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CONTRIBUTION OF GEOELECTRICAL SURVEY METHODS IN STUDYING THE CONDITION OF GROUNDWATER OCCURRENCE IN EL ALAMEIN AREA – NORTHWESTERN COAST - EGYPT

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مساهمة طرق المسح الجيوكهربى فى دراسة ظروف تواجد المياه الجوفية بمنطقة العلمين – الساحل الشمالى الغربى – مصر

الخلاصة: يتناول هذا العمل استخدام طرق المقاومة النوعية الكهربية لدراسة ظروف تواجد المياه الجوفية فى منطقة العلمين، حيث يمتد التتابع الأستراتجرافى فى هذه المنطقة من العصر الميوسينى المبكر إلى العصر الحديث، والذى يشمل العديد من الطبقات الحاملة للمياه، وأهمها خزانات ما بعد الميوسين.
تم اجراء ٣٥ جسة جيوكهربية رأسية موزعة فى ترتيب شبكى بمنطقة الدراسة لتحديد خواص الخزان (العمق والسمك والمقاومة النوعية والأمتداد). كما تم عمل عشرة برفيلات للمقاومة النوعية ثنائية الأبعاد لتحديد الحد الفاصل بين المياه الآسنة (مويلحة) والمالحة بدقة. الى جانب ذلك جرت محاولة لتحديد مسامية خزان الحجر الجيرى البطروخى من القياسات ثنائية الأبعاد. وفى هذا الصدد ، تم تحديد المقاومة النوعية لكل من السوائل والجزء المشبع بالماء المالح من الخزان واستخدامها جنبا إلى جنب فى معادلة "آرشي".
أظهرت النتائج وجود خزان ضحل من الحجر الجيرى البطروخى يتراوح عمق السطح العلوى له من ٣ أمتار تحت المنخفض إلى ١٩ مترا تحت التلال وتتراوح جودة المياه فى هذا الخزان من الآسنة الى المالحة. ويتكون هذا الخزان من ثلاثة أجزاء ، الجزء العلوى مشبع بماء آسن و الجزء الأوسط مشبع بالمياه المالحة والجزء السفلى مشبع جزئياً بالمياه المالحة ويتراوح عمق الحد الفاصل بين الماء الآسن والمالح من ٦ أمتار إلى ٣٧,٧ متراً. كما وجد أن المسامية المحسوبة للجزء المشبع بالماء المالح من هذا الخزان تتراوح من ٣٣% الى ٣٩% والتى توضح تطابقاً جيداً بين المسامية المقاسة عن طريق اختبارات ضخ الآبار وتلك المحسوبة من القياسات ثنائية الأبعاد.
يتأثر هذا الخزان الضحل بغزو مياه البحر من اتجاه الشمال (البحر المتوسط) ونتيجة لذلك يغوص الماء المالح ذو الكثافة العالية تحت الماء الآسن فى اتجاه اليابسة وبالتالى يصبح الحد الفاصل بينهما أعمق اتجاه الجنوب تحت التلال الحالية و بدوره يزيد سمك طبقة المياه الآسنة فى هذا الاتجاه.
يوصى بحفر الآبار اليدوية فى التلال بحيث يكون عمقها أقل من عمق الحد الفاصل بين الماء الآسن والمالح، وينبغى أن يكون السحب من تلك الآبار تحت السيطرة لتجنب الاستنزاف وارتفاع هذا الحد الفاصل وبالتالى التلوث بالمياه المالحة.

ABSTRACT: *The present work deals with the use of the geoelectrical methods to study the condition of groundwater occurrence in El Alamein area. The stratigraphic section of this area extends from Early Miocene to Holocene. It includes several water - bearing formations, the most important of them is the Post Miocene aquifers.*
A total of 35 Vertical Electrical Soundings distributed in the form of a grid were carried out in the study area to determine the aquifer parameters (depth, thickness, resistivity & extension). Ten 2-D electrical profiles were also carried out to accurately detect the brackish/saline water interface. In addition, an attempt was made to determine the porosity of the oolitic limestone aquifer using 2-D measurements. In this respect, the fluid and bulk resistivities of the part of the aquifer saturated with saline water were determined and used in conjunction with Archie's formula.
The results revealed the presence of a shallow oolitic limestone aquifer. The depth to top of that aquifer varies from 3 m under the depression to 19 m under the ridge. The water quality ranges from brackish to saline. The aquifer is regarded to be consisting of three parts; an upper part saturated with brackish water, a middle part saturated with saline water and a lower part, partially saturated with saline water. The brackish/saline water interface was found to be at a depth varying from 6 m to 37.7 m. Calculated porosity of the saline water saturated portion of this aquifer was found to vary from 33% to 39% that exhibits a good agreement between the measured porosities and that calculated from 2-D measurements.
This shallow aquifer is invaded by sea water from the north direction (Mediterranean Sea). As a result, the denser saline water penetrated inland below the brackish water. Consequently, the brackish/saline water interface becomes deeper towards the south under the present ridge which, in turn, increases the thickness of the brackish water layer in that direction.
Hand dug wells are recommended on the ridge with total depth less than that of the brackish/saline water interface. The discharge of such wells should be under control to avoid depletion and rising of that interface and hence, contamination with salt water.

