity are between $4\times10^{-4}$ m$^2$/s and $9\times10^{-3}$ m$^2$/s, while the values of storage coefficient are between $2\times10^{-2}$ and $5\times10^{-2}$.

Recently Water Resources Research Institute *(WRRI, 2006)* constructed

TWO DIMENSIONS MODFLOW model to adapt the groundwater balance. The results of inflow and outflow were tabulated here under. The values of inflow and outflow constant head are 18 936 $m^3$/day and 2 778 $m^3$/day, respectively. This means that the excessive abstraction leads to decline in water table and appearance of negative water table values consequently sea water intrusion.

## 5. Data acquisition and processing

Fourty Eight Vertical Electrical Sounding (VES) *(WRRI, 2006 )* were acquired by means of Schlumberger configuration using Syscal $R_2$ instrument. The maximum current electrode spacing of the VES data varied from 1.5 to 500 m. Fig. 5 shows the location of geophysical measurements by using CH-8708A transmitter and EPR0121A recorder instruments. The measured apparent resistivity of each VES was plotted simultaneously against AB/2 values on log-log paper in the field before leaving the site for quality control of the data. The resistivity data were first inverted in terms of 1-D resistivity-depth model using *Zohdy (1989)*, *Van Der Velpen (1988)* and *IPI2WIN software (2000)* software. Six examples are selected for illustration in this study, cf. Fig. 6. The final model is used to draw the cross-sections and the resistivity maps of the subsurface layers in the study area.

The measured values of resistivity were compared with the resulting samples from four drilled wells along profiles for optimal interpretation. The thickness of water-bearing layers and their true resistivities are shown in Fig. 5.

To delineate the subsurface geoelectrical layers and their extension vertically and laterally, and to locate the geological structures that might exist, to identify the aquifer and its geoelectrical characteristics, eight interpreted geoelectrical cross-sections are constructed.

### 5.1. Results and interpretation

The DC sounding data were obtained and analyzed to delineate the aquifer systems and study the variation of the saltwater contaminated aqui-

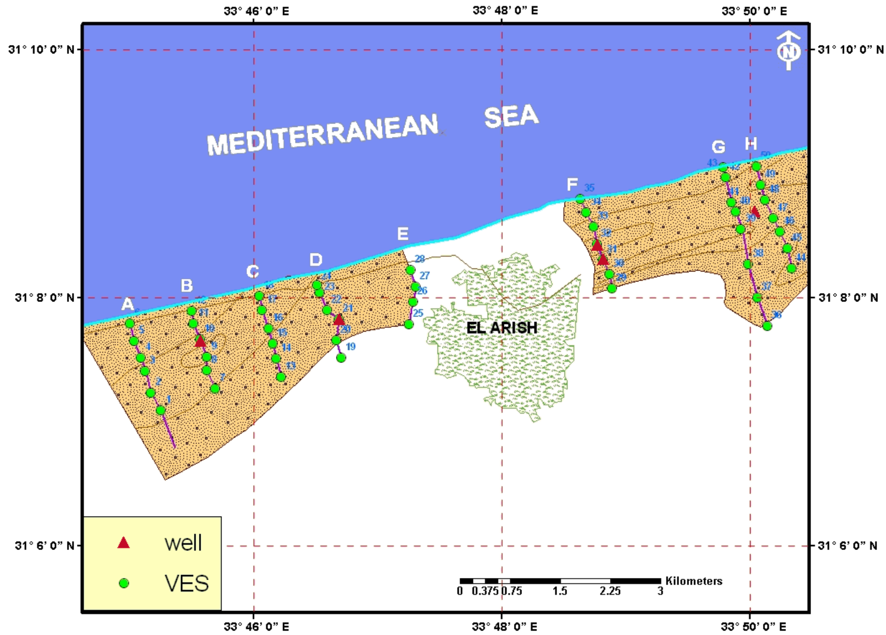


Fig. 5. Location map of Vertical Electrical Sounding (VES) station.

fers. Four soundings were done near the borehole drilling to calibrate between them.

