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THE CONTRIBUTION OF GEOELECTRICAL INVESTIGATIONS IN DELINEATING THE SHALLOW AQUIFER IN WADI EL-NATRUN AREA, WESTERN DESERT, EGYPT

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مساهمة البحث الجيوكهربي في تحديد مستودعات المياه الضحلة في منطقة وادي النطرون بالصحراء الغربية بمصر

الخلاصة: تم إجراء عدد ٤٣ جسة كهربية رأسية في منطقة وادي النطرون وذلك لتوضيح التغيرات الأفقية والرأسية للخصائص الكهربية بالأضافة الي إلقاء الضوء علي الظروف الجيولوجية تحت السطحية والهيدروجيولوجية السائدة في منطقة الدراسة. وتمت التأويلات الكيفية والكمية لبيانات المقاومة الجيوكهربية المتاحة في منطقة وادي النطرون للتعرف علي المدلولات الجيولوجية التحتسطحية الضحلة وبحث امكانيات تواجد تجمعات المياه الجوفية بالأضافة الي تعيين المقاومات الكهربية للوحدات الجيوكهربية وسمك كل وحدة.

وبتقييم نتائج قيم المقاومات الكهربية أمكن تقسيم القطاع المدروس الي ثلاث وحدات جيوكهربية مختلفة، حيث تتراوح المقاومة النوعية للوحدة الاولي (السطحية) بين قيم منخفضة ومتوسطة وعالية نسبياً والتي تتكون من الطفل والرمل والحصي. بينما تتراوح المقاومة النوعية للوحدة الثانية بين قيم منخفضة الي متوسطة نسبياً والتي تكون من الرمل وتداخلات من الطفل وهذه الوحدة تمثل الخزان الجوفي الرئيسى للبلايوسين في منطقة وادي النطرون، أما الوحدة الثالثة فهي تتكون من الرمل ذى المقاومات الكهربية العالية نسبياً.

وبدراسة الوضع الهيدروجيولوجي أمكن الاستدلال علي أن خزان البليوسين الجوفي الرئيسي في منطقة وادي النطرون من النوع المقيد الي شبه المقيد ويتكون من الرمل وتداخلات من الطفل يصل سمكه الي ٢٠٠ متر ويزيد سمك الخزان في الاتجاه الشمالي والشرقي في منطقة الدراسة ويتراوح عمق الخزان الجوفي من ٢ الي ٢٤ متراً.

ABSTRACT: *Forty-three vertical electrical soundings are carried out in Wadi El-Natrun area to delineate the lateral and vertical irregularities of electrical properties, as well as to shed light on the subsurface geological and hydrogeological conditions prevailing in the area under investigation. Qualitative and quantitative interpretations of the available geoelectrical resistivity data are conducted in Wadi El-Natrun to define the shallow subsurface geological inferences and investigate the possibilities of finding groundwater accumulations. Moreover, the geoelectrical resistivity survey carried out within the present work aims at outlining the thicknesses and electrical resistivities of the encountered geoelectrical units.*

The interpretation of the obtained electrical resistivity values reveals the subdivision of the studied section into three geoelectrical units varying in their constituents. The first surface unit is of a relatively low, medium to high resistivity and consists of clays, sands and gravel. A layer of relatively low to medium resistivity sands (the main Pliocene aquifer in Wadi El-Natrun area) with clay intercalations underlie the surface unit. The third geoelectrical unit is of relatively high resistivity sands.

Hydrogeologically, the Pliocene aquifer represents the main aquifer in Wadi El-Natrun area. The water-bearing formations consist of sand layers with clay intercalations. The groundwater in the Pliocene aquifer in the study area exists under confined to semi-confined conditions. The maximum thickness of such an aquifer reaches 200 m. The increase in thickness is marked to the northern and eastern parts of the area under study. Finally, the depth to the Pliocene aquifer ranges between 2 and 24 m..

INTRODUCTION:

The resistivity method has proven to be the most successful of the electrical methods for obtaining information about the substrata of the earth. The resistivity method is acomparatively cheap, rapid and well suited for the upper levels, especially where there is a marked difference in resistivity, such as at the level of the water table. The resistivity method is excellent and is used worldwide for mapping groundwaters. (Dohr, 1981).