INTRODUCTION

The northwestern coast of Egypt receives a greet attention from both the government and people. It is considered to be promising for future land reclamation and sustainable development. The touristic and agricultural activities in this region need new water sources to face the increasing demand for water. The fresh water for domestic uses is transported to this region through water pipes from Alexandria. Groundwater is considered as a significant source of water in this area.

The study area is located between El Alamein to the west and El Omied to the east along the Mediterranean Sea coast. It is bounded by the coastal road (Alexandria - Mersa Matruh) from the north and El Hammam extension canal from the south. This area is bounded by latitudes 30o 44’ 43” & 30o 48’ 45” N and longitudes 29o 01’ 05” & 29o 09’ 26” E. It covers an area of about 80 Km2 (Fig. 1). It set aside for young people as a project of land reclamation. Groundwater exploration along this area using geoelectrical methods (VES & 2-D) can give information about the groundwater occurrences, its potentialities and the extension. The knowledge of this information is of vital importance in the sustainable development of this area.

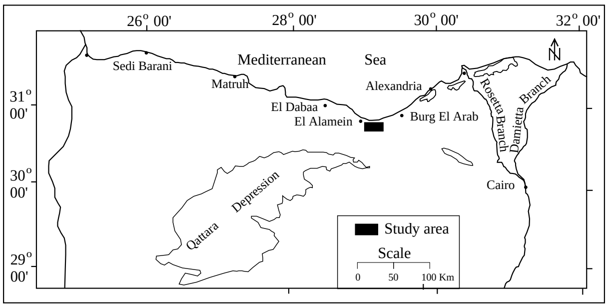

Fig. 1: Location map of the study area.

The study area is characterized by a mild relief with a general slope to the north; also it is characterized by successive elongated high and low landforms. The high landforms are represented by ridges which act as local water divides while the low landforms is represented by depressions which act as water collectors.

The aim of the present work is to study the condition of groundwater occurrence in the study area using conventional Vertical Electrical Sounding together with 2-D profiling. An attempt was made to evaluate the porosity of the oolitic limestone aquifer from the 2-D resistivity measurements and applying Archie’s formula.

Geological and Hydrogeological Settings

Geological and hydrogeological settings of the study area and its vicinities along the northwestern coast of Egypt attracted the attention of many investigations, from which the works of Said et al., 1956; Said, 1962; Abdallah, 1966 b; Abdel Mogheith, 1968; El Shamy, 1968; Omara and Ouada, 1968; Korany (1975), Hilmy et al., 1977 & 1978; Guindy (1989), Abdel Mogheeth et al. (1992), El Maghraby (1997), El Sharabi (2000) and others.

The main physiographic units characterizing this area are: the coastal plain, the frontal plain and the table land as arranged from north to south. The main feature of the coastal plain is the presence of ridges and depressions which run parallel to the shore line. They are composed of white oolitic limestone that varies in age from Sicilian to Monasterian. The frontal plain is located in the area between the third ridge and the table land. It is present in the form of an alluvial plain (Shata, 1970). The table land is located in the southern part of the study area in the form of a structural plateau. It is composed of sandy limestone belonging to Pliocene and Plio-Pleistocene age (El Ghazawi, 1982).

The study area is covered by unconsolidated sand, silt and clay, as well as rock fragments and recent deposits. The subsurface sedimentary succession ranges in age from Quaternary to Miocene. This succession can be classified according to Hilmy et al., 1978 as follows:

Holocene deposits: These deposits cover the land surface and rest unconformably on the oldest rock types with variable thickness. They contain three units (beach deposits, dune sands and alluvial deposits); they are composed of loose, white oolitic sands, chart fragments, shell fragments and finer clastics.

Pleistocene deposits: The Pleistocene section has a great extension along the study area. It thins generally towards the south. It is divided into two main rock units; the first unit is the detrital oolitic limestone which is formed of whitish to creamy brownish layers of oosparite with detrital texture with a thickness of about 60 m. The second unit is the creamy massive limestone which underlies directly the detrital limestone unit with a thickness of about 40 m. It is formed of massive limestone, creamy white to yellow, interbedded with thin bands of sands, sandstones and clays.

Pliocene deposits: These deposits lie under the younger rock unit but in some localities they are exposed with small thicknesses, its average thickness is less than 70 m. The clastic components are the characteristic feature of these deposits. Pliocene section is divided into three rock units namely from top to base sands & clays unit, creamy marly limestone unit and shales & clays interbeds unit.

