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APPLICATION OF RESISTIVITY METHOD FOR GROUNDWATER EXPLORATION IN BARRANI - SALUM SECTOR, NORTHWESTERN COAST, EGYPT

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تطبيق طريقة المقاومة النوعية الكهربية في استكشاف المياه الجوفية

بين سيدي براني - السلوم - مصر

الخلاصة: تعتبر المنطقة الساحلية بين سيدي براني والسلوم واحدة من المناطق الواعدة للتنمية في المستقبل. ويواجه تطبيق أنشطة التنمية مشكلة نقص المياه العذبة، ومصدر هذه المياه العذبة هي المياه الجوفية الضحلة التي تتأثر بشدة من تسرب المياه المالحة من البحر الأبيض المتوسط والذى يسبب تباينا كبيرا في نوعية المياه. عن طريق تطبيق طريقة شلمبرجير، تم تنفيذ ٥٤ سبرا كهربائيا عموديا (VES). كما تمت معالجة البيانات التي تم جمعها وتفسيرها لتحديد معالم الطبقة تحت السطحية وكذلك نوعية المياه الجوفية وأماكن المياه المالحة / المياه العذبة. وتشير النتائج إلى أن منطقة الدراسة تتأثر إلى حد كبير بمياه البحر مما يؤثر على نوعية المياه الجوفية وبالتالي على صلاحيتها للاستخدامات المختلفة. ويمثل الجزء الشمالي الغربي من منطقة الدراسة قرب السلوم المنطقة المتضررة بشدة من تسرب المياه المالحة مما يقلل من احتمال تواجد المياه العذبة. أما الأجزاء الجنوبية الشرقية من منطقة الدراسة القريبة من سيدي براني فهى اقل تأثراً مما يجعلها أفضل المواقع المحتملة لتواجد المياه الجوفية العذبة بها. كشف مسح المقاومة الكهربائية أن المياه الجوفية الضحلة توجد بشكل عام متخللة الطبقتين الجيوكهربائيتين الثالثة والرابعة واللتين تختلفتين في المقاومة النوعية، وتشيران إلى إختلاف نوعية المياه من العذبة و قليلة الملوحة إلي المياه المالحة. وتتحكم التضاريس بشكل رئيسى على غزو المياه المالحة لغزو للأجزاء الشمالية الغربية من منطقة الدراسة أكثر من الأجزاء الشمالية الشرقية كما هو واضح من المقارنة بنموذج الارتفاع الرقمي باستخدام نظام المعلومات الجغرافية. كما تظهر الطبقة الحاملة للمياه زيادة تدريجية في المقاومة نحو الأجزاء الشرقية والجنوبية. ويظهر سمك هذه الطبقة زيادة تدريجية في الجنوب مشيرا إلى أفضل إمكانيات لتواجد المياه العذبة. ويزداد عمق المياه الجوفية بشكل عام نحو الأجزاء الشرقية والجنوبية التي تتراوح بين حوالي ١٠ إلى ٥٠ م. وقد تم الاستدلال أيضا على وجود صدعين في مختلف القطاعات الجيوكهربية. والتي تمتد في الاتجاه شمال شرق – جنوب غرب. الشمال يؤثران على حركة المياه.

ABSTRACT: *The coastal zone between Sidi-Barrani and Salum is one of the promising zones for future development. In such area, the soil quality and climate are generally suitable for agricultural activities. Nevertheless, the application of such activities is facing the problem of water shortage. In this area, the main source of fresh water is the shallow groundwater aquifer which is highly affected by salt water intrusion from the Mediterranean Sea causing a great variation in water type.Using Schlumberger configuration, 54 vertical electrical soundings (VES) have been carried out. The collected data were processed and interpreted to determine the subsurface layer parameters as well as the groundwater quality and location of salt/fresh water interface. Results show that the study area is largely invaded by sea water which affects the groundwater quality and accordingly its suitability for different uses. The northwestern part of the study area near Salum represents the highly affected area by saltwater intrusion which decreases the probability of fresh water occurrence. The southeastern parts of the study area near Sidi-Barrani have limited saltwater intrusion effect which makes them the most probable locations for slightly brackish or fresh groundwater occurrence.*

1. INTRODUCTION

The northwestern coastal area of Egypt is one of the most promising zones for future development and for establishment of new settlements which offer new opportunities for social and economic development. In this area, agricultural activities are facing the problem of water shortage where the main source of fresh water is groundwater aquifer which is highly affected by saltwater intrusion from the Mediterranean Sea (El-Fiky, 1996). The main objective of the present work is to conduct an electrical resistivity investigation in order to explore the shallow subsurface layers and to determine the shallow groundwater aquifer and its relation to salt/fresh water interface.

The geoelectrical resistivity method depends on the electrical resistivity of the subsurface layers which is highly affected by the presence of water which is directly affects the measured resistivity values (Loke, 1999; Cimino *et al.*, 2008; Mohamed *et al.*, 2011). This method is widely used to delineate the groundwater and to study the saltwater intrusion in coastal environments (Abdel-Fattah, 1984 & 1994; Urish & Frohlich, 1990; Ebraheem *et al.*, 1997; Nowroozi *et al.*, 1999; Edet & Okereke, 2001; Mohamaden, 2001, 2005 & 2009; Shaaban, 2001; Choudhury & Saha, 2004; Khalil, 2006; Asfahani, 2007; Cimino *et al.*, 2008; Balia *et al.*, 2009; de Franco *et al.*, 2009; Mohamaden & Abu Shagar, 2009; Kouzana *et al.*, 2010; Sonkamble *et al.*, 2012 & 2014; Atwia *et al.*,2013; Hewaidy *et al.*, 2015; Mohamaden *et al.*, 2016).

