Original Research Article

Application of Geoelectric technique in groundwater protection of Quaternary aquifer in Wadi El Natrun, Egypt

Abstract.

The study conducted in the western region of the Nile Delta on both sides of the Cairo-Alexandria desert road in the north Western Desert of Egypt focuses on understanding the geological and hydrological characteristics of the area. The study uses qualitative and quantitative interpretations of accessible geo-electrical resistivity data to investigate the subsurface geology and the potentiality of underground water accumulations. The study region consists mainly of sedimentary exposures from the Miocene to the Quaternary Era and has been impacted by lithology and geological structures.

The study involves 23 VES using Schlumberger array to define the shallow subsurface geology. The results show that the area is divided into five geoelectrical units with varying thicknesses, lithologies, and features. The five units range in resistivity from high to low and consist of silt clay, sands, gravels, and intercalations of sand and clay. The third and fourth units may represent an aquifer.

Due to extensive water well drilling in the area, significant hydrogeological and environmental issues such as soil salinization, water head decline, and groundwater salinity deterioration have occurred. The study highlights the need for conducting in-depth geomorphological assessments before developing new reclamation projects, as well as soil and water assessments.

Key words: Vertical electrical soundings, Groundwater, Wadi El Natrun, Aquifer Protection.

Introduction

Egypt faces many challenges in its effort to establish and improve its towns and cities. One of the major problems facing the country is the scarcity of water resources. In order to combat this issue and revitalize rural areas, Egyptian experts are looking towards the West Nile Delta region as an ideal location for its distinctive landscape, temperate climate, uncomplicated openness, and accessibility to water sources.

One proposed strategy is to expand existing ghost towns and abandoned settlements, such as South El-Tahrir, El-Sadat City, El-Nubariya, and El-Bustan pilot zones. Additionally, the first 20 kilometers of the Cairo-Alexandria road has seen the haphazard drilling of a few water wells, upon which a few tiny private farms were constructed in the late nineteenth century.

However, this approach has led to a number of hydrogeological and environmental issues, such as soil salinization, water head drop, and groundwater salinity degradation. If Egypt is resolve the issue of water insufficiency, it is imperative that the country looks towards innovative solutions that take into account the environmental impact of its actions. This could include desalination, reuse of water, rainwater harvesting, and better water management systems. Additionally, educational programs and awareness campaigns must be initiated in order to ensure the long-term success of any water-related policies.

The Wadi El Natrun aquifer in Egypt is of great importance for understanding the groundwater resources in the region. In recent years, many studies have been conducted in the area, such as those by Zarif et al. (2022), Leborgne et al. (2021), Ibraheem et al. (2016), Salem et al. (2016), Khalil (2010), and Sayed et al. (2009). Geoelectrical analysis, and in particular electrical resistivity, has been the preferred method to investigate the aquifer due to its sensitivity to changes in the subsurface structure.

Despite the number of investigations already conducted in Wadi El Natrun and its environs, there is still considerable need for further research to gain a deeper understanding of the groundwater conditions. Geophysical techniques, particularly geoelectric ones, have been found to be particularly effective in detecting the new-water/saltwater interface in aquifers. By using resistivity overviews, it is possible to obtain detailed data on the geometry, source, and overall contamination level, The West Nile Delta region's hydrogeological management can be evaluated through geoelectrical surveys, which involves collecting data about the geographical and electrical properties of the area. This data can then be used to create a map to aid decision making, as shown in Figure 1.

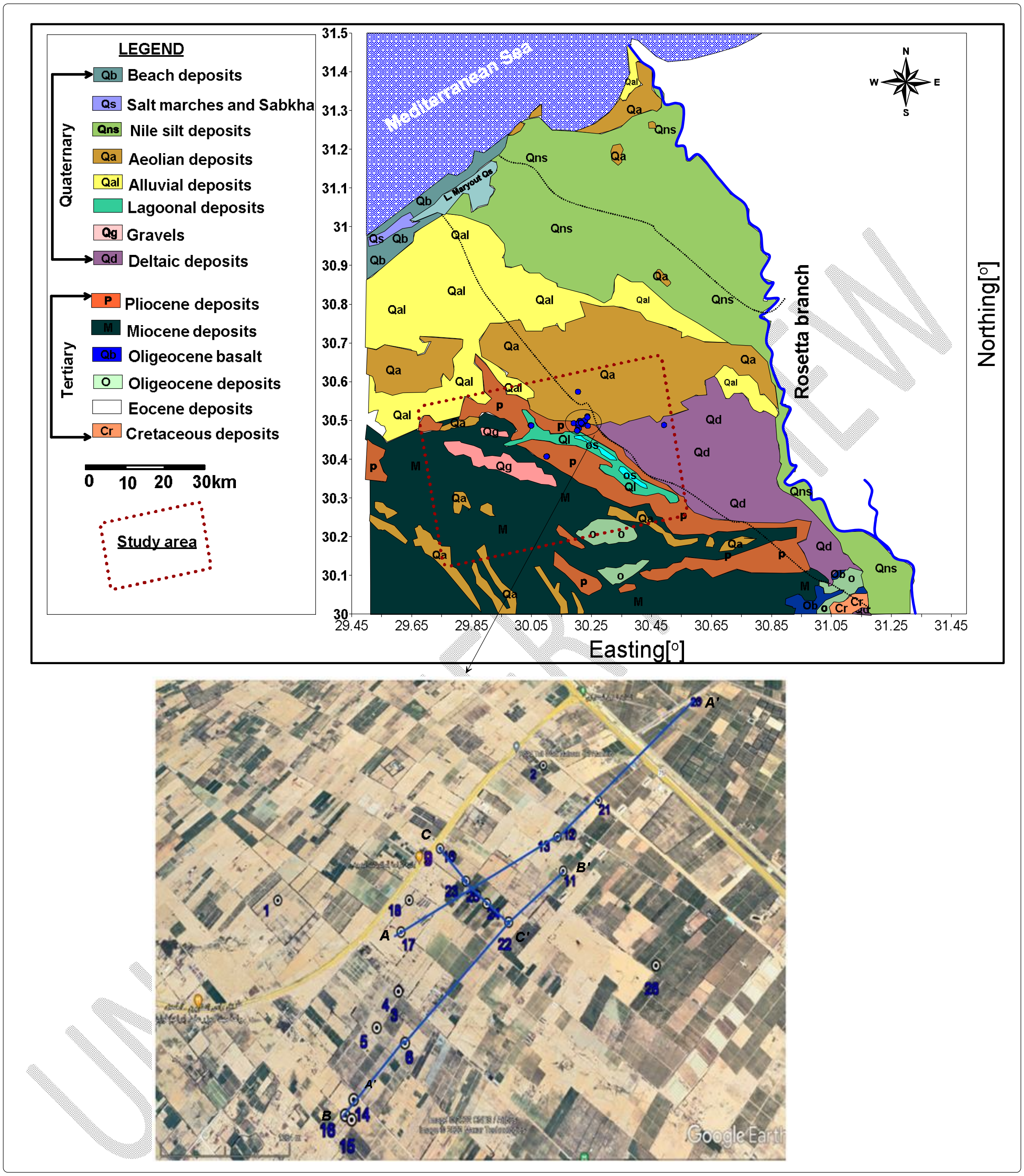


Fig. (1): Location of geoelectrical VES stations and cross sections on the geologic map (Zarif, 2009) in the area of study.

Physiographic setting:

Many authors gave significant attention to the geomorphologic theories of the region west of the Nile Delta, including Sandford and Arkell (1939), Said (1962), Shata and El Fayoumi (1967), Abu El-Izz (1971), El Shazly et al. (1975), Embaby (1980). (2003) and (Sayed et al., 2009). The area of study can be geomorpholgically divided into the following units (Fig. 2) (Sayed et al., 2009):-

1. Coastal plain.
2. Alluvial plains (young alluvial plains and old alluvial plains).
3. Structural plain.
4. Tablelands.
5. Sandy plain.