Figs. 7-14 show eight cross-sections were constructed in order to demonstrate the distribution of the resistivity units, and resistivity and thicknesses of each unit along the surveyed profiles. These cross-sections show the large distribution of geoelectric resistivity and their corresponding lithologic and hydrologic variation in the study area. Detailed interpretation of each cross-section and general correlation between resistivity layers, their thicknesses and depths along all sections indicate that the subsurface geoelectric resistivity layers can be classified into three main geoelectric units. A detailed description of each geoelectric layer from top to bottom is the following:

The first layer is the surface dry layer which is characterized by high resistivity values ranging from 1406 to 20 Ohm.m and varying in thicknesses from 35 to 2 m. This geoelectric unit is continuous in all cross-sections

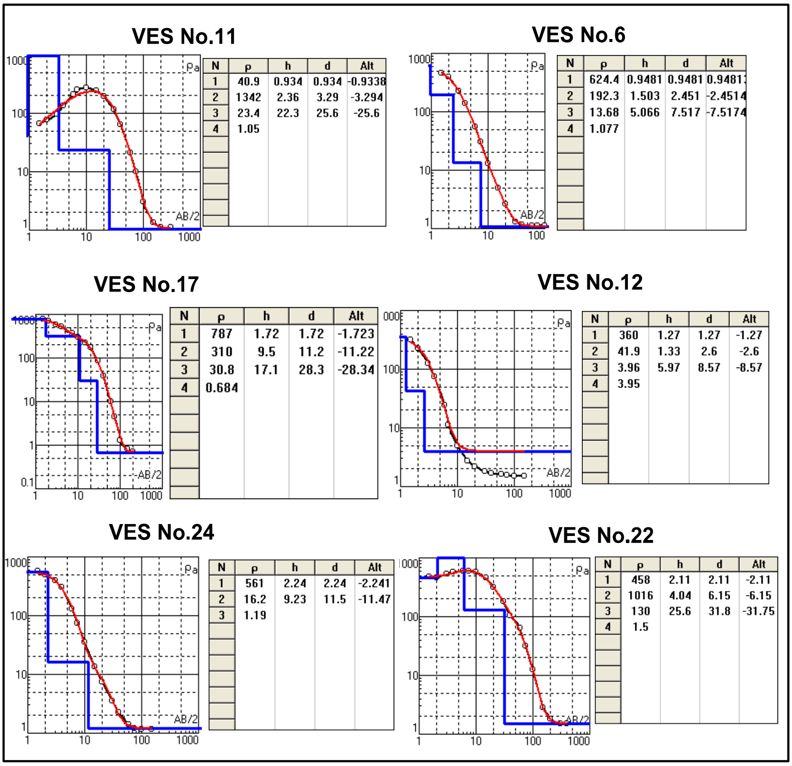


Fig. 6. Example of some observed curve and their interpretation.

and corresponds to the surface dry sand dune bed. The second geoelectric layer is characterized by intermediate resistivity values ranging from 120 to 12 Ohm.m and corresponds to the alluvium aquifer system. This layer is present in all VES except VES No. 2, 3, 7, 19 and 23. This aquifer system is composed of sand, clay and gravel (alluvium) and sometimes contains brackish water. It is characterized by nonuniform thickness. The third geoelectric layer is characterized by very low resistivity. This layer correlated with the wells in the area represented the salt lower horizon of the Quaternary aquifer, which is calcareous sandstone (Kurkar), as in wells. A comparison of the above mentioned results with the drilled boreholes shows a good match with a small difference.