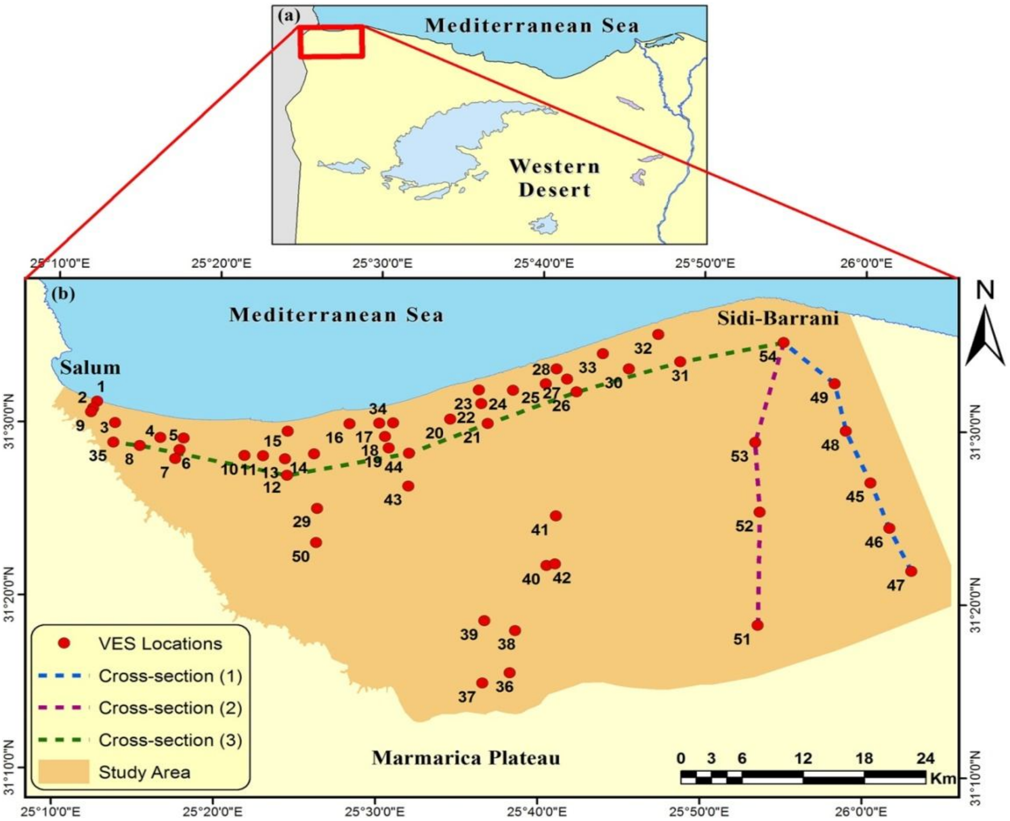

Fig. 1: Location map of the study area.
(a) Location of the northwestern desert. (b) Distribution of VES locations and cross sections.

1.1. Study Area:

The study area is represented by the coastal zone between Sidi-Barrani and Salum, Western Desert, Egypt (Fig. 1a). It lies between latitude 31º 13' 00" and 31º 37' 30" N, and between longitude 25º 10' 00" and 26º 40' 00" E. It is bounded by the Mediterranean Sea in the north and extends southward to the Marmarica Plateau with varying distance from 3 km in the west to 37 km in the east. The main source of fresh water is the rainfall which is responsible to great extend for groundwater recharge. The annual precipitation ranges between 92 mm in Salum and 150 mm in Sidi-Barrani (climate-data, 2015) which indicates that rainfall increases towards the eastern parts near Sidi-Barrani (El-Sayed, 2016). Local inhabitants depend mainly on shallow groundwater and run-off water which is collected in cisterns by different water harvesting techniques (FAO, 1970; Gilli *et al.*, 2012; Sayed, 2013). El-Fiky (1996) and Sayed (2013) classified the shallow aquifers in the study area into two main aquifers; Holocene coastal dune aquifer and Pleistocene oolitic limestone aquifer which represents the most important aquifer in this area.

1.2. Geologic Settings:

In the northwestern coastal zone of Egypt, the exposed rocks are composed of Quaternary sediments followed by Late Tertiary rocks. Quaternary deposits are composed essentially from Holocene alluvial deposits followed by Pleistocene white oolitic limestone, Cardium limestone and pink limestone. Late Tertiary rocks form the major part of the southern plateau. It is represented by Pliocene sediments which acts as a good aquifer (Raslan, 1995), followed by Miocene sediments (Selim, 1969; Atwa, 1979).

Structurally, the dominant structures in the northwestern coast of Egypt are folds and faults. Most folds in this area are formed during Late Cretaceous - Early Tertiary in the NE-SW trend which is related to the Syrian Arc system trend (Shata, 1957; Said, 1990). Most of the faults are step normal faults which have NE-SW and N-S trend. Many sets of joints are recorded which have NW-SE, E-W and N-S directions (Shata, 1955).

2. METHODOLOGY

Electrical resistivity method has been applied in the present study using Schlumberger collinear four Symmetrical electrodes configuration. The principles of Schlumberger configuration survey have been discussed by several authors: Keller & Frischknecht (1966); Kunetz (1966); Bhattacharya and Patra (1968); Zohdy *et al.* (1974); Reynolds *et al.* (2011).