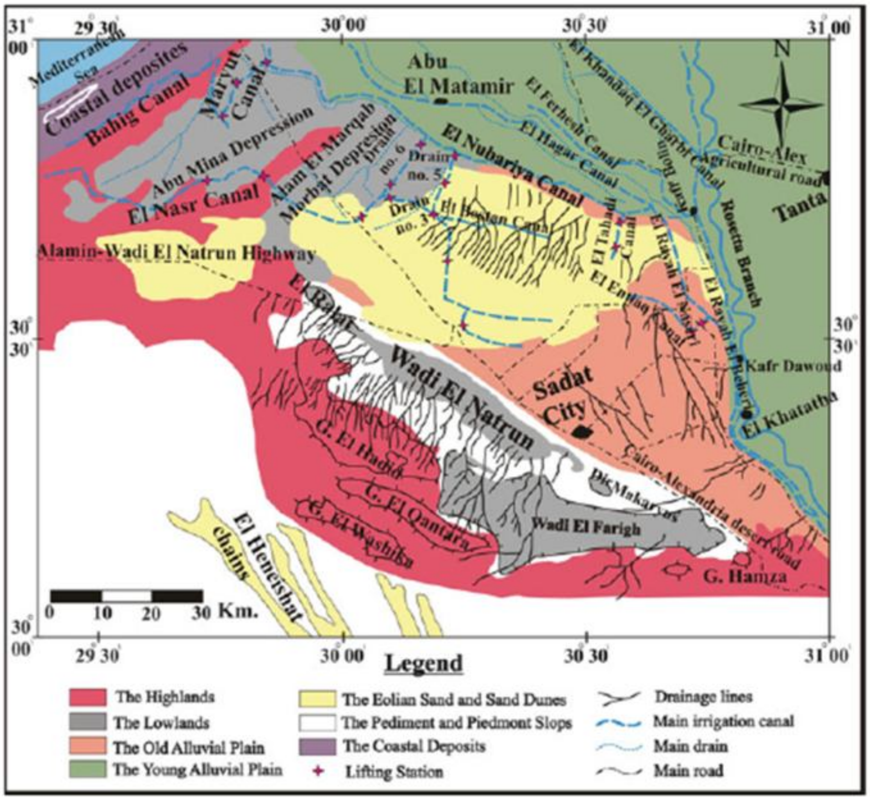


Fig. (2): Detailed geomorphologic map characterized by landforms of the study area and its environs.

Geologically, the area in question and its subregions, as depicted in Figure 3, have been studied and discussed by a number of authors, including Shata (1962), El Fayoumy (1964), Idris (1970), Sanad (1973), Omara and Sanad (1975), El Ghazawi (1982), Taylor & Jones (1983), El Sabagh (1992), and Sayed et. al (2009). The west of the Nile Delta is an area of great geological interest. It is characterized by extensive exposure of sedimentary sequences from both Tertiary and Quaternary periods. The Tertiary period sediments dominate located to the southern and western parts of the El Ralat, Wadi El Natrun and Wadi El Farigh depressions. These sediments consist of sand, sandstone, clay and limestone intercalations. The Miocene rocks are represented by the El Moghra Formation. The Pliocene sediments have a wide distribution within the Wadi El Natrun depression and its adjoining regions. This region is divided into Lower and Upper

Pliocene. The Lower Pliocene is characterized by estuarine clay beds at the base and fluviomarine and shallow marine beds at the top. The Upper Pliocene is characterized by shallow marine white limestone. This area is of immense geological interest and has been the subject of numerous studies and research projects. Agreeing to Said (1962), this arrangement has a place to the Lower Miocene and is composed of interbedded sand, sandstone, and clay with vertebrate remains and silicified wood. This arrangement is spoken to south and west of Quaternary stores of Wadi El Natrun cover wide extends of the region and are identified in water wells.

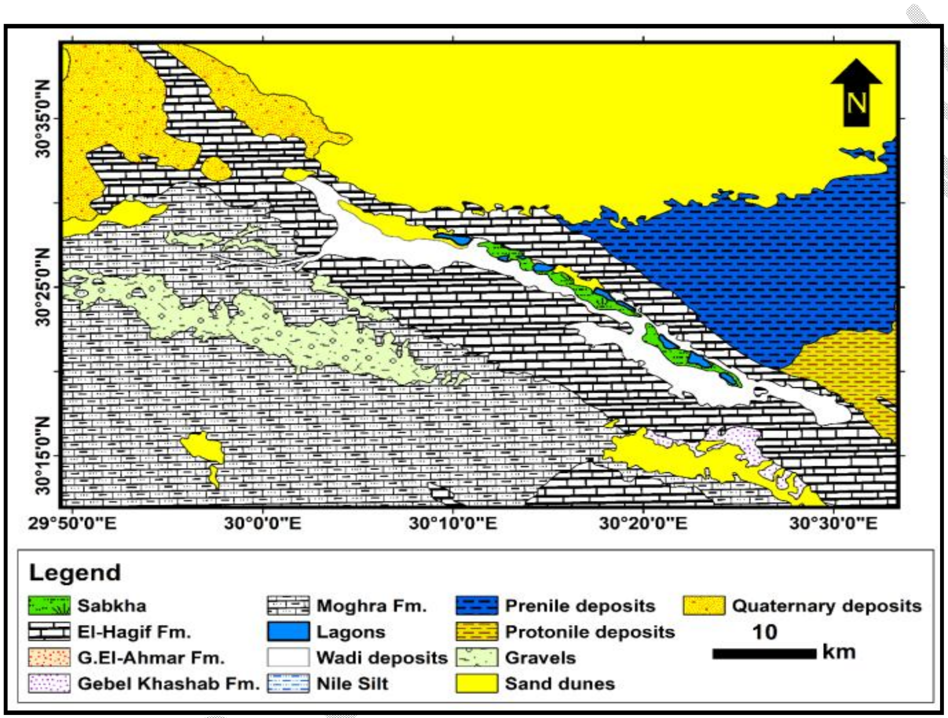


Fig. (3): Regional geological map of the study area (Conoco. 1984).

The structural aspects affecting the range and its surrounds investigated by many authors like Shata (1962), El Fayoumy (1964), Idris (1970), Sanad (1973), Omara and Sanad (1975), El Ghazawi (1982), Taylor and Jones (1983), and El Sabagh (1992). Regarding the components that were presented, the following suggested that Northern Egypt was affected by three structural occurrences. Another event that took place in ENE (Syrian Arc) trending structures and was triggered by NW (Clysmic) or WNW 9Najd or Qattara) trending structures came before the oldest. The third structural occurrence took place in the E-W, NW (Tethyan or Mediterranean), and NNE (Aqaba) trending structures. Folds, faults, unconformities, and the shaky shelf that runs along the region's border all have a significant impact. These structural components are the foremost vital factors influencing the groundwater conditions within the area.

Several researchers, including El Fayoumy (1964), Hefny et al. (1991), Sallouma and Gomaa (1997), El Sheik (2000), Embaby (2003), Khalil et al. (2014), and Massoud et al. (2014), examined the groundwater characteristics of the western Nile Delta region (see Fig. 4)The groundwater of the study neighborhood is generally managed via the geological stipulations which include lithology, topography and structures. The predominant water-bearing formations associate in consequence along Quaternary (Recent then Pleistocene) below Neogene which is consist from Pliocene and Miocene. On the other hand Wadi El Natrun aqueduct's aquifers are among three distinct water-containing strata. These consist of clay-rich Quaternary alluvial sand then rock, marine sand beyond the Pliocene, and fluviomarine sand, sandstone, and clay interbeds beside Miocene. and others have separated Wadi El Natrun aquifers among Pleistocene, Pliocene and then Miocene aquifers. The Pleistocene aquifer is located of the Rosetta Department about the Nile and the eastern entrance regarding Wadi El Natrun which slants appreciably in both the eastward and northward directions. The Pleistocene stores represent the close aquifer. It instituted over about the Nile sands and hail including submission streaks on clay. The clay streaks gotten in imitation of be seriously in the direction of the upper so nicely as much calcareous stores. The aquifer thicknesses reach around 150m close Wadi El Natrun then increments regularly eastwards where it.

The shallow Pliocene aquifer found in the north is caused by surface water canal seepage that develops southward and descends to a depth of about 40 m nearby the boundary of Wadi El Natrun. The Pleistocene aquifer was classified as a tall potential aquifer by Gheorghe, A. (1979). Abd El Baki (1983) The Pleistocene aquifer is specifically restricted to the Nile Delta aquifer because to the pressure-driven interaction between the two aquifers. Surface runoff from the most recent reclaimed lands, as well as the infrastructure for cloud regulation, releases additional energy. Pumps into water wells are what cause emissions to dominate. Groundwater quality in the Pleistocene aquifer ranges from pristine to barely brackish.