Middle Miocene deposits: These deposits are exposed on the surface to the south of the coast by about 35 Km. The Middle Miocene section (Marmarica Limestone Formation) is divided into two rock units, an upper cavernous sandy limestone unit and a lower sandy shale and clay unit.

Early Miocene deposits: These deposits are not exposed on the surface at the study area; they are completely hidden under the youngest rocks. The Early Miocene section north of the Western Desert was defined as Moghra formation by Said (1962). These deposits were divided into two formations; Abu Subeiha formation to the north and Moghra formation to the south. The sandy shale is the dominant rock type in Abu Subeiha formation while the sandstone is the dominant rock type in Moghra formation.

Structurally**,** the study area is considered as a part of the unstable shelf of Egypt and it is highly affected by several stages from orogenic and epeirogenic movements. These movements lead to the development of thick succession of sediments that are affected by folding and faulting with general dip to the north and northeast (Korany, 1975).

The hydro-geophysical investigations on the study area and its vicinities are few, from which the works of Mohamed et al. (1974), Shaaban (2001) & Abd Allatief et al. (2002) may be considered.

Hydrogeologically, the study area has extremely low rainfall (average 160 mm/year) with high evaporation and evapotranspiration rates (Abdel Mogheeth et al., 1992). According to Guindy (1989) the groundwater bearing formations in the study area and its vicinities can be classified into the following aquifers from top downward:

Post Miocene aquifers:

These aquifers contain an upper unconsolidated coastal dune aquifer belonging to the Holocene and a lower consolidated detrital oolitic limestone aquifer of Pleistocene. The thickness of the unconsolidated coastal dune aquifer varies between 8 and 2.5 m. with its lower boundary coinciding with the underlying Pleistocene detrital limestone aquifer (Hilmy et al, 1977). The groundwater in these aquifers exists under unconfined condition.

Miocene aquifers:

These aquifers are composed of a consolidated cavernous sandy limestone aquifer of Middle Miocene and a consolidated sandstone and sandy shale of Lower Early Miocene.

Post Miocene aquifers represent the main aquifers distributed along the study area; they are located at shallow depths from the ground surface. The groundwater of these aquifers was exploited through hand dug wells (sawani) along the Mediterranean coast. These aquifers are the main target of this work. The seaward seepages of the fresh water from the aquifer maintain the hydraulic equilibrium between the upper fresh water and the underlying intruded seawater (Korany, 1975).

In the discussed area, the post Miocene and Miocene aquifers are well developed into successive water-bearing layers, and are exposed in parts on the surface with elevations above mean sea level. These aquifers have direct contact with the Mediterranean Sea at different levels with different thicknesses. They are connected hydraulically with each other by a proper leaky connection. They have great intake areas of well defined characters, with adequate gradient for the groundwater movements (Hilmy et al., 1977).

MATERIALS AND METHODS

To achieve the main target of this work, 35 VES were carried out along a grid to cover the study area (Fig. 2). Some VES stations were located adjacent to hand dug wells to obtain parametric measurements which are considered as the basis of the quantitative interpretation. The conventional 4-electrodes Schlumberger array was used with a maximum current electrode separation (AB) ranging from 600 m to 1400 m. Field resistivity measurements were made using direct current resistivity meter (Terrameter SAS 300 & SAS 1000) with high accuracy. Field measurements in the form of AB/2 and apparent resistivity were plotted on bilogarithmic paper with scale 6.25 to obtain field curve for each VES station.

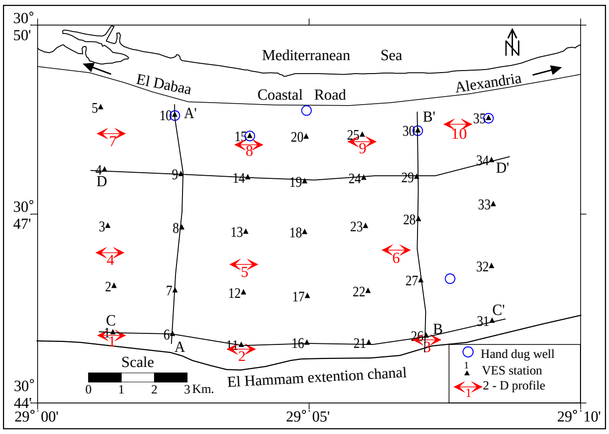

Fig. 2: Location map of VES stations, profiles and hand dug wells.

Quantitative interpretation of these field curves was made using the computer program RESIST (Vander Velpen, 1988) for non automatic iteration method in which the field data are compared with data calculated for an assumed earth layer model. This assumed model is based on all available information obtained primary from hand dug wells and geological and hydrogeological settings.