2.1. Data Acquisition:

Fifty four vertical electrical soundings (VESs) were measured in the study area with maximum current electrode separation of 600m using IRIS Syscal-Pro instrument through two field visits. The first field visit was in November, 2013 and the second was in

February, 2014. (Fig. 1b). The ground resistance was checked to assure good contact between the ground and each electrode.

2.2. Data Inversion:

The obtained data is plotted using "IX1D v.3, Interpex" software. Generally, the sounding curve is drawn by plotting the apparent resistivity versus the current electrode spacing (AB/2), on log-log scale. Because the potential electrodes are fixed while the current electrodes spacing expands, the plotted line is segmented. The overlapping line segments may not coincide with each other due to the variation in probing depth, which result from changing the AB/MN ratio at the end of one line segment and the beginning of another line segment or because of the more common reason; lateral in-homogeneities (Deppermann, 1954; Zohdy *et al.*, 1974).

The last line segment, which is measured at the largest potential electrode spacings, is fixed and the other segments are moved up or down to form the continuous field curve (Zohdy *et al.*, 1973, 1974, 1994a&b; Zohdy, 1975, 1988 & 1989; Koefoed, 1979; Mundry, 1980; Al-Garni, 1996). Filed curves have been interpreted qualitatively and quantitatively according to Zohdy (1965, 1989), Ghosh (1971), Telford *et al.* (1990) and Reynolds *et al.* (2011). After data processing and interpretation, layer parameters (true resistivities and thicknesses or depths) of the various penetrated layers can be obtained.

At first, the vertical electrical soundings which are located near some drilled wells have been interpreted to make a calibration with the collected information and to validate the output model. Then, the rest of the soundings have been interpreted. There are several sources of information which have been used to calibrate the interpretation models. Previous geological information about the study area has been used to help in the interpretation process (Selim, 1969; Raslan, 1995; Hosny *et al.*, 2005; Barseem, 2006; Moustafa, 2013). During the field visits, an extensive survey has been done with the local inhabitants to collect beneficial information about the drilled wells, water quality and water depths in different areas. Some groundwater wells were found near some vertical electrical soundings, these wells have been checked to measure the water depth at each well.

2.3. Geographic information system:

Geographic information system (GIS) was utilized to build a geo-database containing the study area and the field measurements in order to generate contour maps showing the spatial variation of the apparent resistivity values and the groundwater depth in the study area. These data were analyzed statistically and then prediction maps were generated using the most suitable kriging method by the statistical analyst of ArcGIS software.

3. RESULTS AND DISCUSSIONS

3.1. Qualitative Interpretation:

The obtained field curves were qualitatively interpreted to indicate the probable number of subsurface layers. Several curve types have been observed such as H, HK, HKH, K, KHK and Q curves. The variation of field curves reflects the lateral and horizontal heterogeneity in the study area (Fig. 2).

The dominant curve type at the study area is HK-type that indicates the presence of a surface high resistivity layer which may be composed of surface dry unconsolidated sediments. These dry surface layer is followed by a shallow clay lens, and followed by a higher resistivity unsaturated zone, then the water bearing layer (Osman, 2011; Reynolds, 2011).

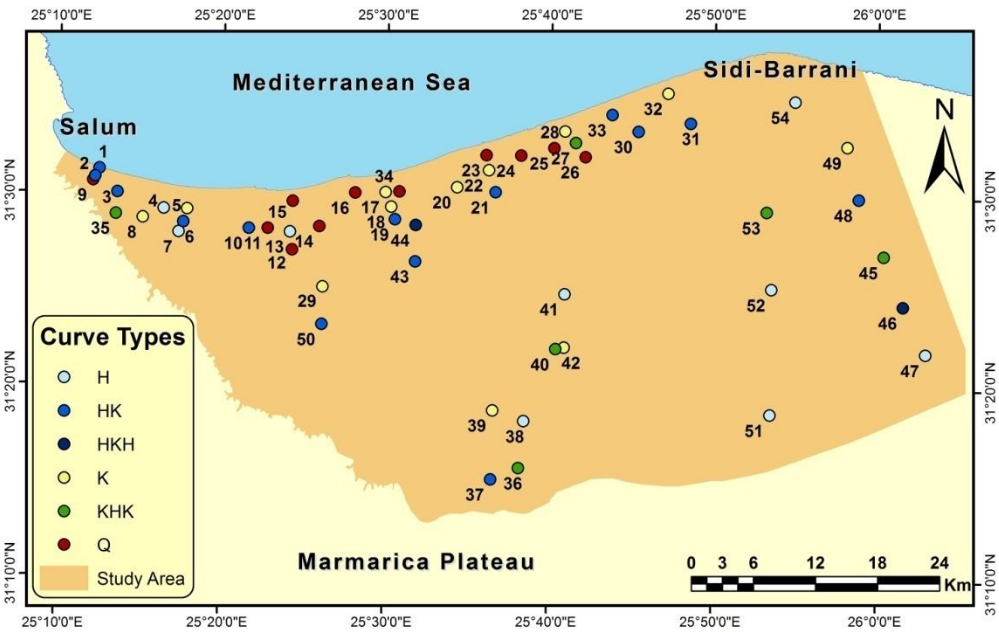

Fig. 2 Different curve types in the study area

K-type curve is commonly observed at the northern parts indicating the presence of a surface low resistivity layer which may be attributed to the soil moisture content. This surface layer is followed by the unsaturated zone and the water bearing layer which are characterized by a high resistivity then a decreasing resistivity, respectively. Q-type is usually detected in the most northern coastal area, where a surface friable sand of a relatively high resistivity is followed by fully saltwater saturated layers due to the intrusion of Mediterranean Sea water.