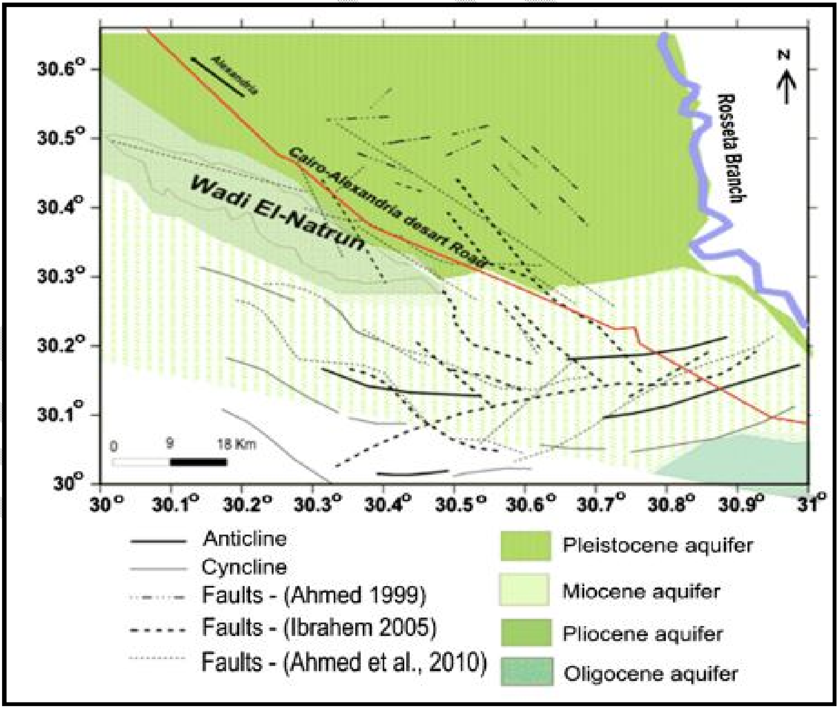


Fig. (4): Distribution of shallow aquifers in the study area and its vicinities (Ahmed, 1999; Ahmed et al., 2011; Ibrahim, 2005, Salem and El-Bayumy, 2016).

The study site is situated in the arid zone of Egypt where a lengthy, scorching summer and brief, mild winter are common. The climatic data for the area was gathered from the meteorological stations at Wadi El Natrun, Ganaklees, and El Tahrir. The data range from 1988 to 1998 (zarif, 2009). The highest and lowest recorded temperatures are typically seen in January (19.4°C - 7.8°C) and Eminent (35.7°C - 21.9°C), respectively. The harsh annual precipitation concentrates progressively moves northward. It increases to 190 mm/year close to the Mediterranean shore from almost 50 mm/year in the northern part of Wadi El Natrun. The months with the most extreme precipitation are January and December, whereas the months with the lowest amounts are June, July, and Eminent (Sayed et al., 2009). Generally speaking, winter has more relative stickiness than Summer.

Based on the previous studies of the Wadi El Natrun area and its surroundings, it can be concluded that the geology of the area has a significant impact on the environment, particularly on the soil layer and groundwater. This is evident in the varying quality of groundwater and the occurrence of water logging. The changes in groundwater quality are due to the connection between the aquifers in the region and different recharge sources. The presence of clay lances in the soil layer also contributes to water logging problems and affects the quality of groundwater by increasing its salinity. The current study in the region aims to provide new data In order to foster sustainable development by environmental and hydro-geophysical studies.

Methodology and data acquisition

The Syscal Junior is an all-purpose resistivity sounding system for environmental, it can detect both resistivity and chargeability (IP). With a maximum power output of 100W at 400V, the Syscal Joiner is suitable for the majority of near-surface geophysical prospection applications, including pollution monitoring and mapping, depth-to-rock estimation, salinity management, and mapping of weathered bedrock.

The Schlumberger array's layout was used to obtain data on VES. The recorded data were employed to ascertain the thicknesses and actual resistivities of the subsurface models based on their electrical properties (Khalil, 2010). There were several wells accessible at or close to the measured soundings in every case that was examined to accomplish creating the first model and calibrating the data. Following the quantitative interpretation was once employed the technique was once raised using the IPI2WIN programme. Copyright 2000, 1D interpretation regarding VES profile, the actual resistivities and thicknesses of the stratigraphic units close according to each VES status had been considered using a quantitative interpretation.

In this study, the resistivity method was utilized as it is highly sensitive to both salt and clay content, which is critical in determining the potential of groundwater as resistivity decreases with increasing salinity. The resistivity decreases when rock contains clay, as reported in several studies (Zohdy, 1974; Telford et al., 1990; Reynolds, 2011). To better understand the underlying structures and the state of groundwater in relation to drilling data, "23" one-dimensional vertical electrical resistivity soundings (1D VES) were performed at various locations near Wadi El Natrun Alalmin road (Figure 1). The setup of this array has been explained in previous works, including (Kumar et. al., 2020, Telford et al., 1976). The VES were conducted with a maximum current electrode spacing ranging from 500 to 700 meters.

The ability of an earth medium to protect against percolating fluid by filtering and delaying it is referred to as its protective capacity and is inversely proportional to its hydraulic conductivity and Scaling with its thickness (Olorunfemi et al., 1999). Permeability, resistivity, hydraulic conductivity, and longitudinal unit conductance show low values are typical characteristics of clay-rich materials. Therefore, it is possible to consider the protective capacity as being proportional to the longitudinal conductance (S). As a result, an overburden's protective capacity increases with increasing longitudinal conductance. The resistivity method is used to establish relationships between electrical resistivity and hydrogeological characteristics such as porosity, permeability, transmissivity, and hydraulic conductivity through the use of Dar Zarrouk Parameter - Longitudinal Conductance. This connection is based on the similarities between equations that describe the flow of groundwater through a permeable material and the flow of electricity through a conductive medium. The hydrogeological properties of an aquifer can be determined by using geoelectric measurements taken from the surface, as shown in the research by Umar et al. (2012).

Longitudinal unit conductance values of the overburden rock units in the area are used to characterize the protective capacity of the aquifer, with the longitudinal layer conductance (S) at each station being obtained through the use of an equation:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i}$$

Where hi is the layer thickness, ρ_i is layer resistivity while the number of layers from the surface to the top of aquifer varies from i= 1 to n

While the transverse resistance (T) was obtained from the equation:

$$S = \sum_{i=1}^{n} hi\, \rho_i$$

It can be concluded that the protective nature of the overlying layer of an aquifer is dependent on the relationship between its thickness and resistivity. The transmissivity of the aquifer can be estimated by multiplying the hydraulic conductivity by the layer's thickness. Transverse resistance (T) depends on product of the resistivity and the thickness as well as the hydraulic conductivity (Kelly, 1977). Clay layers have lower resistivities and hydraulic conductivities, which corresponds to a lower transmissivity level. Thus, it is reasonable to assume that the protective quality of the overburden is in direct proportion to the thickness and resistivity of the layer.

The topographic survey is carried out to determine the locations (latitudes and longitudes) of the sounding stations on the topographic map by using the GPS apparatus (Trimble type) contact with nine satellites.

Interpretation and results

The geoelectrical data can be more effectively understood when they are presented in the form of contour maps and cross sections. Contour maps demonstrate the lateral variation of a particular parameter such as depth or resistivity, across the study area. Cross sections provide an understanding of the complete layering of the area with depth along a particular direction. These forms of presentation provide a clearer picture of the underlying structure of the area. An example of this is shown in Figure (5), which displays the interpretation of the modeled resistivity data from sounding VES No. 12 near a well. The vertical geoelectrical section of the area is believed to consist of five geoelectrical layers.

1- A surface geoelectrical layer “A” which is characterized by relatively high resistivity values range from 8.1 to 595.3Ohm.m. The thickness of this layer varies from 2.1 to 8.86 m. This layer represents the dry surface cover of the area and consists of Gravel, sand and silty clay.