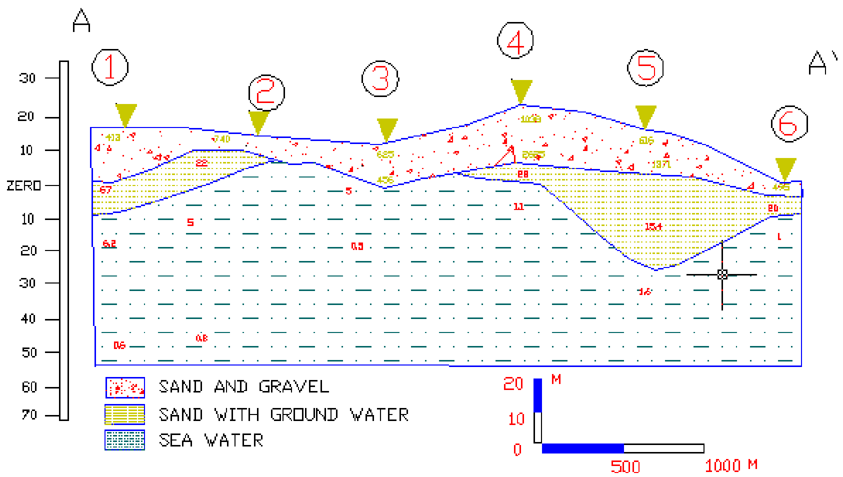


Fig. 7. Geoelectric cross-section A–A′.

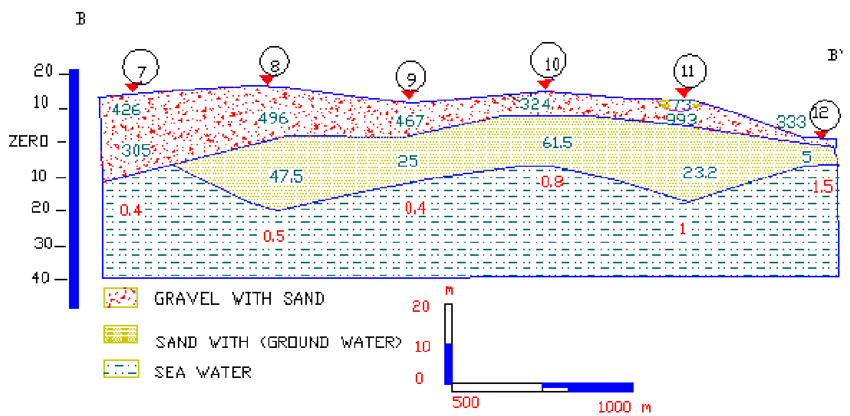


Fig. 8. Geoelectric cross-section B–B′.

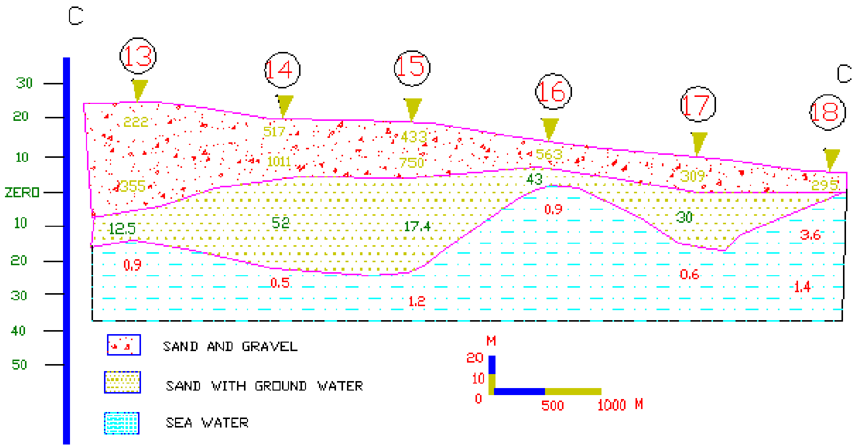


Fig. 9. Geoelectric cross-section C–C′.