Beside the resistivity soundings, ten 2-D profiles were carried out in the study area to accurately locate the brackish/saline water interface and help estimating the porosity of the oolitic limestone aquifer. Field measurements of these 2-D profiles were made by applying Wenner configuration using ABEM LUND imaging system (Terrameter SAS 1000, electrode selector ES 10-64, and multi conductor cables). Field survey technique was carried out with a system where the electrodes are arranged along a line with a constant spacing (a) between adjacent electrodes at the same datum points and increasing this space by a multiply factor (2, 3, 4, etc.…) of a spacing to increase depth penetration (Fig. 3). RES2DINV program was used to interpret these 2-D measurements. This program automatically determines a two-dimensional (2-D) resistivity model for the subsurface for the data obtained from electrical imaging surveys (Griffiths and Barker, 1993).

Four water samples were collected from the hand dug wells (sawani) in the study area beside a water sample from the Mediterranean Sea. These water samples were analyzed using methods adopted by USGS (Rainwater and Thatcher, 1960) to determine their electrical conductivity (EC) and total dissolved solids (T.D.S). Electrical resistivity of these water samples were obtained using Schlumberger log interpretation charts (1984) to calculate the formation resistivity factor of the part of the oolitic limestone layer saturated with saline water.

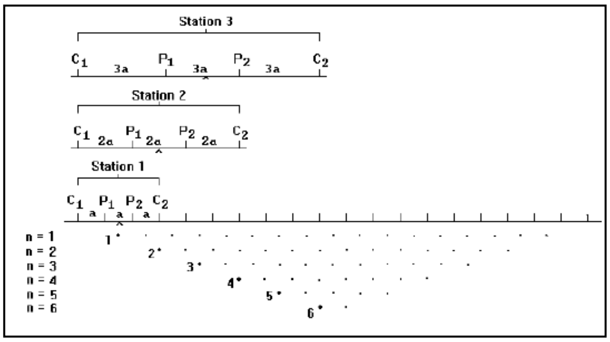

Fig. 3: Measurement sequence of the 2-D profiles. (after Geotomo, 2004)

RESULTS AND DISCUSSION

1- Vertical Electrical Sounding:

Qualitative interpretation can be used to compare between different Vertical Electrical Sounding stations; it gives an idea about the relative changes in the apparent resistivities and thicknesses of the different layers. Also, it gives information about the types of curves, the number of layers and the degree of homogeneity of the subsurface layers. The study area is characterized by five field curve types (Fig. 4) which are QQ, KQ, QH, KH and HKH. All field curves, except the northern field curves, end by H type that reflects homogeneity and continuity of the subsurface. The surface layers are characterized by either Q, K or H types which reflect the variation in resistivities and thicknesses of these layers.

Quantitative interpreted data of each VES station was represented in terms of thicknesses and resistivities which were correlated with the actual data obtained from the adjacent water points. The interpreted sounding data were used to construct 4- geoelectrical cross sections (Figs. 5, 6, 7 & 8) to identify the distribution of the resistivities, thicknesses, depth to water and depth to brackish/saline water interface along the study area. These interpreted data reveal that the geoelectrical succession in the study area consists of five geoelectrical layers, the following is the brief discription of these layers from top downwards:

1- Geoelectrical layer A:

This layer is considered as the dry surface cover, it consists of few thin layers that are composed of alluvial deposits (calcareous sand, shell fragments, silt & clay). The average resistivity of this layer varies widely from 16 Ohm.m at VES 25 to 429 Ohm.m at VES 23. This wide variation in resistivity can be attriuted to the variations in moisture content and fine materials of this layer. The thickness of this layer ranges from 0.3 m at VES 15 to 2.4 m at VES 28.

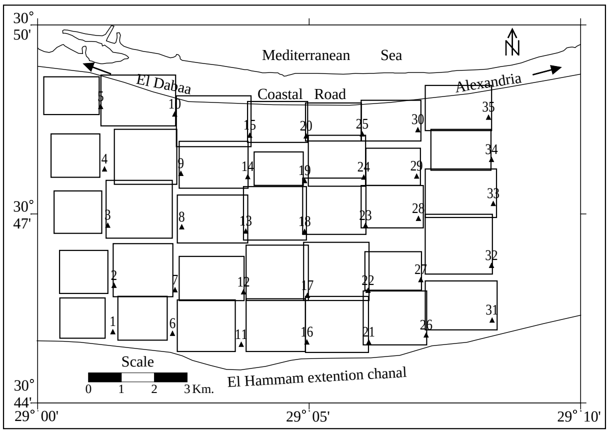

Fig. 4: Aerial distribution map of the VES stations.

