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Geoelectrical Survey for Groundwater Exploration at the Asyuit Governorate, Nile Valley, Egypt

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Abstract. Asyuit area is considered as the most promising area for irrigated agriculture and development in both the Eastern Desert and the Western Desert. Groundwater is the most important resources necessary for such development. Forty-two vertical electrical soundings (*VES.*'s), using Schlumberger array were carried out in Asyuit area. The main goal of such survey was to elucidate hydrogeological information and to delineate subsurface structural elements.

VES. curves were interpreted using a 2-D horizontal layering resistivity model assumption. The interpretation results showed that the geoelectrical succession consists of four layers. The top layer is formed of gravely sand with relatively high electrical resistivity values, the second layer is composed of sand (aquifer) with relatively intermediate electrical resistivity values, the third layer is made up of clay (aquiclude) with relatively low electrical resistivity values and the fourth layer consists of limestone with relatively high electrical resistivity values. As for groundwater potentiality, the second layer is highly promising to be the water-bearing layer. The maximum depth to water ranges between 9.9 to 522 m.

Keywords: Groundwater, VES., Aquifer.

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Introduction

Asyuit area which lies on both sides of the Nile River is considered as one of the promising areas for sustainable irrigated agriculture. It is located to the east of Asyuit city between Longitudes 27°10' and 27°20' E and Latitudes of 31°10' and 31°30' N (Fig. 1). Groundwater is important in environmental geophysics *i.e.* many of the environmental studies are directly or indirectly related to groundwater, such as exploration, effects of groundwater on the soil, effects on archaeological sites and groundwater pollution (Gaber *et al.*, 1999; Mesbah, 2003; and Mohamaden, 2005). Geophysics, particularly geoelectrical resistivity techniques, has been extensively used for a wide variety of geotechnical and groundwater exploration problems (*e.g.* Zohdy, 1975; Barker, 1980; Bernard and Valla, 1991; Nowroozi *et al.*, 1999; Mousa, 2003, Ibrahim, *et al.*, 2004; Youssef *et al.*, 2004; Al-Abaseiry *et al.*, 2005; Hosny *et al.*, 2005; Alotaibi and Al-Amri, 2007; Nigm, *et al.*, 2008). This is due to the fact that, the electrical resistivity survey is one of the simplest and less costly geophysical surveys employed. Moreover, it can be used either in the form of vertical electrical soundings (VES's) or horizontal profiling to search for groundwater in both porous and fissured media (*e.g.*, Barker, 1980; Van Overmeeren, 1989; Abd El-Rahman, A. and Khaled, M.A., 2005; and Abd Alla *et al.*, 2005).

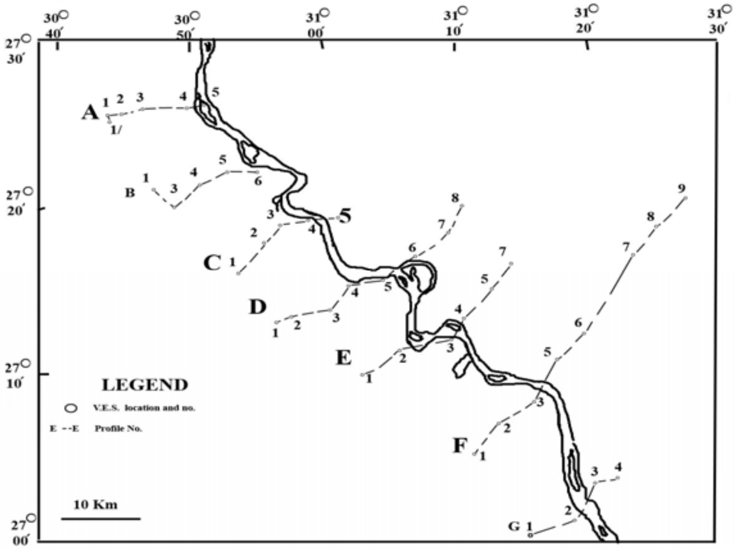

Fig. 1. Location map.