Iso-apparent resistivity maps show the lateral variation in the measured apparent resistivity at the same current electrode spacing. It provides information about the homogeneity or heterogeneity of apparent resistivity values in different locations at almost the same depth.

Near the shoreline, saltwater gradually invades inland as shown in figure (3 a, b, c & d). The northwestern area and the most northeastern part of the study area are the highly affected locations by saltwater intrusion at shallow depths which may be attributed to the low elevation in these areas as shown in the digital elevation model (Fig. 4). Conversely, the southern parts are characterized by higher resistivities because these locations have high elevation and the shallow layers may be characterized by shallow unsaturated limestone rocks (Osman, 2011). Probable zones of fresh water have been detected, especially in the central and southern parts of the study area which is followed by compacted limestone bedrocks of the southern plateau. Water table is predicted to be nearly at depth ranging from 20 to 30m.

3.2. Quantitative Interpretation:

Three different vertical electric soundings (6, 36 and 49) and their interpreted layers models are shown in Figures (5 a, b & c). They represent three different locations in the study area with different geologic and geomorphologic conditions.

VES no. 6 is located at the northwestern part, near Salum City; this area is characterized by low elevation and high saltwater intrusion. The obtained layer model consists of four geoelectrical units. The resistivity of the first unit is 1807 ohm.m and its thickness is 1.8m. The significant high resistivity values of this unit are attributed to the surface friable and unconsolidated sediments. The second unit is composed of limestone intercalated with clay. It has a resistivity of 187 ohm.m and a thickness of 7.3m. This unit represents the unsaturated zone. The third layer represents the fresh to brackish water bearing layer which is characterized by a resistivity value of 49.9 ohm.m and has a thickness of 12m. The last detected geoelectrical unit is the saltwater bearing layer which is characterized by a very low resistivity (2.51 ohm.m).

VES no. 36 is located at the southern part of the study area, near the southern plateau. This area is relatively high and the effect of saltwater intrusion is limited. The layer model consists of four main geoelectrical units. The first geoelectrical unit is the surface sediments and alluvial deposits. Its resistivity and thickness are 18 ohm.m and 0.4m, respectively. The second geoelectrical unit is the unsaturated limestone intercalated with thin clay bed. This unit has a resistivity ranging from 193 to 278 ohm.m and a thickness of 63.3m. The electrical resistivity value of the third unit decreases to 119 ohm.m with a thickness of 27.7 m. This unit represents the fresh water bearing layer. The layer parameters indicate good water quality and thickness. The main sources of this water are the rainwater and run-off from the southern plateau. The last unit has a resistivity of 6.9 ohm.m and represents the saltwater bearing layer.

VES no. 49 is located at the northeastern part of the study area, near Sidi-Barrani City. The layer model consists of three geoelectrical units. The first unit represents the surface deposits which has a relatively low resistivity (11.3 ohm.m) due to the high soil moisture content in this area. Its thickness is 1.6 m. The second unit represents the unsaturated limestone intercalated with clay. Its resistivity ranges from 30 to 38 ohm.m and its thickness is 43 m. The last detected unit is the water bearing layer that has a resistivity of 12 ohm.m which indicates the presence of brackish water.

Generally, the subsurface geoelectrical units in the study area have been determined and distinguished into five different units; the surface unit of alluvial deposits and friable sands which has a wide range of resistivity values due to its high heterogeneity, the second unit is the unsaturated fractured limestone intercalated with clay, the third unit is the fresh to brackish water bearing layer which has an increasing thickness towards the south, the fourth unit is the saline water bearing layer and finally, the last unit is the compacted limestone bedrock which have been detected in some locations in the most southern part of the study area.

3.3. Geoelectrical Cross-Sections:

Three cross-sections have been generated in the study area. Two of them have almost the north-south direction extending from the southern plateau to the Mediterranean Sea coast. The third cross-section extends from west to east; parallel to the shoreline.

3.3.1. Cross-Section No. 1:

This cross-section extends along 28 km from VES no. 47 near the southern plateau towards the north passing through VES no. 46, 45, 48, 49 and 54 (Fig. 6). The first geoelectrical unit represents the surface layer of alluvial deposits and friable sand. It has a uniform thickness of about 0.5 m. The second unit is composed of unsaturated fractured limestone intercalated with clay lenses. It is characterized by a relative high resistivity especially in the southern part, and gradually decreases towards the north due to increasing the clay content. The third unit represents the water bearing layer which has a resistivity ranging from 12 to 64 ohm.m indicating brackish to fresh water types. The water depth in this area increases from 25 m beneath VES no. 54 to about 50m in the central part of this cross-section. Two probable normal faults have been inferred in this cross-section.