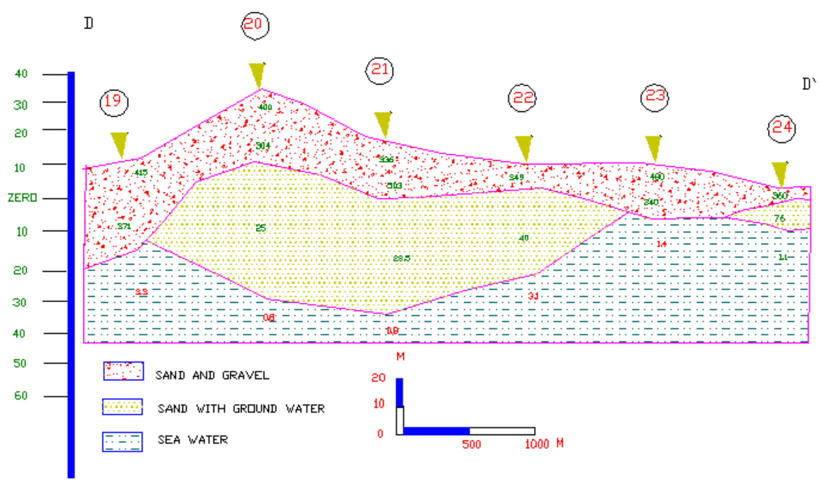


Fig. 10. Geoelectric cross-section D–D′.

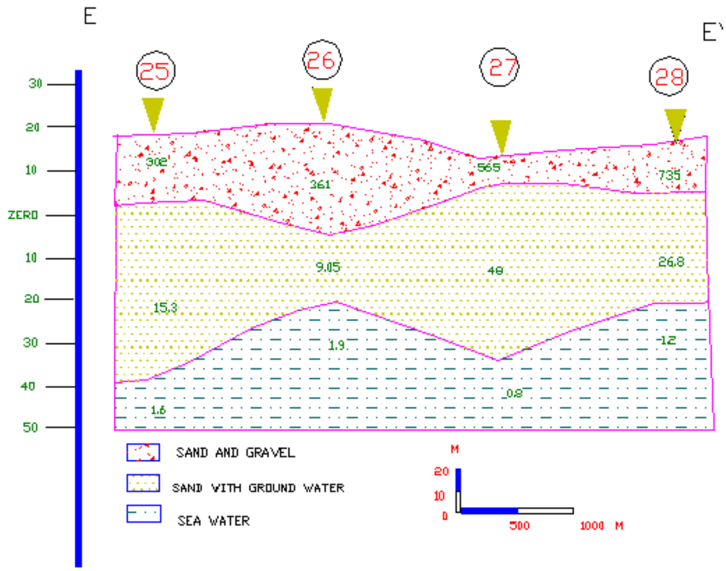


Fig. 11. Geoelectric cross-section E–E′.

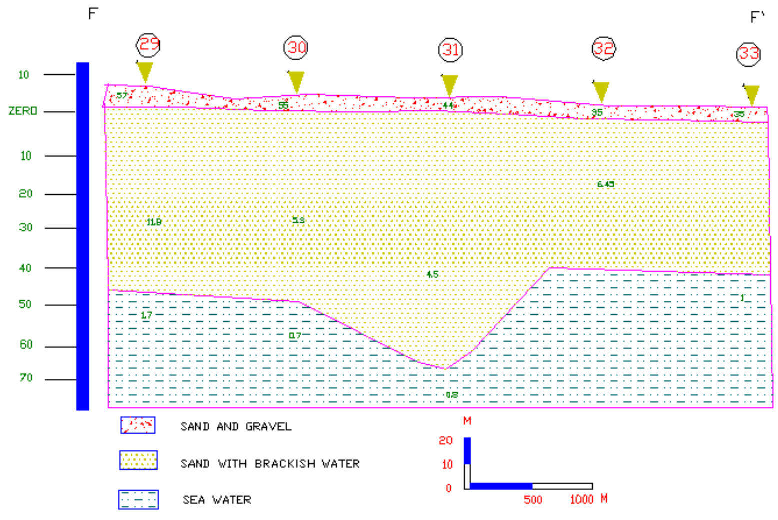


Fig. 12. Geoelectric cross-section F–F′.