Wadi El-Natrun Depression is the northernmost among the depressions and oases of the Western Desert. It has an oval shape extending in a NW-SE direction parallel to Cairo-Alexandria Desert Road and starts 97km northwest of Cairo City. The area under investigation (Fig. 1) lies to the west of the Nile Delta, Northern Western Desert. It is located between latitudes 30° 14´N and 30° 36´ N. and longitudes 30° 03´E and 30° 37´ E. The area of Wadi El-Natrun is characterized by semi-arid to arid desert climatic conditions, where summer is long and hot and winter is warm with occasional precipitation.

The present work is essentially concerned with the interpretation of the results of 43 Vertical Electrical Sounding profiles in order to subdivide the considered sequence, in the area under investigation, into layers of varying resistivities and lithologies and to delineate the

ground water aquifers with respect to their depths, thicknesses and lithologic contents. This allows one to map geologic structures and lithologic changes.

GEOMORPHOLOGY

Topographically, the area of Wadi El-Natrun extends into an oval depression in the North Western Desert at the western fringes of the Nile Delta of Egypt. It has an elongated shape trending NW-SE. The entire area of the depression lies below mean sea level (maximum -24m.). It occupies an area of about 260 sq. km with a maximum length of about 52 km (in the middle portions). Its width varies between 13 Km and 0.5 km. (at the extreme southeastern tip). Scarps of about 55 m high surround it. The floor of Wadi El-Natrun depression has a relatively flat terrain and is dissected with several low-areas occupied mostly with free water lakes. Among them are El-Fasda, Um-Risha, Razonia, El-Hamra, Zaggig, El-Beida, El-Khadra, El-Sabkha and Gaar lakes from southeast to northwest, (Fig. 2).

Geomorphologically, the area under study, is distinguished by Shata and El-Fayoumy, (1967); Abdel Baki, (1983) and Gomaa, (1995) into the following three geomorphologic units, (Fig. 3):

(1) The Old Alluvial Plains, which occupy the eastern border of Wadi El-Natrun. The surface is mainly formed of brown gravel and coarse sand.

(2) Wadi El-Natrun Structural Depression which lies to the east of the table land of Gebel El-Hadid. The down washes gravels, which have been derived from Gebel El-Hadid to the west, cover the western slopes of the depression.

(3) Gebel El Hadid Tableland, which lies immediately to the west of Wadi El-Natrun Depression. A thin blanket of dark brown gravel and conglomerate covers the surface. It is dissected by a number of old drainage channels.

GEOLOGY AND HYDROGEOLOGY

Many researchers have investigated the geology and hydrogeology of the study area among those are El-Fayoumy (1964), Diab et al., (1980), Said (1990), Gomaa (1995) and Abd El-Wahab (1999). The most important water-bearing formation in the area under study is confined to Pliocene deposits. The exposed rocks in the study area range from Oligocene to Recent (Fig.4, Conoco, (1987)).

The succession of Quaternary and Late Tertiary is discussed from top to base as follows:

(1) Quaternary deposits: They are built up of Recent and Pleistocene deposits. Recent deposits are formed of eolian sands occupying the low-lying areas of Wadi El-Natrun, while the Pleistocene deposits are distinguished into two rock units; Crust Formation and Deltaic deposits. Crust Formation is formed of a sandstone layer having a thickness of 0.25 to 4 m. It caps the Pliocene deposits to the west and northwest of Wadi El-Natrun. Deltaic deposits are composed mainly of sand and gravel intercalated with clay lenses. They extended between the eastern part of Wadi El-Natrun and the cultivated lands of the Nile Delta.

(2) Pliocene deposits: They are defined particularly in Wadi El-Natrun area and are formed generally of alternating sand and clay layers. They are distinguished into two Formations; Wadi El-Natrun Formation and Mekhimien Formation. Wadi El-Natrun Formation (Upper and Middle Pliocene) is formed of two successive Members; El-Muluk Member at top and Beni Salama Member at the base. The sandy layers of Wadi El-Natrun Formation represent the main aquifer. El-Mekhimien Formation (Lower Pliocene) is mainly composed of dark clay. It is also recognized outside Wadi El-Natrun under the deltaic deposits.

Hydrogeologically, the Pliocene aquifer is the only aquifer present in Wadi El-Natrun area (Shata et al., 1970). It is a structurally controlled aquifer. It is mainly composed of alternating clay and sand (El-Fayoumy, 1964). Outside Wadi El-Natrun area, the Pliocene deposits are observed to change into dark clay, which is, considered to be the Lower Pliocene unit.