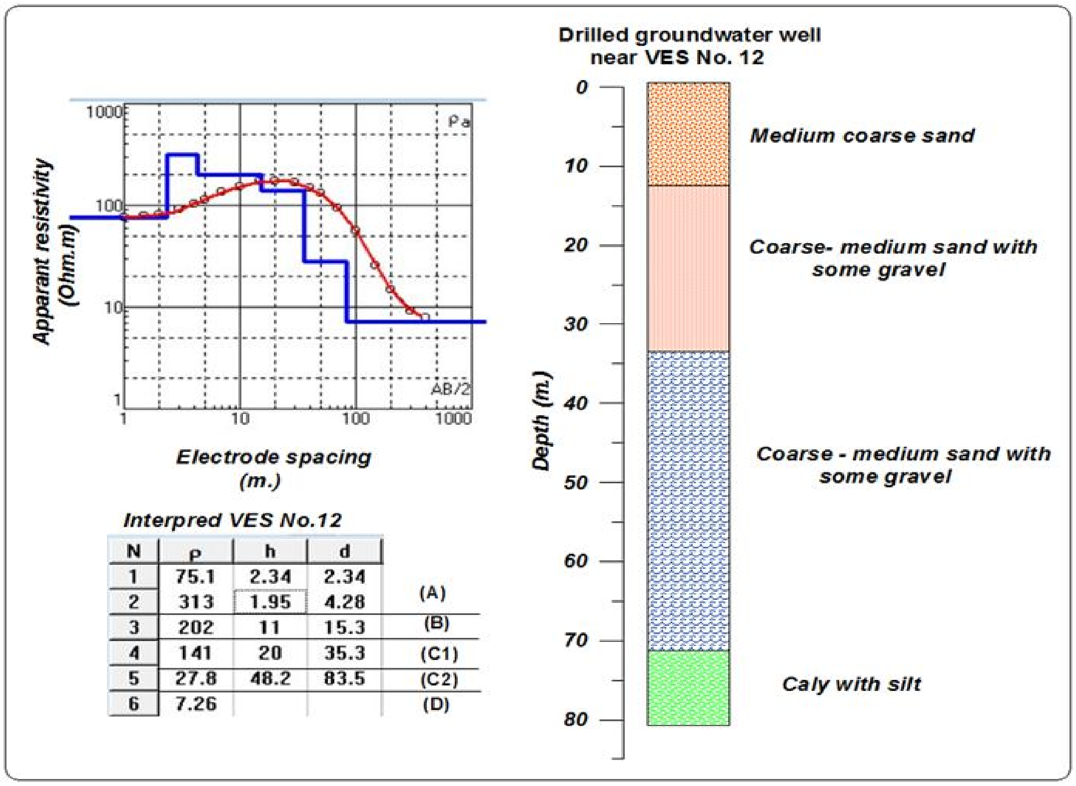
2- A dry geoelectrical layer “B” overlying the water-bearing formation represents the dry layer lying above the water-bearing formation. It consists generally of Sand and clay intercalation. The resistivity of this layer varies from 3.49-91.18 Ohm.m. The thickness of this layer shows range from 17.13 to 38.17m.

3- A saturated geoelectrical zone (C) that divided in to two layers (C1 & C2) according to resistivity values as follow:

  a) The upper part of the water-bearing formation, geoelectrical layer “C1” is the water-bearing formation consists generally of coarse sand and clay. The resistivity of this layer varies from 4.41 to 37.5 Ohm.m. The thickness of this layer varies from 4.41 to 54 m.

  b) The lower part of the water-bearing formation, geoelectrical layer “C2”) represents the lower part of the water-bearing formation. It consists of clayey sand and clay. The resistivity of this layer varies from 1.83 to 30.1 Ohm.m . The thickness of this layer varies from 17.78 to 31.35 m..

4- The last geoelectrical layer “D” represents the lower layer of investigated section. It consists mainly of clay. The resistivity of this layer is generally low and varies within a narrow range (6.44 – 39.8 Ohm.m.).



Interpred VES No.12

N	ρ	h	d	
1	75.1	2.34	2.34	(A)
2	313	1.95	4.28	
3	202	11	15.3	(B)
4	141	20	35.3	(C1)
5	27.8	48.2	83.5	(C2)
6	7.26			(D)

Fig. (5) Interpreted VES No 12 and the data of the near drilled groundwater in the study area

A detailed description from geoelectrical parameters (resistivity & thickness)of each layer from top to bottom is given in Table. (1) as follows:

Table (1) Thickness and resistivity ranges of the different geoelectrical layers

Geoelectrical layer		*Resistivity (Ohm.m)*		*Thickness(m.)*		*Desribtion*
		Min.	*Max.*	*Min.*	*Max.*	
(A)		*9.2*	*376.5*	*3.28*	*8.86*	Gravel, sand and silt clay
(C)	*(C1)*	*4.41*	*37.5*	*10.83*	*54*	Coarse sand and clay
	(C2)	*1.83*	*25.44*	*17.78*	*34.8*	Clayey sand and clay
(D)		*6.44*	*39.8*	***	***	Clay & silt

The geoelectrical layers gotten from the interpretation of the sounding curves have been sequenced through cross sections in terms of thickness and resistivity ranges. Such geoelectrical cross areas would complete the picture of the subsurface, and outline the level variation in thickness of the diverse geoelectrical layers along specific directions.

Geoelectrical cross-sections:

The outcomes of the quantitative analysis and interpretation of geoelectrical resistivity sounding are used to construct three geoelectric cross-sections that represent the variation of layers according to their resistivity values. Five geoelectrical cross-sections have been measured in trends A - A`, B - B` and C - C` are shown in Fig. 6, 7 & 8 respectively as follow:

1- Cross section A-A`:

The cross section A-A' runs in the SW-NE direction (Fig. 6). Includes the VES stations V17, V25, V13, and V20. The following four major geoelectrical strata are seen along this crossing area:

A surface geoelectrical layer (layer A) it is characterized by relatively high resistivity range from 44.7 to 162.2 Ohm.m. The thickness of this layer varies from 4.2 to 5.6 m. This layer corresponds to the arid surface covering of the region and is composed of a mixture of gravel, sand. The geoelectrical layer immediately below it (known as layer B) signifies the dry layer located atop the water-containing stratum. Typically, it is made up of alternating layers of sand and clay. The resistivity of this layer varies from 22.2 to 44 Ohm.m . The least resistivity value of this layer is found at VES station V20 (22 Ohm.m), The thickness of this layer varies from 29 to 32.7 m. The third geoelectrical layer (layer C1) is The water-containing stratum exists generally of coarse sand and clay. The resistivity of this layer varies from 8.1 to 24.1 Ohm.m . The least resistivity value of this layer is found at VES station V25 (10.6 Ohm.m), the thickness of this layer varies from 27 to 46 m. The fourth geoelectric layer (layer C2) represents the lower part of the water-bearing formation. The resistivity of this layer varies from 2.8 to 11.7 Ohm.m . The least resistivity value of this layer is found at VES station V25 (5.8 Ohm.m).

2- cross-sections B-B`:

This cross section is constructed along the SW-NE direction cross section A-A` (Fig. 7). It incorporates VES stations V6, V11, V14, V16 and V22. Four main geoelectrical layers are observed along this cross area as follows:

Layer A is the uppermost geoelectrical layer with a resistivity ranging from 44.7 to 376.5 Ohm.m and a thickness ranging from 5.2 to 8.8 m. It is composed of a mixture of gravel, sand, and silt clay and signifies the dry surface covering of the area. Layer B, located directly below layer A, is also a dry layer that lies atop the water-containing stratum. It is generally comprised of sand and clay intercalations with a resistivity varying from 11.6 to 39.3 Ohm.m, and a thickness ranging from 17.1 to 29 m. The third layer, layer C1, represents the water-bearing formation and consists of coarse sand and clay with a resistivity range of 4.4 to 87.7 Ohm.m. This layer's thickness varies from 23 to 45.9 m, and its least resistivity value is identified at VES station V16 (4.4 Ohm.m). The fourth layer, layer C2, is the lower part of the water-containing formation and is made up of clayey sand and clay. It has a resistivity range of 1.3 to 11.2 Ohm.m, and the layer's lowest resistivity value is found at VES station V22 (1.3 Ohm.m).

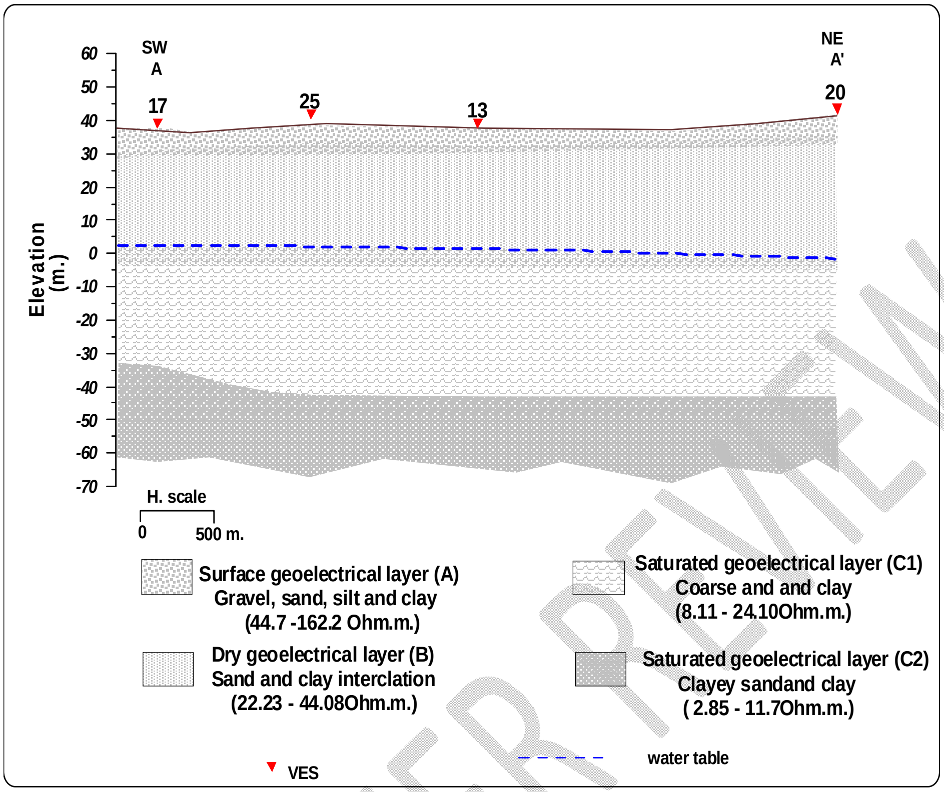


Fig.(6) .Geoelectrical cross-sections A-A`.