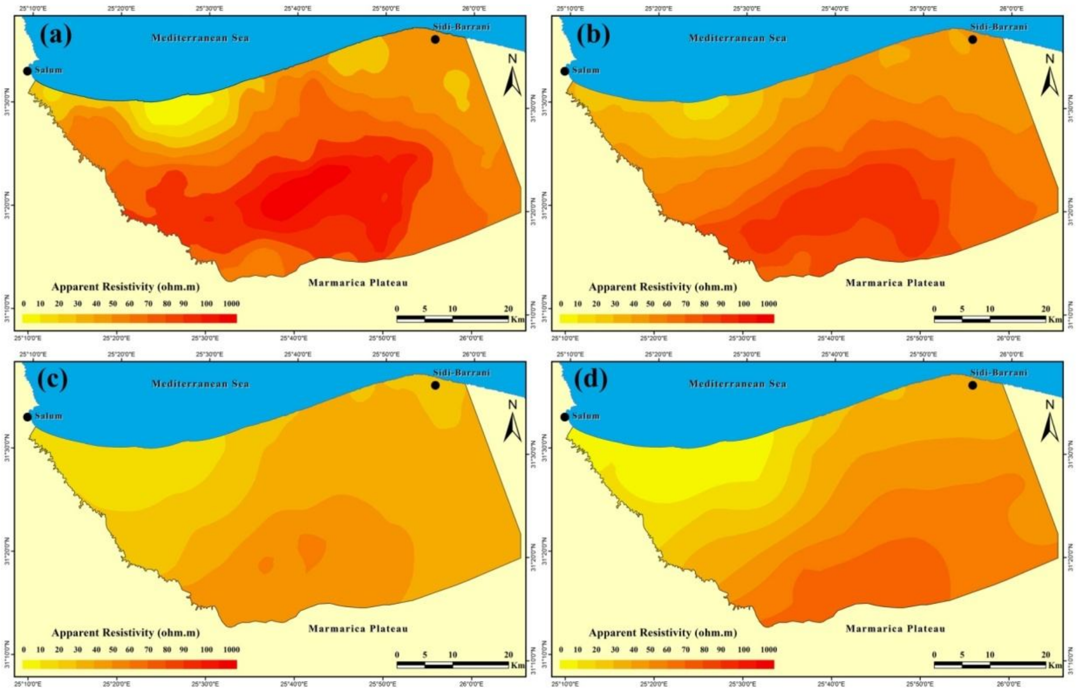

Fig. 3: Iso-apparent resistivity maps at (a) AB/2 = 3 m, (b) AB/2 = 6 m, (c) AB/2 = 25 m, (d) AB/2 = 50 m.

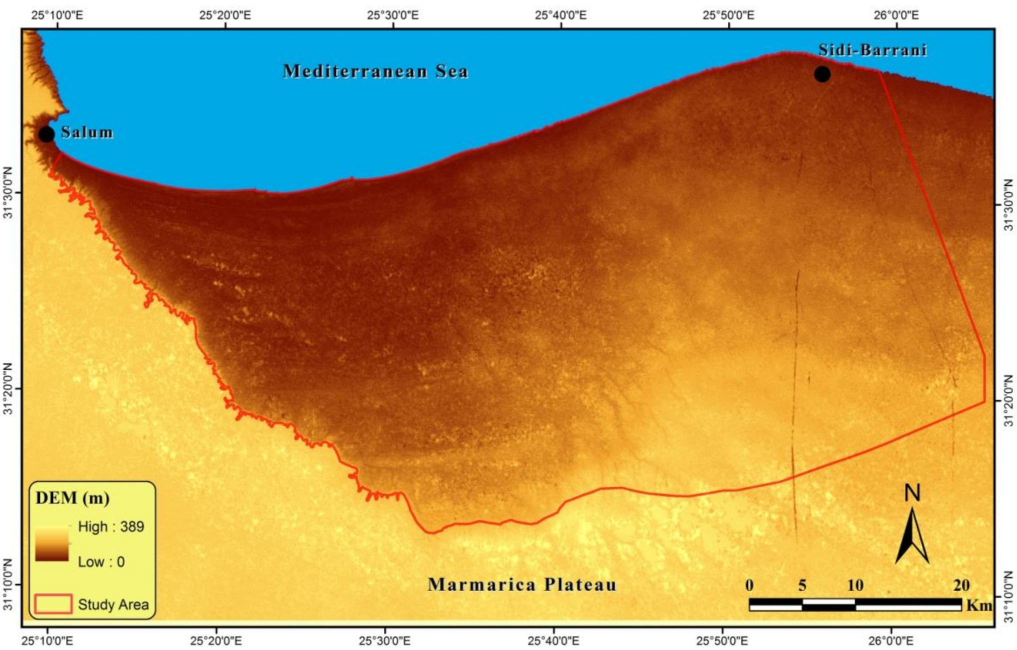

Fig. 4: Digital elevation model of the study area.