Geology of the Study Area

Geologically, the Nile Valley is surrounded from both sides by escarpments that are capped by rocks ranging in age from Pre-Cambrian to Eocene (Fig. 2). The stratigraphic sequence in the study area is ranging in age from Upper Cretaceous to Lower Eocene, Pliocene and Quaternary deposits from base to top. The geological succession consists of seven formations, which are from base to top: The Nubia Sandstone Formation that is subdivided into the Taref sandstone Member and Qusier clastic Member, and consists mainly of sandstone with ferruginous band and glauconitic shale of Senonian and older age. The Dawi Formation belongs to Campanian to Lower Mastrichtian age, and composed of shale, marl, limestone, and phosphate beds. The Dakhla Formation is composed of shale of Mastrichtian-Danian age. The Tarawan Formation includes chalky limestone of Danian-Landenian age. The Esna Formation is composed of shale with limestone and marl of Landenian-Lower Eocene. Thebes Formation consists of chalky limestone of Lower Eocene age. Issawia Formation consists of clay with conglomerate with Pliocene age (Said, 1981).

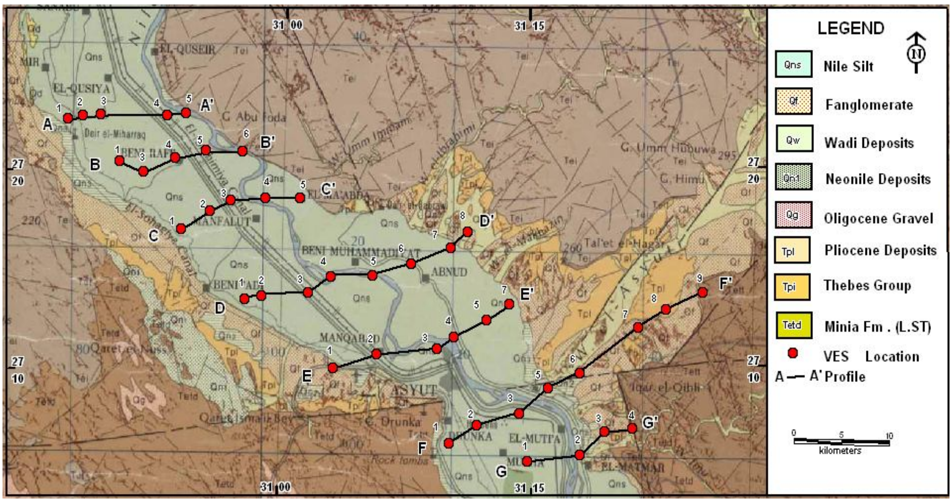

Fig. 2. Geological map of the Asyuit area (after Said; 1981).

Geophysical Data Acquisition

In the present study geoelectric resistivity field survey was carried out by applying the vertical electrical sounding (VES) technique which measures the electrical resistivity variation with depth. It is worth mentioning here that the electric resistivity of a rock formation varies according to the rock nature of material (density, porosity, pore size and shape), water content and its quality and temperature. Hence, there are no sharp limits for electric resistivity of porous formations. The resistivity is more controlled by the water contents and its quality within the matrix of the formation than by the solid granular resistivity value itself. Therefore, the geological unit may be subdivided into different geoelectrical units according to the different percentage of humidity within it. (Parasnis, 1997).

In present work, Schlumberger array was applied with half current electrode spacing (AB/2) starting from 1m to 1000 m. This spacing is sufficient to reach adequate depths covering the Quaternary aquifer in the study area (Abd El Fattah, 1994). A total number of 42 vertical electrical soundings were measured along 7 profiles (Fig. 1). The sounding number 1 is located to the extreme north eastern part of the investigated area. These profiles run mainly from west to the east direction to cut the Nile River.

The geoelectrical resistivity measurements were performed applying two U.S.A. multimeter units of the type Fluke-27 allowing to filter the potential of the earth and measure the potential difference (ΔV) due to the fed current (I) and the current itself simultaneously. About 20% of the total measurements were recorded twice by changing the supply voltage. According to these repetitions the mean relative error for the field measurements was calculated and found to be $\pm$ 1.45% or within the permissible limits.