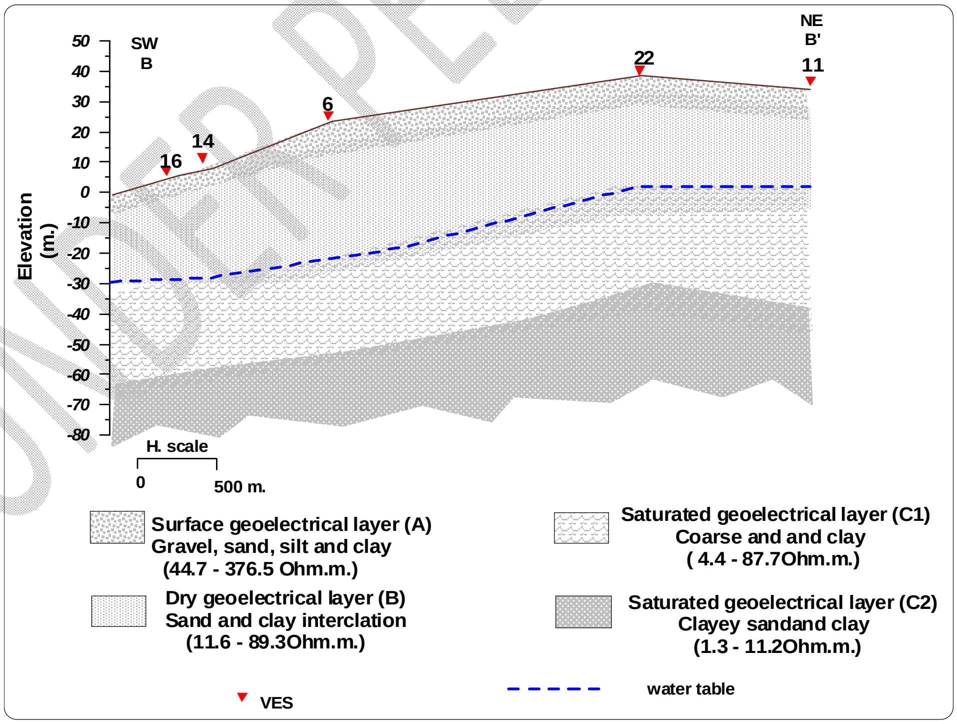


Fig.(7) . Geoelectrical cross-sections B-B`.

3- cross-sections C - C`:

This cross section is constructed along the S-N direction cross section A-A` (Fig. 8). It incorporates VES stations V9, V10 , V23 , V25, V24 and V22 . Five main geoelectrical layers are observed along this cross area as follows:

A surface geoelectrical layer (layer A) which is characterized by relatively high resistivity range from 21.4 to 44.7 Ohm.m. The thickness of this layer varies from 4.4 to 5.2 m. This layer represents the dry surface cover of the area and consists of Gravel, sand and silt clay. The second geoelectrical layer downwards (layer B) represents the dry layer laying above the water-bearing formation. It consists generally of Sand and clay intercalation. The resistivity of this layer varies from 11 to 44 Ohm.m . The least value for resistivity in this layer is observed to be at VES station V24 (11 Ohm.m), The thickness of this layer varies from 29 to 37 m. The third geoelectrical layer (layer C1) is the water-bearing formation consists generally of coarse sand and clay. The resistivity of this layer varies from 8.1 to 13 Ohm.m . The least resistivity value of this layer is found at VES station V22 (8.1 Ohm.m), The thickness of this layer varies from 25.8 to 46.8 m. The fourth geoelectric layer (layer C2) Indicates the basal region of the water-bearing formation. It consists of clayey sand and clay. The resistivity of this layer varies from 2.8 to 9.7 Ohm.m . The least resistivity value of this layer is found at VES station V22 (2.8 Ohm.m). The last geoelectric layer (layer D) represents the lower layer of investigation. It consists of mainly clay. The resistivity of this layer is generally low and varies within a narrow range (2.8 – 9.7 Ohm.m.).

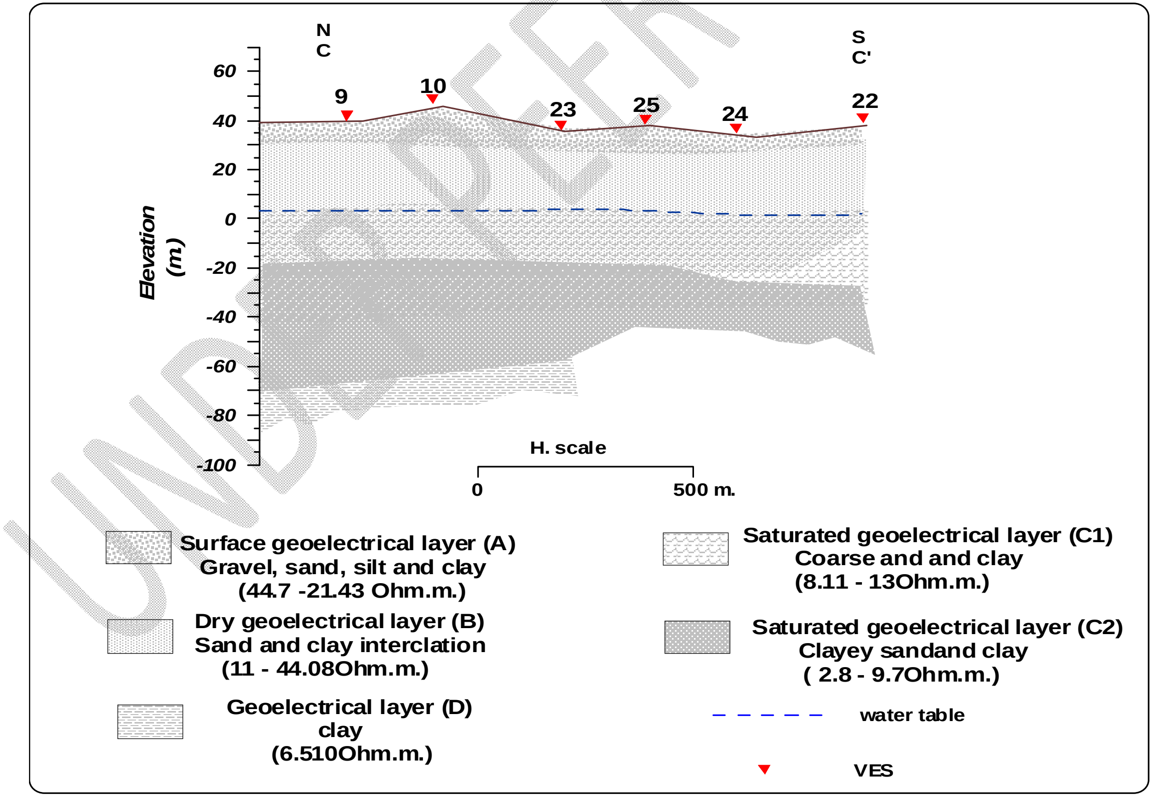


Fig.(8) . Geoelectrical cross-sections C-C`.

Groundwater conditions

The research area is dominated by Pleistocene and Miocene aquifers. A contour map of water depth was produced (Fig. 9) and it only shows the estimated depths to the top of the water-containing formation. The map is useful for determining the water depth in areas where new dry wells are planned to be drilled and is significant for the region's growth in agriculture or industry that relies on its groundwater supply. The map indicates that the area with the shallowest water depth (22.7–42.3m) is located in the center of the research region. The water depth gradually increases towards the northern and eastern boundaries. This can be assigned to the variation in the area's surface geography. As a result, the central part of the area with a depth of 34m is the preferred location for drilling new wells.