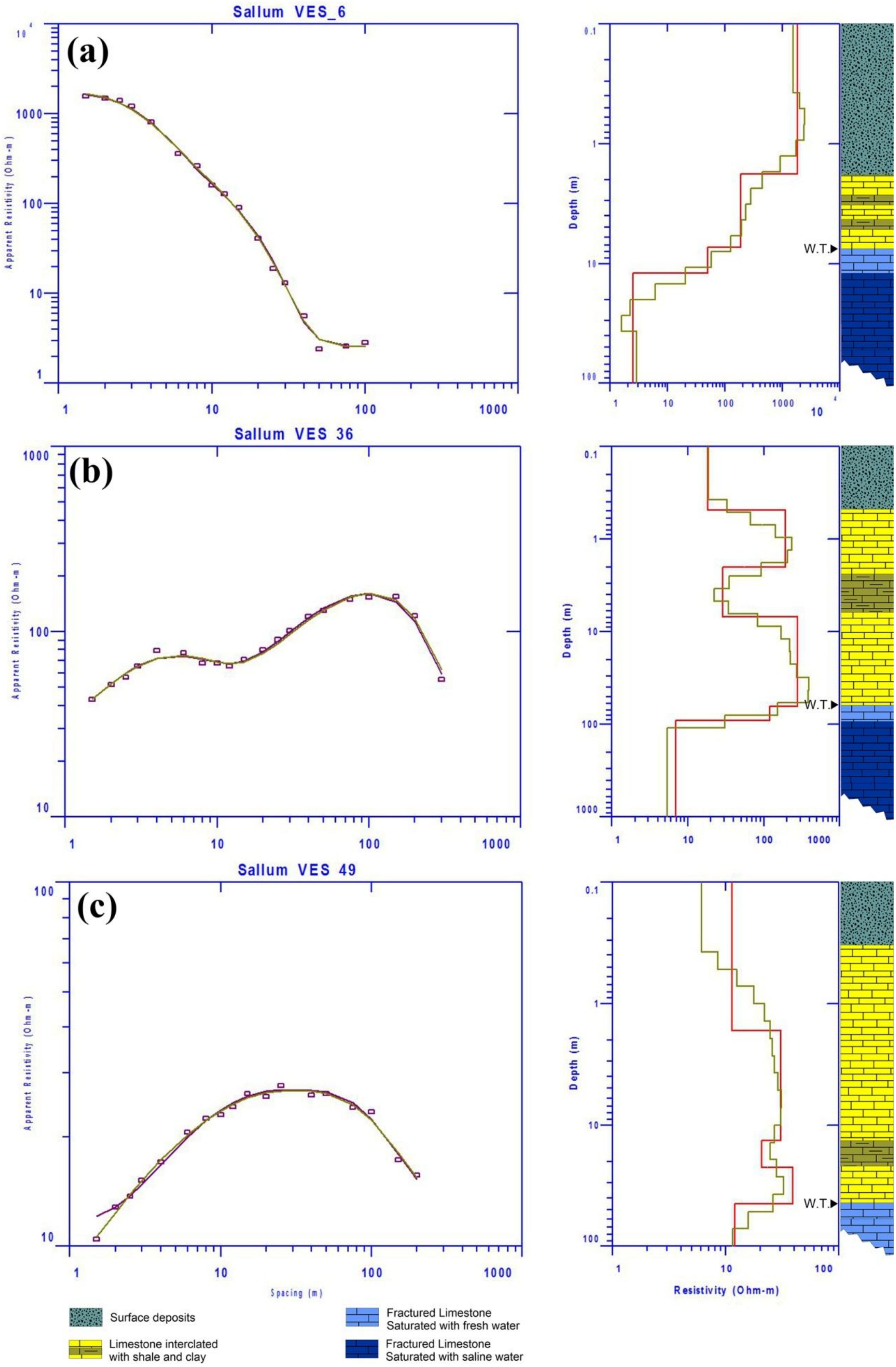

Fig. 5: Layers model of (a) VES-6, (b) VES-36 & (c) VES-49.

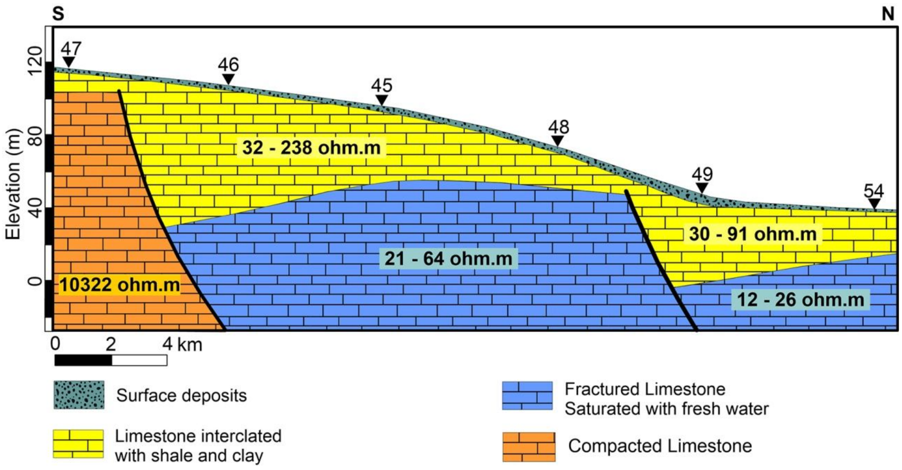

Fig. 6: Cross-section no. 1.

3.3.2. Cross-Section No. 2

This cross-section extends along 30 km from VES no. 51 near the southern plateau towards the north passing through VES no. 52, 53, and 54 (Fig. 7). The surface unit is composed of alluvial deposits and friable sand. It has a uniform thickness of about 0.5 m. The second unit is composed of unsaturated fractured limestone intercalated with clay lenses. Its resistivity ranges between 54 ohm.m in the northern part to 604 ohm.m in the southern part. The third unit represents the water bearing layer which has a resistivity ranging from 22 to 27 ohm.m indicating brackish water type. Two probable normal faults have been inferred in this cross-section which may be the extension of the same detected faults in cross-section no. 1.

3.3.3. Cross-Section No. 3

This cross-section (Fig. 8) extends along 68 km from VES no. 35 in the northwestern part, near Salum City, towards the northeastern part, near Sidi-Barrani City, passing through VES no. 8, 12, 44, 21, 26, 31 and 54. The surface unit is composed of alluvial deposits and friable sand. It has a relative high thickness in the west which decreases gradually to the east. The second unit is composed of unsaturated fractured limestone intercalated with clay lenses. Its resistivity ranges from 16 to 231 ohm.m and its thickness increases towards the east due to the gradual increase in elevation towards the east. The third unit represents the water bearing layer which has a resistivity ranging from 22 to 27 ohm.m indicating brackish water type due to the effect of sea water.