Forty-three (43) Vertical Electrical Soundings are conducted in the area under study, along five nearly NE-SW profiles and three nearly NW-SE profiles, (Fig. 5). The Schlumberger configuration of electrode separation starting from AB/2 = 1.5m to AB/2 = 1000m (maximum AB/2) is selected and applied.

INTERPRETATION METHODS OF FIELD DATA

There are two main approaches followed for interpreting the field measured geoelectrical data, namely the qualitative the quantitative. The qualitative interpretation of geoelectrical data obtained for the present work involves the preparation of the iso-apparent resistivity maps, where the apparent resistivity values (ρ_a) are plotted for a given electrode spacing (AB/2) on maps, contoured and interpreted.

The iso-apparent resistivity contour maps outline fault zones characterizing the anomalies of considerable aerial extension along a given direction and having maximum horizontal electric resistivity amplitudes. These maps reveal, also, the zones of relatively low electric resistivities values, which may indicate areas of groundwater accumulations. The purpose of mapping is to determine the lateral variations in the conductivity of the ground. Mapping is primarily useful for detecting local, relatively shallow inhomogeneties and is employed typically in ore prospecting and in delineating geologic boundaries, fractures cavities, paleo-channels, etc. It has also been used for archaeology for finding ancient buried structures (Parasnis, 1997).

Iso-apparent resistivity contour maps are constructed for different electrode spacings to show the successive levels penetrated by the artificial electric current. Each map is prepared for a given electrode separation, to illustrate the geological and hydrogeological conditions prevailing within a horizon approximately parallel to the ground surface. In the area under investigation, nine iso-apparent electrical resistivity contour maps are constructed five from them are selected for the electrode separations (AB/2 of 1.5, 25, 100, 500 and 900 m) to cover nearly most of the succession penetrated by the electric current.

From the iso-apparent electric resistivity contour maps, the following manifestations can be outlined:

(1) There is a great similarity in the shape of the major anomalous features and contours with their directions through the studied maps. This infers that the subsurface conditions are nearly similar.

(2) The obvious lateral variations of the iso-apparent resistivities indicate comparable lateral changes in the encountered types of rocks.

(3) The comparison among the two iso-apparent resistivity contour maps at AB/2 = 1.5m (Fig.6), and AB/2 =25m (Fig. 7) for the surface unit reveals that, the resistivities for the smaller depth of penetration generally begin with relatively high values (in the eastern, northwestern and southeastern zones), which laterally change to relatively low to medium resistivity values (between the northwestern and southeastern zones), then decrease gradually in the southeastern zone. This gives indications that the surface unit in most of the locations in the eastern and northwestern zones is sands and gravels, while between the northwestern and southeastern and the southern zones, the surface unit is composed of sands and clays.

(4) The comparison among the other iso-apparent resistivity contour maps, from AB/2 = 100m to AB/2 = 900m (for the aquifer units) indicates that, the resistivity values decrease gradually allover the area in all these maps (Fig. 8 through Fig. 10). This gives indications that the resistivity of the aquifer unit ranges between low to medium values (sand with clay intercalations). The final slight increase in the resistivities, in some localities, indicates the presence of the sand unit.

VERTICAL ELECTRICAL SOUNDING CURVES

There are several methods for the quantitative interpretation of electrical data. Some of them are empirical methods, others are graphical and the more complicated ones are the analytical methods, using digital computers. However, in the 1970s several methods developed for computerized interpretation of Vertical Electrical Sounding (VES) curves over horizontally stratified media. These methods may be divided into two groups. The first group relies on the transformation of a VES curve into its corresponding resistivity transform (or Kernel function) curve using forward filters such as those developed by Strakhov and Karelina (1969), Ghosh (1971a) and Koefoed (1979). The resistivity transform curve is interpreted using methods based on Pekeris (1940) and Koefoed's (1979). The second group of interpretation methods relies on inverting the sounding curve itself without first transforming it to its resistivity transform curve (Kunetz and Rocroi, 1970; Zohdy, 1975 and Anderson, 1979a).

The interpretation of the electrical resistivity sounding data aims firstly to determine quantitatively the true resistivit-ies and thicknesses of the successive strata below the different stations utilizing the measured field curves. Secondly, the geological interpretation translates the quantitative values into a realistic picture within the known geological framework.