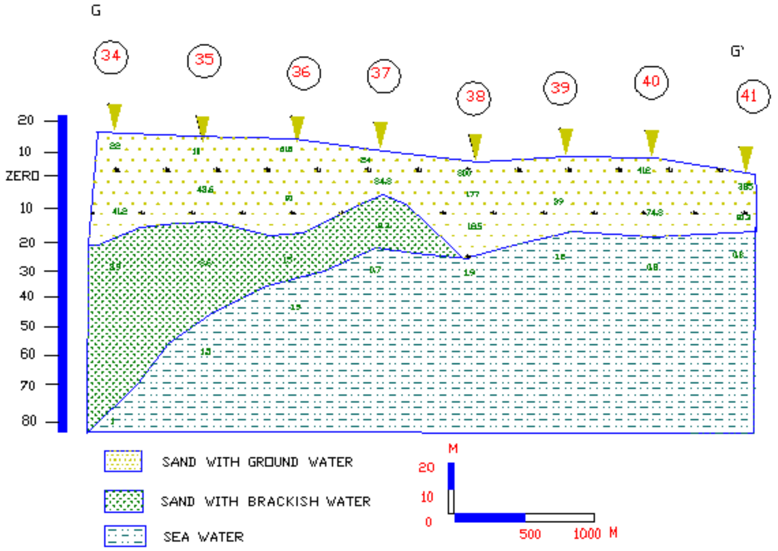


Fig. 13. Geoelectric cross-section G–G′.

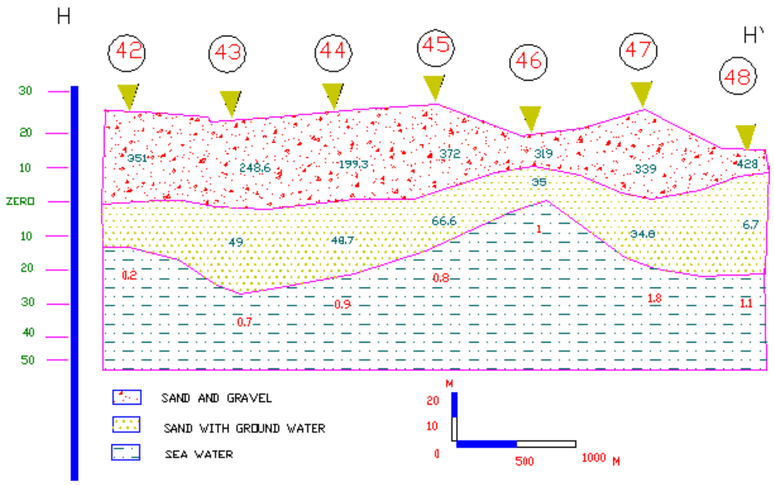


Fig. 14. Geoelectric cross-section H–H′.

## 6. Conclusion and recommendations

Hydrogeological and geophysical studies reveal three aquifer systems named sandstone, alluvium, and calcareous sandstone with shell fragments (kurkar). Aquifer transmissivity ranges between $4\times10^{-4}$ $m^2/s$ and $9\times10^{-3}$ $m^2/s$, while its storativity ranges between $2\times10^{-2}$ and $5\times10^{-2}$. The results of the constructed 2D model illustrate unbalance state, where the excessive abstraction leads to decline in water table and gives the chance for sea water to intrude through the Quaternary aquifer, especially the basal Kurkar aquifer system. The results are confirmed by eight constructed geoelectrical cross-section and drilled wells. The second geoelectric layer is characterized by intermediate resistivity values ranging from 120 to 12 Ohm.m and corresponding to the alluvium aquifer system. This layer is present in all VES except VES No. 2, 3, 7, 19 and 23. This aquifer system is composed of sand, clay and gravel (alluvium) and sometimes contains brackish water.

The study area occupies the north part of wadi El-Arish area. The main target of hydrogelogical and geophysical study is to help in locating the area of ground water potentiality, and delineate the salt water intrusion in the area using geoelectric method.

Recommendations: The drilling results match well with geophysical interpretation concluded from the present work.

- Water extraction should be managed to keep the aquifer in its normal state. This can be done by installing counters on each well.
- Aquifer unbalance due to excessive extraction can be compensated by applying artificial recharge.
- This technical study should be applied in other coastal areas to determine the effective parameters for the acceleration of sea water intrusion.
- Finally monitoring the network can be adjusted to follow up any abrupt changes in water table and water quality.

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