Generally, the water bearing layer shows a gradual increase in resistivity towards the eastern and southern parts. This may be attributed to the presence of fresh water at these locations (Fig. 9).

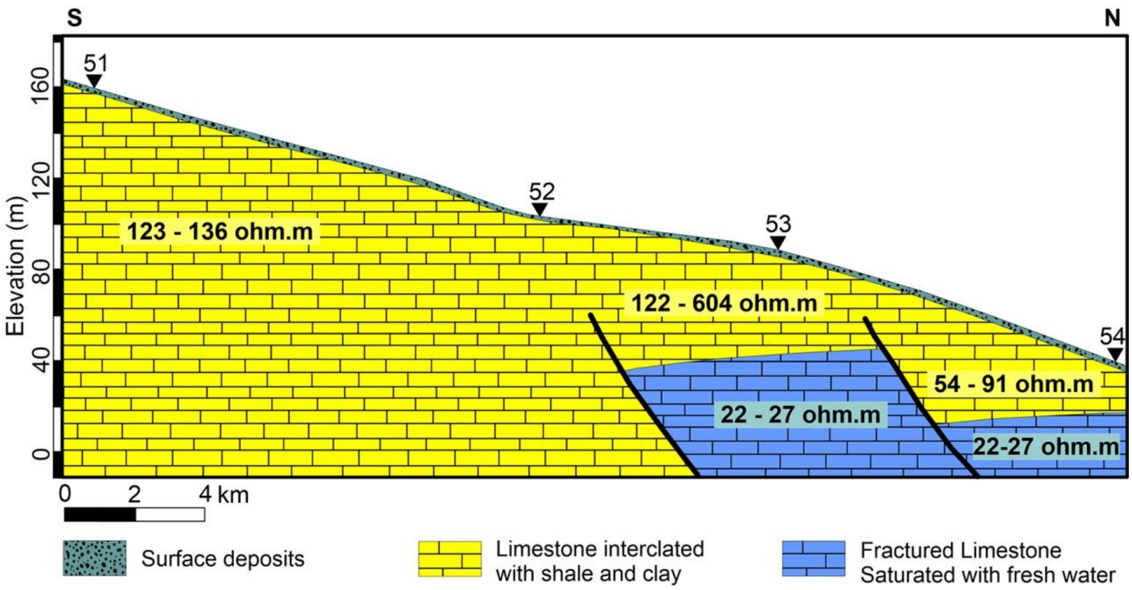

Fig. 7: Cross-section no. 2

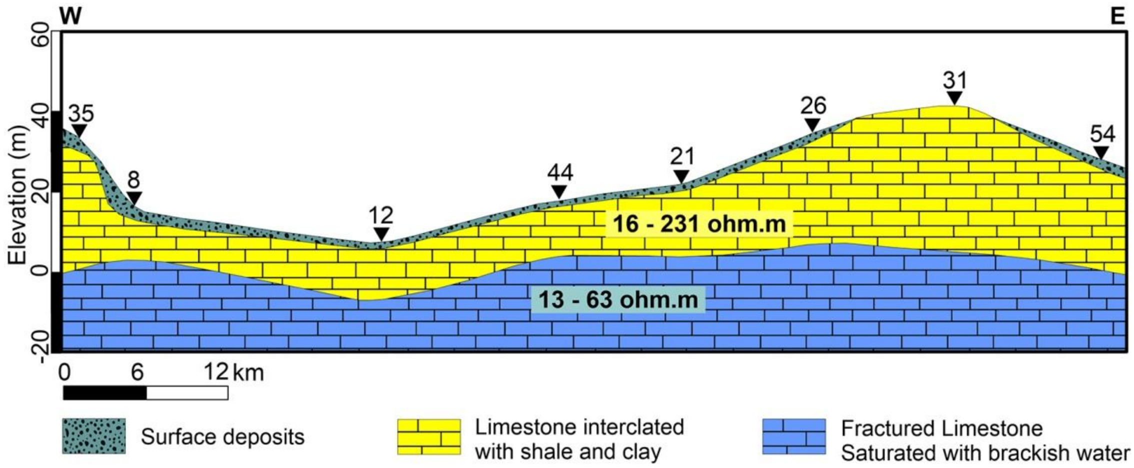

Fig. 8: Cross-section no. 3.

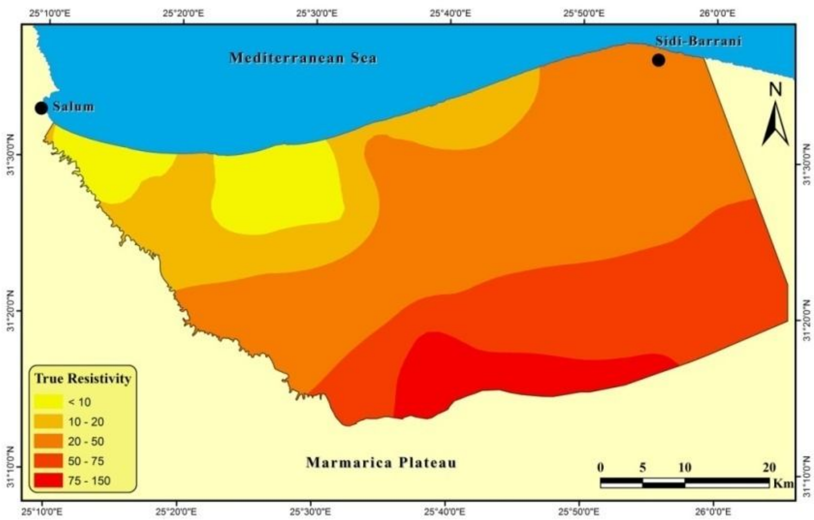

Fig. 9: True resistivity map for groundwater aquifer.