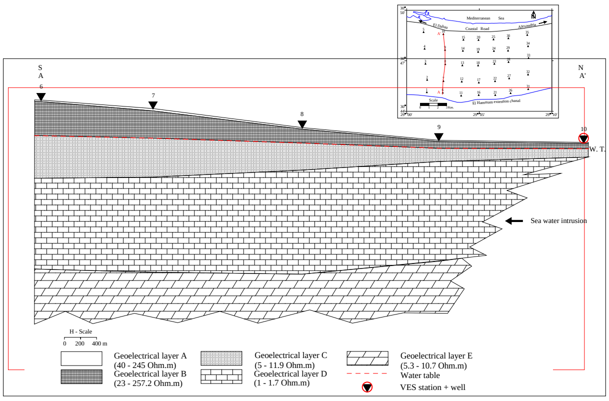

Fig. 5: Geoelectrical cross section A-A'.

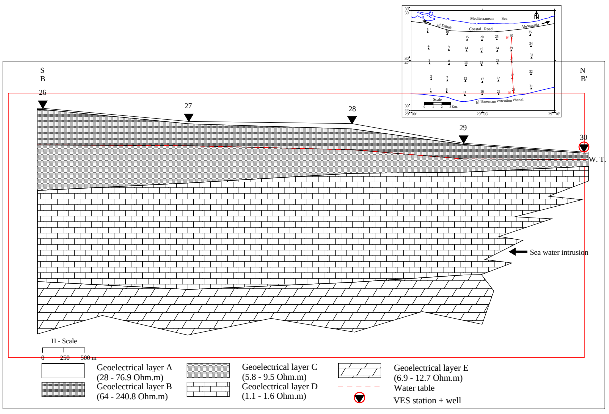

Fig. 6: Geoelectrical cross section B-B'.

2- Geoelectrical layer B:

This layer corresponds to dry oolitic limestone, it consists essentially of dry oolitic limestone present above the water table in the study area. Its resistivity varies from 13 Ohm.m at VES 5 to 536 Ohm.m at VES 17 and its thickness ranges from 2.5 m at VES 10 to 18.1 m at VES 2. Generally, the resistivities and thicknesses of this layer decrease towards the north. The lower boundary of this layer can be correlated with the water table in the study area.

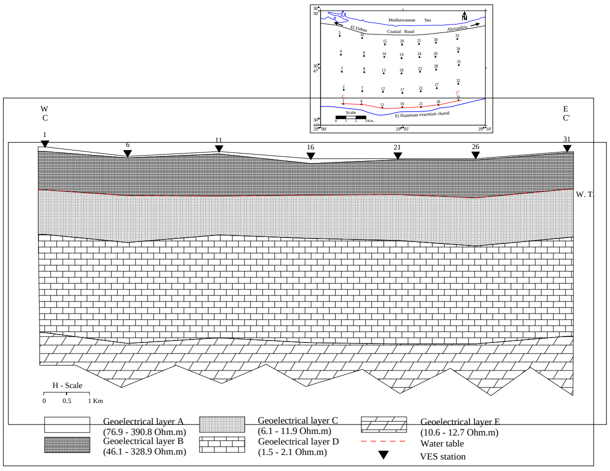

Fig. 7: Geoelectrical cross section C-C'.

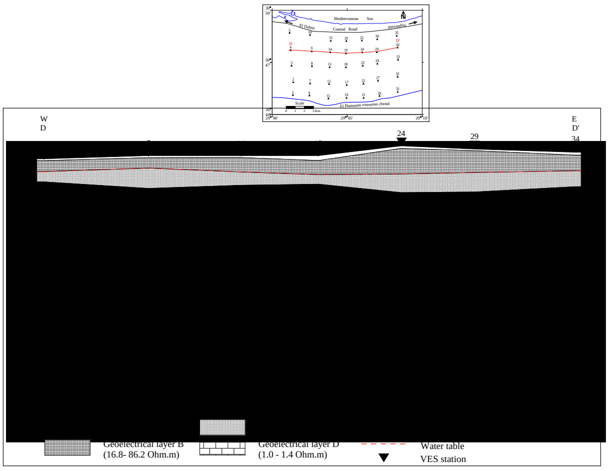

Fig. 8: Geoelectrical cross section D-D'.

3- Geoelectrical layer C:

This layer is represented by the Pleistocene oolitic limestone saturated with brackish water. The TDS measured of the groundwater samples collected from hand dug wells of this layer range from 1859.2 ppm to 3465.8 ppm. It has resistivity values ranging from 5 Ohm.m at VES 10 to 12 Ohm.m. at VES 6 and its thickness varies from 2.1 at VES 20 to 21.6 m. at VES 31. The resistivity of this layer decreases generaly toward the north and increases toward the south west (Fig. 9). Its thickness increases from north to south (Fig. 10). The depth to the upper surface of this layer, which is considered as the depth to the water in the study area ranges from 3 m at VES 10 to 19 m at VES 2 as measured from the ground surface, it increases from north to south (Fig. 11).