The result of the geoelectric survey was processed and quantitatively interpreted using available geological information and presented as geoelectrical sections along the various profiles. Many authors such as Koefoed (1965 a, b, and c), Gosh (1971), Zohdy (1975 and 1989), and Hemeker (1984) studied the quantitative interpretation of the geoelectric resistivity measurements. The interpretation of the apparent electrical resistivity data were achieved using two methods, the first is based on curve matching technique using Generalized Cagniard Graph method constructed by Koefoed (1960), in which the results obtained treated with the inverse problem method using computer programs constructed by Hemeker (1984).

Geoelectrical Sections

The careful examination of the constructed geoelectrical sections (Fig. 3 - 9 and Table 1) indicates the following:

Profile A (Fig. 3 and Table 1)

This profile lies at the extremely northern part of the area under investigation. It is covered by 6 vertical electrical soundings namely A_1, $A_1^{\backslash}$, A_2, A_3, A_4 and A_5. The results of the geological information and electrical interpretation assumed that:

The superficial geoelectrical layer is characterized by relatively high electrical resistivity values (125-1060 ohm-m) and thin thicknesses (0.45-1.4 m). This layer from late Pleistocene to Holocene age. It covers the area west of VES. A3.

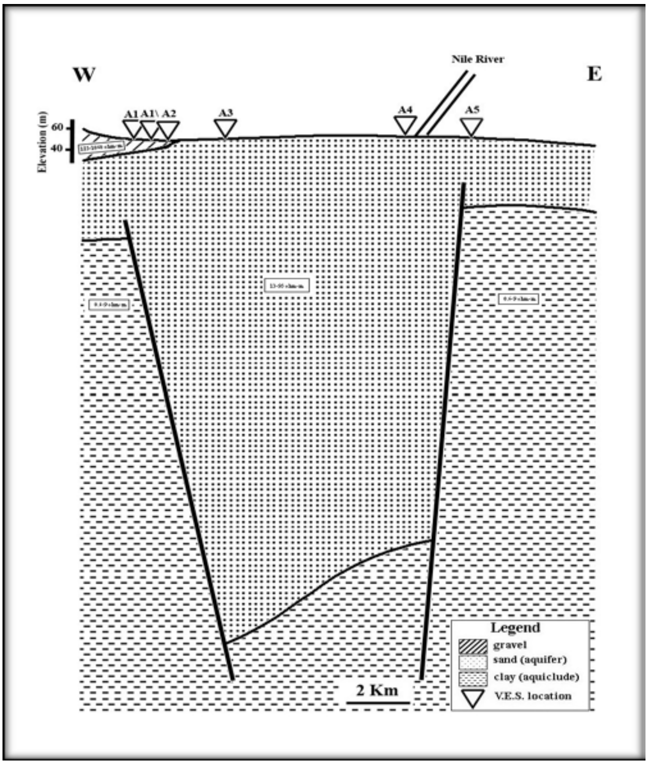

Fig. 3. Geoelectrical section for profile A.

The second geoelectrical resistivity layer extends from the Qena-Dandara complex (Prenile) is formed from fluviated sand with thin clay lenses. This layer is the main groundwater aquifer. It is characterized by relatively moderate electrical resistivity values (13-95 ohm-m) and the maximum depths from 64.2 to 467 m. We can notice that the maximum thicknesses of this unit occupy the central part of this profile. While it thins toward the eastern and western directions as a result of two deep faults at the west of VES. $A_1^{\backslash}$, and west of VES. A_5 with down thrown side toward the central part.

The third geoelectrical layer can be represented by the maximum depth of this profile. It is considered as the aquiclude from Pliocene age. It is characterized by relatively very low electrical resistivity values (0.6-9 ohm-m).

Table 1. Geoelectrical parameters for the area under investigation.