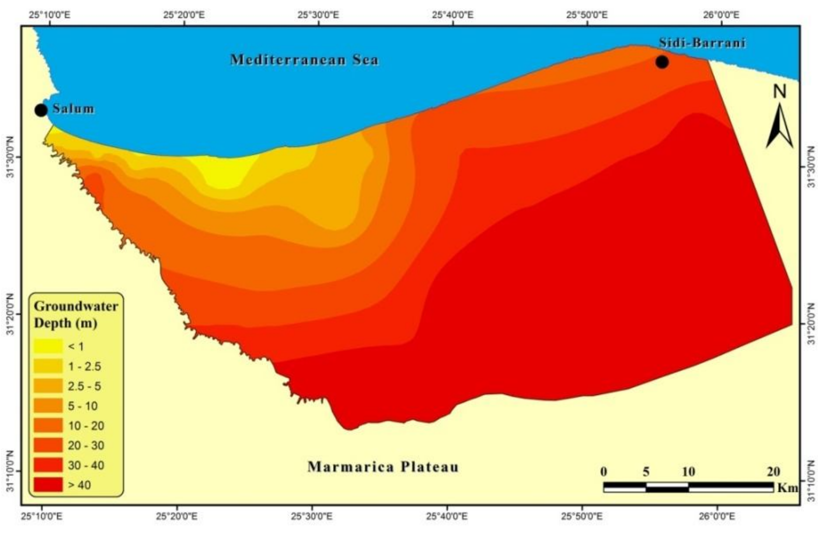

Fig. 10: Depth map for groundwater aquifer

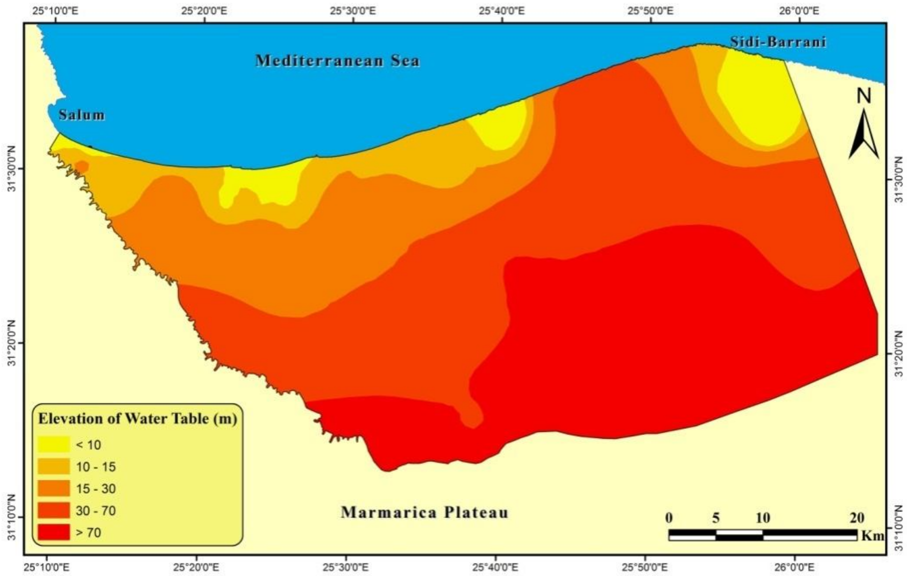

Fig. 11: Elevation of water table from sea level.

The detected thickness of this layer shows a gradual increase to the south indicating better fresh water potentiality. The depth of groundwater generally increases towards the eastern and southeastern parts ranging from about 10 to 50 m as shown in Figures (10 and 11).

Generally, two probable faults have been inferred from the different cross-sections. Both of them are probably extending in NE-SW direction. Many authors discussed the faults distribution in the study area. Bakr & Helmy (1990), EGPC (1992), Ayyad & Darwich (1996) and Moustafa (2008 & 2013), concluded that the study area as a part of the northwestern desert, has affected by the Syrian arc-system. El-Etr *et al.* (1973) concluded that the majors trends to north, northeast and east. Hosny *et al.* (2005) detected the presence of E-W and NE-SW faults in the area between Sidi-Barrani and Salum. Barseem (2006) concluded that the study area has a number of major faults and determined their downthrown towards the north.

4. CONCLUSIONS

The electrical resistivity survey revealed that the shallow groundwater exists in the study area. Its depth and quality show wide changes through the area under investigation that is attributed to the lateral and vertical heterogeneity in this area. The water bearing zone is generally represented by the third and fourth geoelectrical units which vary in resistivity indicating water quality variation from fresh, brackish to saline water. Saltwater intrusion is the main source of water salinity in such area. It is mainly controlled by the topography which explains the tendency of saltwater to invade in the northwestern parts of the study area more than the northeastern parts as revealed from the integration between electrical resistivity data and the digital elevation model using geographic information system.

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