4- Geoelectrical layer D:

This layer can be correlated with the oolitic limestone saturated with saline water, it indicate sea water intrusion on the shallow Pleistocene aquifer. It is characterized by low resistivity values which range from 1 Ohm.m at VES 9 to 2 Ohm.m. at VES 21, and its thickness varies from 42 m at VES 1 to 55 m at VES 24. The depth to the upper surface of this layer, which considered as depth to brackish/saline water interface in the study area, ranges from 6 m at VES 5 to 37.7 m at VES 31 as measured from the ground surface, it increases from the north under the depression to the south under the ridge (Fig. 12).

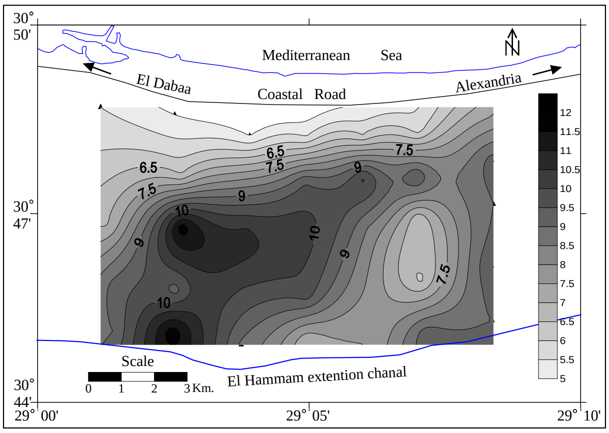

Fig. 9: Iso-resistivity contour map of geoelectrical layer C.

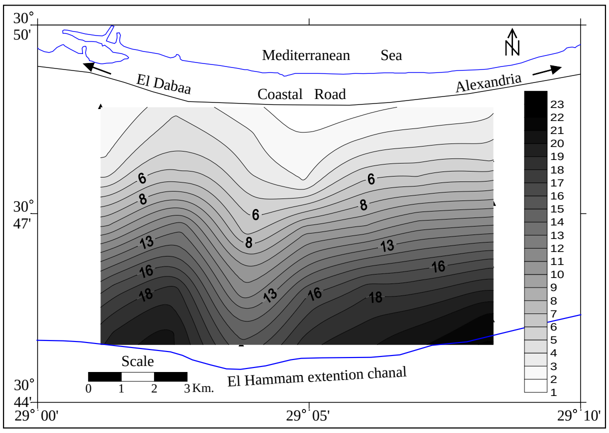

Fig. 10: Iso-pach contour map of geoelectrical layer C.

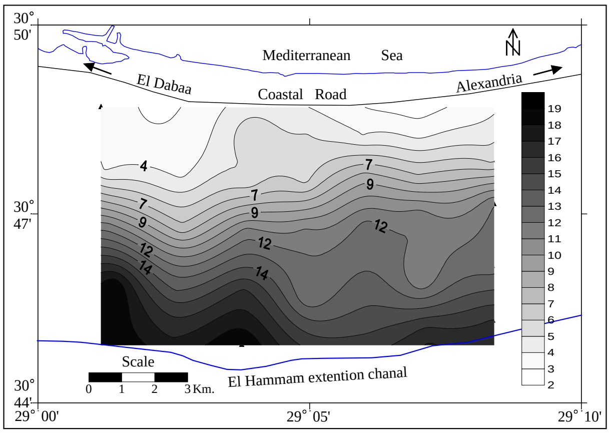

Fig. 11: Depth to water contour map in the study area.

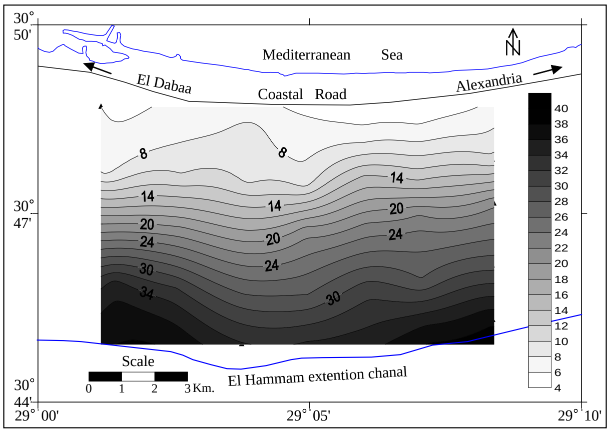

Fig. 12: Depth to brackish/saline interface contour map in the study area.

5- Geoelectrical layer E:

This layer is represented by Pleistocene massive limestone, it is partialy saturated with saline water. It has resistivity values ranging from 5 Ohm.m at VES 9 to 14 Ohm.m. at VES 23. Its lower boundry was not reached.

2- Two dimensional (2-D) technique:

To follow up the brackish/saline interface in the study area, ten 2-D profiles were carried out (Fig. 2). They are distributed along the study area in the form of a grid, three profiles in the southern part, three profiles in the central part, and four profiles in the northern part where the interface is expected to be at shallow depths.