For the present work, the interpretation of the geoelectrical resistivity data involves the following steps:

(1) Application of the computer program of Zohdy (1989) to the forty-three field sounding curves to obtain, for each of them, a multi-layer model in which the number of layers is equal to the number of digitized points. The multi-layer models are reduced manually to less number of layers and then, subjected to successive iterations till a best fit is reached between the calculated and observed curves using WINSEV 3.4 program. This program is provided by GEOSOFT (1998) for assisting in the interpretation of resistivity sounding curves. The results obtained from WINSEV 3.4 are applied for both resistivities and thicknesses to give the final workable results. The interpretations of the Vertical Electrical Sounding data for the study area are shown in Fig. (11).

(2) The obtained resistivity and thickness values are used for the construction of the geoelectrical cross-sections. These are analyzed and correlated with the available geologic information to provide an interpretation for the hydrogeological conditions predominant within the investigated area.

(3) Construction and interpretation of the thickness maps for the aquifer unit. The maximum and minimum thicknesses of the aquifer unit allover the study area are determined.

The Vertical Electrical Sounding profiles in the studied area are interpreted in terms of the actual resistivities and depths for the upper and lower surfaces of the encountered layers. The quantitative interpretation of the sounding curves plays an important role in reflecting a clear picture about the depth, thickness, resistivity and extension of the layers forming the shallow section of the study area. The distribution of the Vertical Electrical Sounding curves in the study area is

consistent and reflects the subsurface geologic conditions. The interpretation of these resistivity curves shows a relative wide range of values in their resistivities.

The number of interpreted layers is three and the true resistivities of these layers range between less than 10 Ω m and more than 700 Ω m. The thicknesses of these layers vary from a sounding station to the other. A detailed discussion of the constructed geoelectrical cross sections is given below.

GEOELECTRICAL CROSS-SECTIONS

Eight geoelectrical cross-sections covering the considered area are constructed. Five cross-sections are oriented nearly NE-SW and three cross-sections are directed mostly NW-SE. Four geoelectrical cross sections are selected and presented in Figs. 12 through 15.

From these cross-sections, it can be concluded that:

(1) The Pliocene sequence in the area under investigation is composed essentially of three geoelectrical units.

(2) The first geoelectrical unit is characterized by a wide range of electric resistivity values ranging between 8.3 Ω m (VES No. 37) and 727 Ω m (VES No. 13) which gives an indication about the change of the surface layer from clay to sand and gravel. The thickness of this unit varies allover the studied geoelectrical cross-sections.

(3) The second geoelectrical unit is characterized by a relatively low-medium electric resistivity value ranging between less than 20 Ω m (VESes No. 6, 18, 27 and 40) to 80 Ω m (VES No. 14). This gives an indication about the presence of a sand aquifer (the main Pliocene aquifer unit in the area under study) with clay intercalations. The thickness of this unit increases towards the eastern and northern sections. It ranges between 0 to more than 200 m.

(4) The third geoelectrical unit is characterized by relatively high electric resistivity ranging between 100 Ω m (VES No. 30) and 310 Ω m (VES No. 9) which corresponds to the sand unit.

(5) Hydrogeologically, the Pliocene aquifer represents the main aquifer present in Wadi El-Natrun area. The water-bearing formation consists of sand layers with clay intercalations. The maximum thickness of the aquifer reaches 200 m to the northern and eastern parts of the area under study (Fig. 16). The depth to the Pliocene aquifer ranges between 2 and 24 m. It increases towards northeastern part (Fig. 17).

SUMMARY AND CONCLUSION

Forty-three Vertical Electrical Soundings are carried out in Wadi El-Natrun area to define the shallow subsurface geological inferences and to investigate the ground-water accumulation. The evaluation of the electric resistivities the Pliocene sequence in the area under investigation into three geoelectrical units. A layer with a wide range of electric resistivity which gives an indication to the change of its lithology from clay to sand and gravel. The second geoelectrical unit is characterized by a relatively low-medium electric resistivity values, the presence of a sand aquifer (the main Pliocene aquifer unit in the area under study) and clay intercalations. The thickness of this unit increases in the eastern and northern parts of the study area from 0 to more than 200 m. The third geoelectrical unit is characterized by relatively high electric resistivity values, corresponding to the sand unit. Hydrogeologically, the Pliocene aquifer represents the main aquifer in Wadi El-Natrun area. The water-bearing formations consist of sand layers with clay intercalations. The groundwater in the Pliocene aquifer in the study area exists under confined to semi-confined conditions. The maximum thickness of such an aquifer reaches 200 m. The increase in thickness is marked to the northern and eastern parts of the area under study. Finally, the depth to the Pliocene aquifer in the area ranges between 2 and 24 m. It increases towards northeastern part.