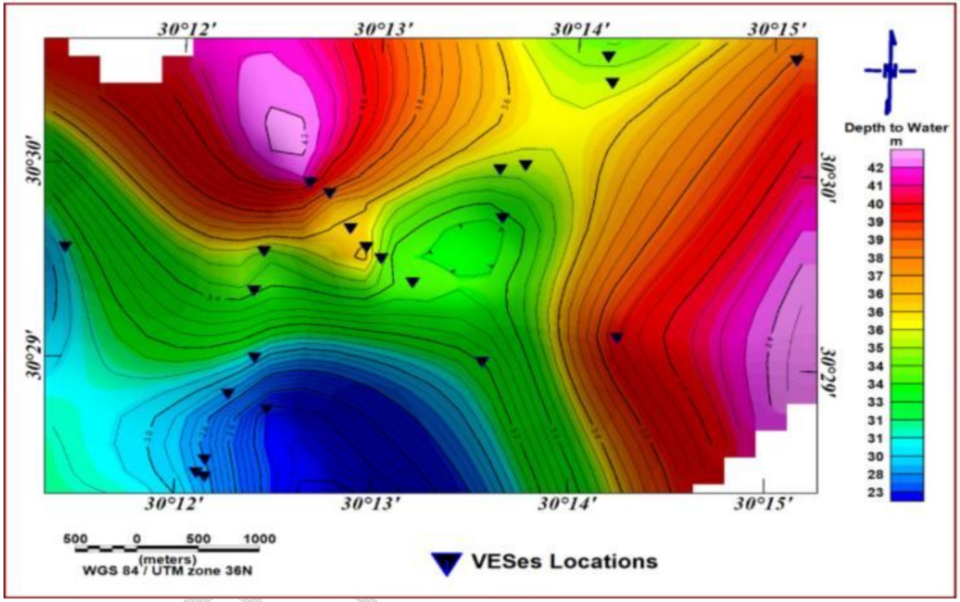


Fig.(9) Depth to water contour map in the study area.

With the objective of identifying the lithology of the saturated geoelectrical zone, located below the water table, which could indicate layers of the underground with larger or smaller capacity of protection to contaminants, a resistivity map was elaborated. This map refers to the geoelectrical level, whose top was determined by the position of the water table, separating the dry portion of the saturated. The Water table contour map appeared in Figure (10) was constructed using the upper surface of water-bearing formation related to sea level. The water table is shown on the map to be between 2.9 and -34 m., and in the most areas of the region, the usual water powered sharp is around 3.5 m.

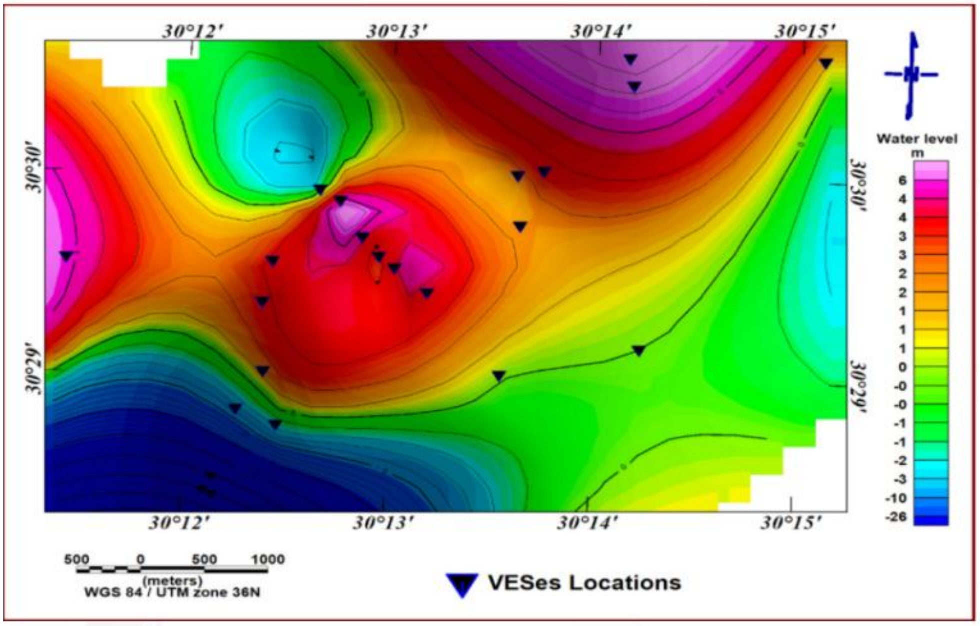


Fig. (10) Water table contour map in the study area.

Saturated geoelectrical zone:

According to the interpretation of geoelectrical data, it found that the saturated zone (C) in divided in two layers (C1 & C2). The layer (C1) represents the upper part of the water-bearing formation. This layer's 1soresistivity (Fig. 11) is modest and has a restricted range (4.4 to 37.5 Ohm.m.). This can be attributed to the lithologic nature of the stratum, which is comprised of coarse sand and clay on the one hand and high-quality water on the other. The typical resistivity of this layer falls within this low resistivity range and is less than 10 Ohms in most of the area's western and southern regions.

The iso-pach map (Fig. 12) shows that thickness that grows at the southern, western, and northeastern portions of the area under study, reaching a thickness of 54 m, while the northwestern and eastern portions are distinguished by a smaller thickness of around 10.8 m. The groundwater's topmost layer is represented by this unit, where clay and coarse sand make up the lithology of this stratum.

The saturated geoelectrical layers (C2) represents the lower part of the water-bearing formation. The resistivity of this layer (Fig. 13), which is low and has a constrained range (1.8 to 25.4 Ohm.m.). This can be attributed to the lithological composition of clayey sand and clay on the one hand, and the quality of water saturating this layer on the other. Here in the southwest, particularly where the resistivity is less than 1.8 Ohm.m, the impact of lagons is evident. The typical resistivity of this layer a fall within this low resistivity range and is less than 10 Ohms in most of the area's western and southern regions.

According to (Figure 14), the area of study's thickness grows in the southwestern, western, and northeastern regions, where it reaches 34.8 metres. In contrast, the area's northwestern and eastern regions have a thinner thickness of around 17.7 metres. This unit corresponds to an aquifer containing brackish or salty groundwater, and its lithology is made up of sandy clay. Lagoons, one of the primary sources of recharge, have an impact on water salinity.

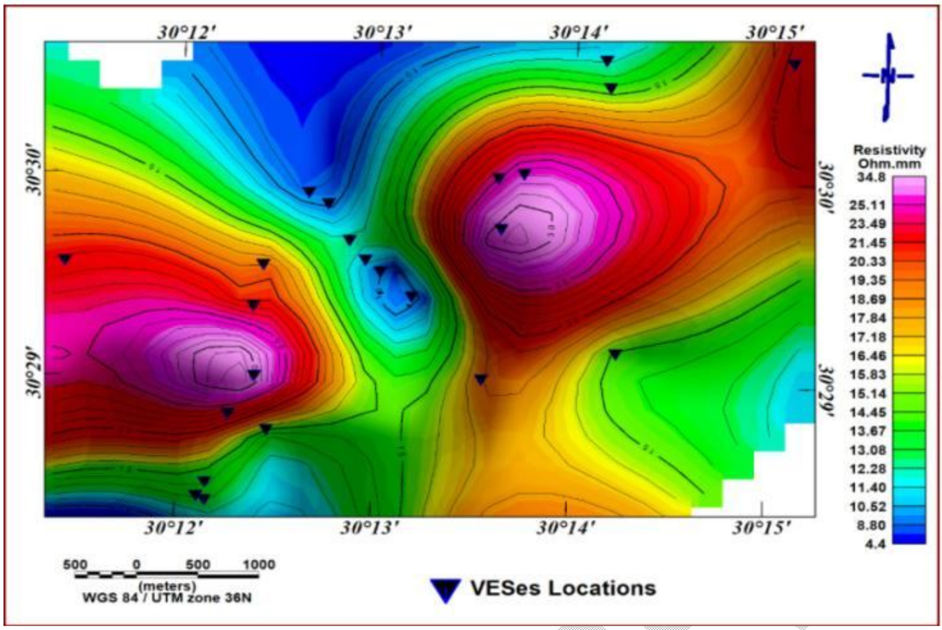


Fig.(11) Iso-resistivity contour map of the geoelectrical layer C1.