In the southern part, three 2-D profiles were carried out with a total length of each profile of 300 m. The minimum distance between the adjacent electrodes (a) was 10 m and 5 m. The interpreted model of these profiles (Fig. 13) indicates that the depth to water in the southern part varies from 18 m at profile No. 1 to 21 m at profile No. 2 and depth to brackish/saline interface varies from 32 m at profile No. 2 to 39 m at profile No. 3 which lies due to the east direction.

In the central part, three 2-D profiles were carried out, the total length of each profile was 300 m and the smallest distance between the adjacent electrodes (a) was 10 m and 5 m. The interpreted model of these profiles (Fig. 14) indicates that, the depth to the water in the central part varies from 12 m at profile No. 6 to 17 m at profile No. 4 and depth to brackish/saline interface varies from 20 m at profile No. 5 to 29 m at profile No. 6.

In the northern part, where the water table and the brackish/saline interface are located at shallow depths from the ground surface, four 2-D profiles were carried out. The total length of each profile was 150 m with (a) varying from 2.5 m to 5 m. The interpreted model of these profiles (Fig. 15) indicates that the depth to the water in this part varies from 4 m at profile No. 7 to 6.4 m at profile No. 8 and depth to brackish/saline interface varies from 6.5 m at profile No.10 to 7 m at profile No. 7.

3- Porosity Estimation:

Formation resistivity factor is a function of the effective path length of the electric current flow and the effective cross-sectional area available for electric conduction (Pantode & Wyllie, 1950). It is defined as the ratio between the electric resistivity (ρo) of a rock sample saturated with a conducting salt solution and the resistivity of that salt solution (ρw) saturating such rock sample. Formation factor can be calculated from Archie's equation (1942) as: $F = \rho o/\rho w$

Also, Archie, 1942 proposed the relation between the formation factor and the effective porosity as:

$F = a\ \Phi\text{-}m$

Where: m= cementation factor

a= a function of tortuosity

So, $\rho o/\rho w = a\ \Phi\text{-}m$ or $\rho w/\rho o = a\ \Phi m = 1/F$ (1)

To estimate the porosity of the oolitic limestone aquifer the brackish/saline interface in this aquifer must be accurately determined first from 2-D profiles and then applying Archie's equation to the saline portion of this aquifer to avoid the uncertainties of both fluid and bulk resistivities of the brackish portion of the aquifer, also to avoid the effect of the double electrical layer which tends to decrease the electrical conductivity in dilute concentration of the electrolytes.

ρo (bulk resistivity) is directly obtained from 2-D interpreted model. It ranges from 2.01 Ohm.m to 1.4

Ohm.m. Where, ρw (saline water resestivity) is exactly obtained from the salinity of the Mediterranean Sea water sample at 25°C, and Schlumberger log interpretation charts, to be equal to 0.18 Ohm.m. Also, a and m are obtained from Humble's formula for soft formations (Schlumberger, 1984) as :

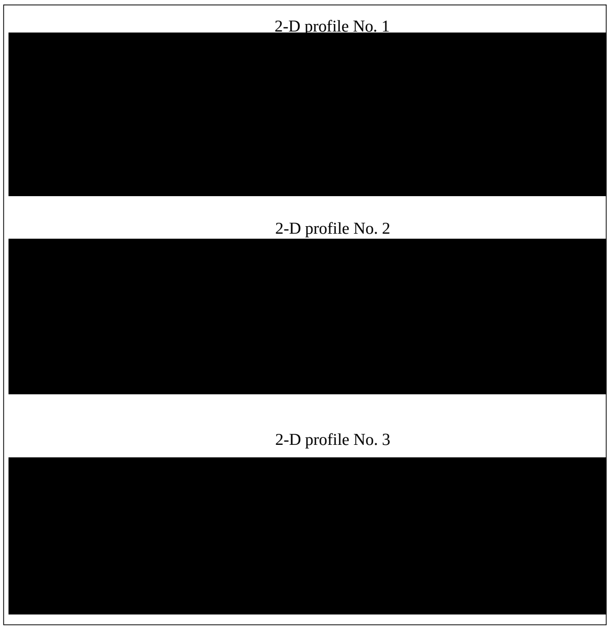

Fig. 13: Interpreted model of the 2-D profiles No. 1, 2 &3.