REFERENCES

Abdel Baki, A.M.A., (1983): Hydrogeolo-gical and hydrogeochemical studies on the area west of Rosetta Branch and south of El-Nasr Canal; Ph. D. Thesis unpublishes Fac. Sci., Cairo Univ., Egypt, 156 P.

Abd El-Wahab, S., (1999): Hydrogeolo-gical and isotope assessment of groundwater in Wadi El-Natrun and Sadat City, Egypt. Ph. D. Thesis unpublishes Fac. Sci., Ain Shams Univ., Egypt, 237 P.

Anderson, W.L.,(1979a): Program MAR-QDCLAG, Marquard inversion of D.C. Schlumberger sounding by lagged-convolution; U.S. Geol. Survey, Open file rep. 79- P.1432-1458.

CONOCO, (1987): Geological map of Egypt. Scale 1:500 000, Maadi, Cairo, Egypt.

Diab, M. Sh.; Abdel-Latif, T. and Abdel Baki, A.A., (1980): Groundwater occurrences in the southern sector of Cairo-Alexandria Desert Road: Annals Geol. Surv. Egypt, Vol. X, pp. 797-805.

Dohr, G., (1981): Introduction to geophy-sical prospecting; Wiley Ltd, Halsted Press, New York.

El-Fayoumy, I.F., (1964): Geology of groundwater supplies in Wadi El-Natrun: M. Sc. Thesis unpublished Fac. Sci., Ain Shams Univ., Egypt, 109 P.

Ghosh, D.P., (1971a): The application of linear filter theory to direct interpretation of geoelectrical resistivity sounding measurements. Geophys. Prosp, 19, P.192-217.

Golden Software, INC., (1998): Surfer computer software. Golden, Colorado, U.S.A.

Gomaa, M.A.A., (1995): Comparative hydrogeological and hydrogeochemical studies on some aquifers, west of Nile Delta, Egypt; Ph. D. Thesis published Fac. Sci., Ain Shams Univ., Egypt, 224 P.

Geosoft, (1997): WINSEV 3.4 User's Manual; Interpretation of Resistivity Sounding Curves, Geosoft Co., Italy.

Koefoed, O., (1979): Geosounding Prin-ciples 1, Elsevier Amsterdam, 276 P.

Koefoed, O., (1979): Resistivity sounding on an earth model containing transition layers with linear change of resistivity with depth; Geophys. Prosp, Vol. 27, P. 862-868.

Kunetz, G. and Rocroi, J.P., (1970): Traitement automatique des sondages electriques, Geophys. Prosp., Vol. 18, P. 157-198.

Parasnis, D.S., (1997): Principles of Applied Geophysics; Chapman and Hall, London.

Pekeris, C.L., (1940): Direct method of interpretation in resistivity prospecting; Geophysics, Vol. 5, P. 31-42.

Said, R., (1990): The Geology of Egypt. Balkema Publ., Rotterdam, Netherlands, 734 P.

Shata, A.A. and Attia, F.A., (1994): Socio-economic and environmental aspects of water harvesting, Egyptian experience, FAO-Rome, water report 3, P. 257-270..

Shata, A.A. and El-Fayoumy, I.F., (1967): Geomorphological and morphopedolo-gical aspects of the region west of the Nile Delta with special reference of the Wadi El-Natrun area", Inst. Desert d'Egypt, T.XVIII, No.1. P.1-28.

Strakhov, V.N. and Karelina, G.N., (1969): On the interpretation of Vertical Electrical Sounding data with an electronic machine (in Russian), Prikladnaya Geofizika 56, P. 118-129.

Zohdy, A.A.R., (1975): Automatic inter-pretation of Schlumberger sounding curves, using modified Dar Zarrouk functions; U.S. Geol. Survey Bull, 1313-E, 39 P.

Zohdy, A.A.R., (1989): A new method for the automatic interpretation of Schlumberger and Wenner sounding curves; Geophysics, Vol. 54 (2), P. 245-253.