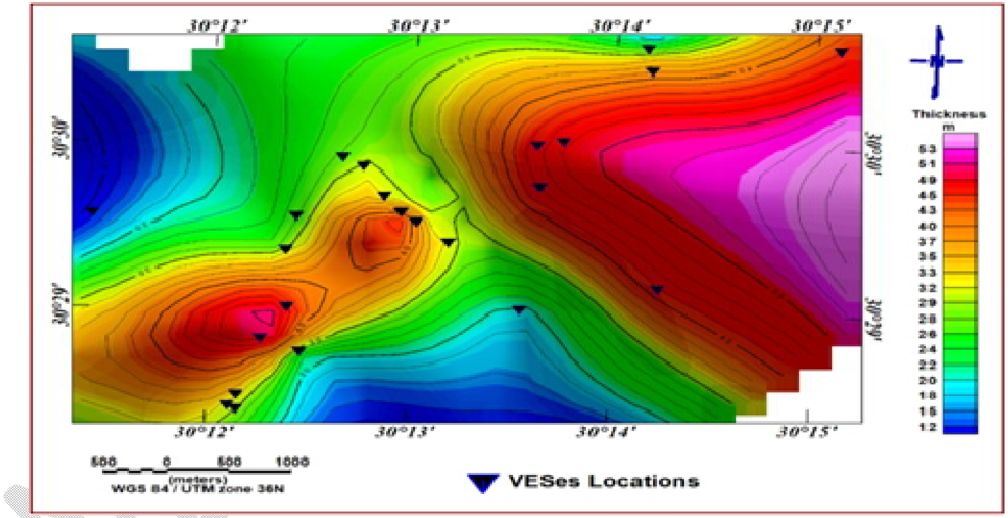


Fig.(12) Iso-pach contour map of the geoelectrical layer C1.

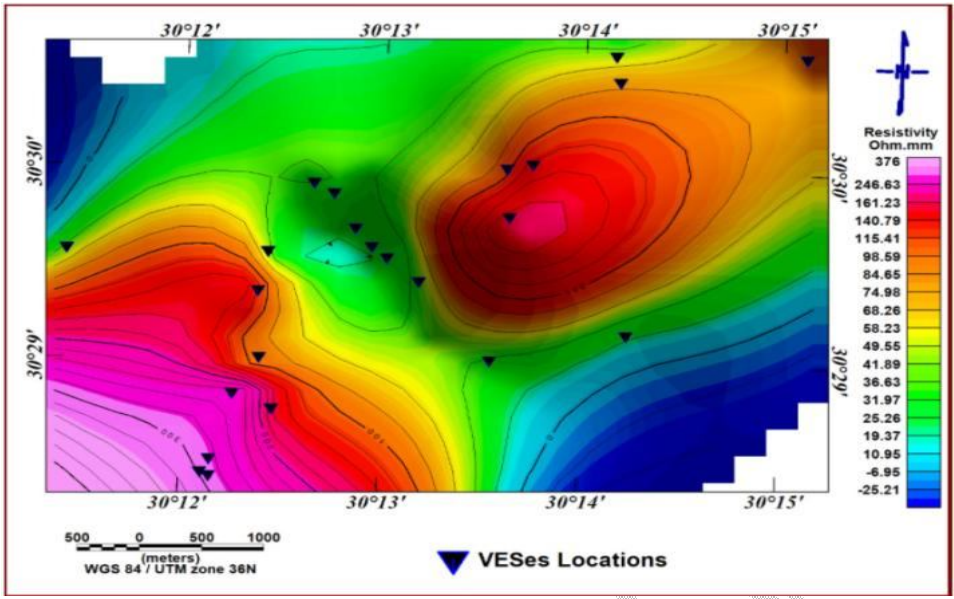


Fig.(13) Iso-resistivity contour map of the geoelectrical layer A.

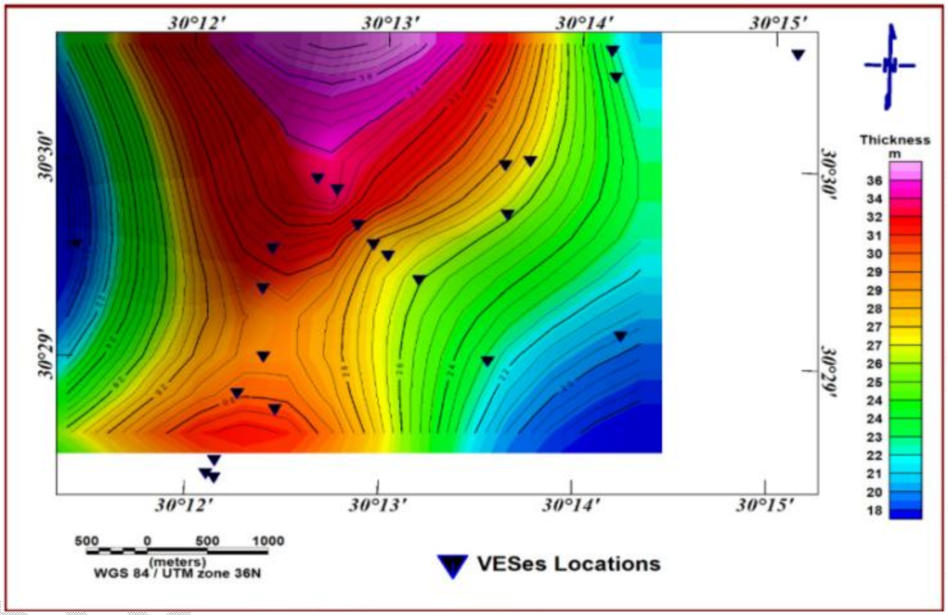


Fig.(14) Iso-pach contour map of the geoelectrical layer C2.

Aquifer protective capacity:

The values of the first layer resistivity can be used to create corrosivity maps that are used to assess the level of soil corrosivity at shallow depths in the area (Fig. 15). Corrosive regions are those with comparatively low resistivity values, and non-corrosive regions are those with high resistivity values (Rahaman, 1988). The principal natural defense against pollution in granular and unconfined aquifers is connected to the presence of overlapping clay layers, whose capacity for protection is limited by the delay in the penetration of solutions because of their poor permeability. According to (Braga et al., 2006), the protection level of an aquifer can be thought of as directly proportionate to the relationship between thickness and resistivity.

Figuring out the aquifers' geo-electric properties, then utilizing that knowledge used to calculate the soil corrosivity and aquifer protective capacity.

On the other end of the range are clay soils, particularly those affected by contaminated substance. Table (2) presents a classification of soil resistivity according to corrosivity.

Table (2): Classification of soil resistivity in terms of corrosivity [after Baeckmann and Schwenk (1975), Agunloye (1984), and Oladapo et al. (2004)]

Soil resistivity (ohm-m)	Soil corrosivity
10	Very Strongly Corrosive (VSC)
10 – 60	Moderately Corrosive (MC)
60 – 180	Slightly Corrosive (SC)
>180	Practically Non – Corrosive (PNC)

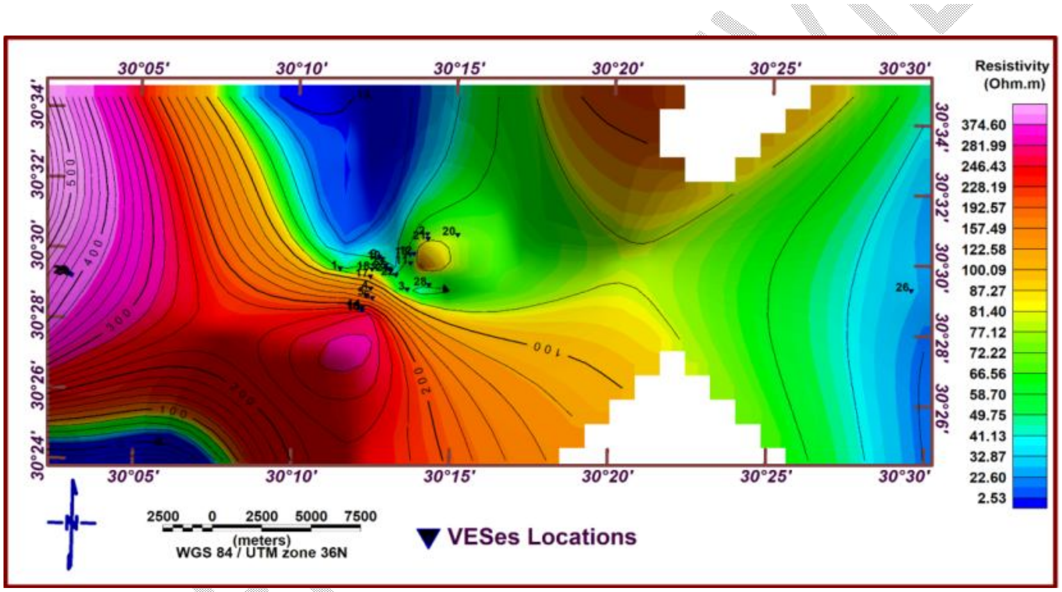


Fig.(15) Iso-resistivity contour map of the geoelectrical layer A.