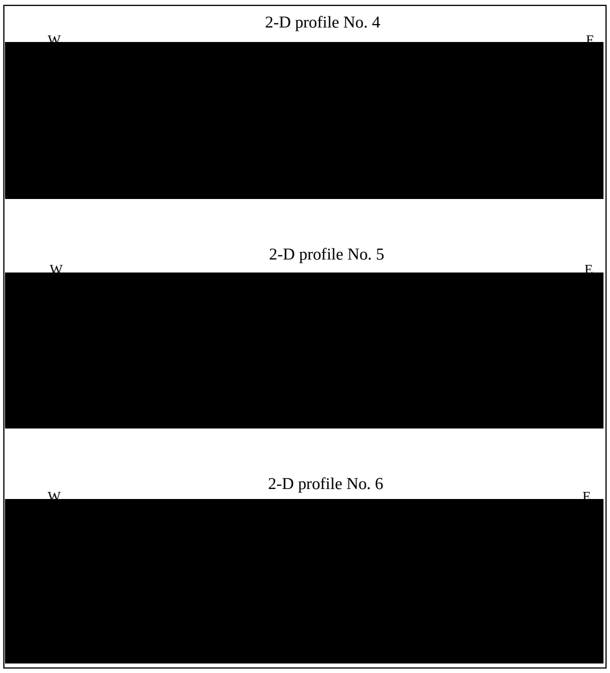

Fig. 14: Interpreted model of the 2-D profiles N0. 4, 5 & 6.

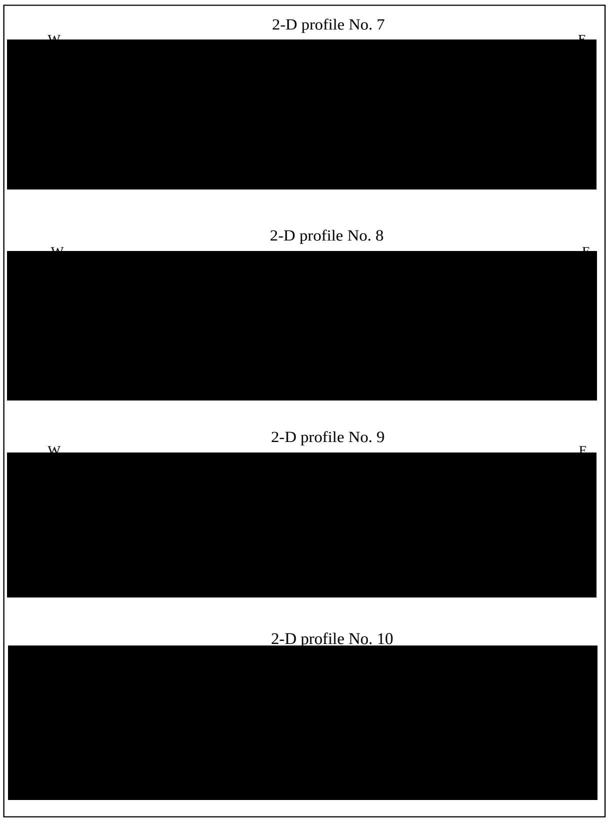

Fig. 15: Interpreted model of the 2-D profiles N0. 7, 8, 9 & 10.

$F = 0.81/\Phi^2$ then, $0.18/\rho_o = 0.81\ \Phi^2$ …… (2)

Applying equation (2) using the previous values of the bulk resistivity, the obtained porosities were found to be ranging from 33% to 39%. The calculated porosity values are comparable with that measured in the work of Hilmy et. al. 1977, where the measured porosity (pumping test) of the Pleistocene oolitic limestone in the coastal area was found to be vary from 29% to 45% with an average value of 34%.

CONCLUSION AND RECOMMENDATIONS

Geoelectric methodes represented by Vertical Electric Sounding and 2-D profiling were used in this work to study the condition of groundwater occurrence in east El Alamein area, Northwestern coast of Egypt. From this study it is clear that:

1- The geoelectrical succession in the study area consists of three main zones. The first two zones are dry while the third zone is saturated and diffrentiated to three successive geoelectrical layers, the upper is saturated with brackish water, the middle with saline water and the lower being a partially saturated layer.

2- The water table possesses a smooth curved surface above the mean sea level and follows the land topography. Depth to the water table varies from 3 m at the depression to 19 m at the ridge. It increases southward (inland direction).

3- Pleistocene oolitic limestone represents the main aquifer in the study area. It contains an upper brackish water-bearing layer, a middle saline water-bearing layer and a lower: partially saturated massive limestone layer.

4- The Pleistocene aquifer is affected by sea water intrusion, where the denser saline water tends to penetrate inland below the brackish water. The brackish/saline water interface is located at depths varying from 6 m at the depression to 37.7 m at the ridge. Its depth increases southward under the ridges (inland direction).

5- The calculated porosity of the saline water saturated portion of this aquifer was found vary from 0.33 to 0.39 which exhibit a good agreement with the measured porosity of this aquifer through pumping test analysis.

6- Hand dug wells are recommended, and the best locations of the proposed water wells are at VES stations No. 1, 6, 7 & 12 (southwest corner of the study area). The rate of discharge of these wells must be controlled to avoid depletion and rise of the brackish/saline interface which causes contamination with salt water.

7- The newly cultivated land projects must use modern irrigation and drainage systems to avoid the rise of the water table in the low land areas (depressions) where the water table exists at shallow depths.

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