The distribution of electrical resistivity across the forest layer is shown in Figure (15). This layer extends from the surface to a depth ranging from 2.1m. to 8.8m. This layer is lithologically composed of gravel, sand, silt and clay. This composition is well reflected through the wide range of resistivity (8.21 to more than 595Ohm.m.). The resistivity values smaller than 40 ohm.m are associated predominantly with clay sediments (clay-sand and clay) and moderately to strongly corrosive. The transition from clay to sand is gradual as increase resistivity values, presenting intermediary layers of clay-sand and sand-clay sediments also, practically non corrosive. Generally, Areas characterized by relatively low resistivity values are considered corrosive while areas with high resistivity values are considered non-corrosive n (Rahaman, 1988).

In order to ascertain the aquifer protective, transmissivity and soil corrosivity of the area under consideration, the longitudinal conductance for overburden layers to saturated zones and transverse resistance values for saturated zone were evaluated from the measured resistivity values and the thicknesses of the layers. Excellent conductance values in the longitudinal direction correspond to high values very good and good Aquifer Protective Capacity (APC), low longitudinal conductance values are associated with poor and weak (APC) are presented in Table (3).

Table (3): Longitudinal conductance/aquifer protective capacity rating [Oladapo et al. (2004) and Adeniji et al. (2014)]

Longitudinal conductance (mhos)	Aquifer protective capacity rating
> 10	Excellent
5 – 10	Very good
0.7 – 4.49	Good
0.2 – 0.69	Moderate
0.1 – 0 .19	Weak
< 0.1	Poor

The thickness of the resistivity results is defined as transverse resistance (T) (Figure 16). Based on empirical evidence, it can be concluded that the transmissivity of an aquifer is proportional to its transverse resistance (Henriet, 1975; Ward, 1990). Clay layers are associated with low resistivity and low hydraulic conductivity, while high resistivity is linked to high hydraulic conductivity. Therefore, the protective capacity of the overburden can be evaluated based on the ratio of thickness to resistivity. The transverse resistance map shows that high values of (T) (>400 ohm.m2) are found in zones of high transmissivity in the southern part of the study area.

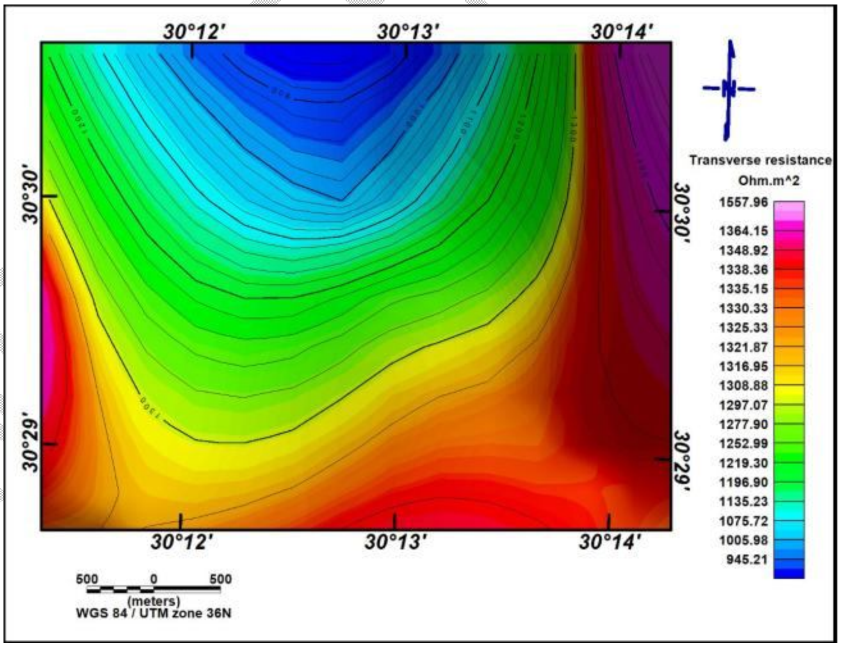


Fig. (16): Transverse resistance map

The map of longitudinal conductance (Fig. 17) illustrates the protective capacity of the overburden layers on the saturated zone. In this illustration, values of S > 1.0 siemens would indicate zones in which the aquifer would be protected. In comparison, values of S < 1.0 siemens would indicate zones of probable risks of contamination. According to table (3) the rating of longitudinal conductance is > 2 the aquifer protective capacity is moderate to excellent that observed in the northwestern and southeastern of the study area. When, the rating of longitudinal conductance is < 2 the aquifer protective capacity is weak to poor that observed in the central and southwestern part of the study area.

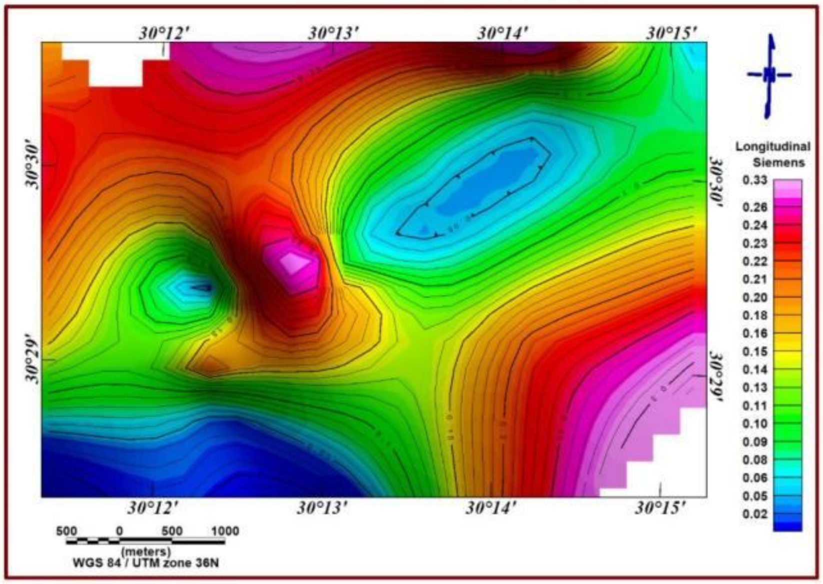


Fig. (17): Longitudinal conductance map

Conclusion and recommendation

The results of the quantitative interpretation of the geoelectrical resistivity sounding data have been used to create five cross-sections which show how the strata vary in terms of their resistivity values. Three subsurface sections, each made up of five geoelectrical layers, have been measured along the trends (A - A', B - B', and C - C'). The presence of groundwater in the study area was identified using information from a drilled well and the results of the geophysical interpretation. According to the analysis, the center of the area is expected to have a shallow depth of water (22.7-41.4m). The water depth increases in other parts of the area, reaching 40-60m near the northern and eastern boundaries. This can be attributed to the changes in the surface geography of the area. As a result, the central section of the area with a 34-meter depth is preferred for drilling new water wells.

The results of the study reveal that the water-bearing layer in the research area is the thickest in the center with a maximum thickness of 46.8 meters and gradually decreases towards the south, reaching a thickness of 8.86 meters. The water table in the area ranges from 8.6 to -22.7 meters and the gradient of the water flow is typically around 3.5 m/km. The primary aquifer in the region is made up of Pleistocene layers of Nile sands and gravels with occasional clay layers. In the north, there are more occurrences of calcareous deposits and clay streaks. The thickness of the aquifer in the area near Wadi El Natrun is approximately 150 meters and gradually increases to about 300 meters as it moves to the east. Most of the groundwater in the Pleistocene aquifer is either semi-confined or in a free water table state, and the water table has an east-west and north-south gradient.

Although there are sources of contamination on the surface, aquifers are likely to form a direct pathway for contamination. This study indicates that future development projects can be constructed in first-class districts without worrying about aquifer contamination, but that businesses and other projects should be established with extreme caution in the location. The transverse resistance map shows high values of (T) (> 400 ohm.m^2) can be associated with zones of high transmissivity that exist in the southern part of the study area. Finally, the rating of longitudinal conductance is > 2 the aquifer protective capacity is moderate to excellent that observed in the northwestern and southeastern of the study area.

From the above mention, it can be recommended the following items:

1. Government, individuals or estate developers who wish to site borehole within the study area are strongly advised to consider the VES points at the central part of the study area.
2. Laboratory checks can be conducted in order to access the protective capacity of aquifers within regions described as poor and weak before carry any form of activity there.
3. Areas with poor aquifer protective capacity should be avoided for sinking borehole to reduce leachates infiltration to the groundwater.
4. Plastic pipes are more preferable in the areas of good and moderate aquifer protective capacity.

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