V.E.S. no.	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5
	ρ_1	ρ_1	P_2	ρ_2	ρ_3	ρ_3	ρ_4	ρ_4	ρ_5
A_1	286	1.4	62	9.6	52	88.6	2		
$A_{1\backslash}$	1060	0.45	67	10.9	21	38.1	15	224	0.6
A_2	125	0.45	13	3.1	38	199	4		
A_3	14	9.3	45	467	4				
A_4	42	0.76	16	19.8	95	95.9	30	384	4
A_5	32	2.3	93	3.2	17	6.6	56	64.2	9
B_1	691	0.47	138	3.5	42	39.4	19	210	2
B_3	126	2.2	35	135	10	413	0.8		
B_4	9	13.8	65	350	6				
B_5	10	5.1	29	99	19	427	2		
B_6	105	5.5	10	23.2	94	82.3	4		
C_1	1200	1.7	84	9.5	21	117	155	144	3
C_2	78	84.4	50	351	10				
C_3	293	26.8	60	522	8				
C_4	21	10.9	50	204	4				
C_5	87	10.5	116	47.3	11	186	2		
D_1	2990	0.81	329	2.7	30	9.9	8		
D_2	259	7.1	7						
D_3	126	0.5	19	17.6	50	292	3		
D_4	151	0.9	20	33.9	71	129	5		

Table 1.Contd.

V.E.S. no.	Layer 1		Layer 2		Layer 3		Layer 4		Layer 5
	ρ_1	ρ_1	ρ_2	ρ_2	ρ_3	ρ_3	ρ_4	ρ_4	ρ_5
D_5	169	16.8	19	154	4				
D_6	229	12.2	76	105	4				
D_7	6110	0.59	830	2.1	597	8.6	16	161	3
D_8	6270	0.87	1220	2.1	175	14.4	7		
E_1	2110	5.8	274	20	23	66.3	2		
E_2	223	5	69	7.7	15	24.2	80	52.4	6
E_3	298	0.5	66	1.8	14	294	16		
E_4	14	5.3	93	20.9	29	57.9	86	211	5
E_5	21	117	13	289	2				
E_7	448	1.1	95	6.5	21	28.3	3		
F_1	11	3.8	66	9.4	18	165	7		
F_2	7	6.3	36	207	10				
F_3	154	2.6	30	12.2	25	298	2		
F_5	125	0.84	249	9.3	54				
F_6	35300	2.7	920	16.3	10	31.7	12		
F_7	9500	1.1	592	3.5	1000	35	110	145	1840
F_8	40400	1.3	174	6.8	9	29.9	950		
F_9	4820	1.9	1380	7.8	58	100	3050		
G_1	6	10.9	58	74.2	6				
G_2	37	0.51	6	8.3	84	88.3	20		
G_3	773	0.55	6	3.1	34	137	3		
G_4	8	16.9	55	27	13	150	3		

ρ = true resistivity   d = depth (m)

Profile B (Fig. 4 and Table 1)

At the south of profile A you can locate profile B, which is covered by 5 vertical electrical soundings namely B_1, B_3, B_4, B_5 and B_6. We conclude from the geological information and electrical interpretation that:

The superficial geoelectrical layer is mainly gravel with relatively high values (105-291 ohm-m) and thin thicknesses (0.47-5.5 m). The age of this layer is from late Pleistocene to Holocene. This layer can be detected at VES.'s B_1, B_3 and B_6.

The second geoelectrical layer from Qena-Dandara complex (Prenile) is formed from sand (main aquifer). It is characterized by relatively moderate electrical resistivity values (9-94 ohm-m). The maximum depth (350-427 m) is located at the area between west of VES B_3 and east of VES B_5. The area is bounded by two deep sited faults with downthrown side towards the central part. While at the eastern and western part the thicknesses of this unit ranges from 82.3 to 210 m.

At the maximum depth of penetration can be regarded as the third layer with relatively very low electrical resistivity values (0.8-6 ohm-m) formed from clay and silt (aquiclude). It reached to the maximum depth of penetration along this profile.

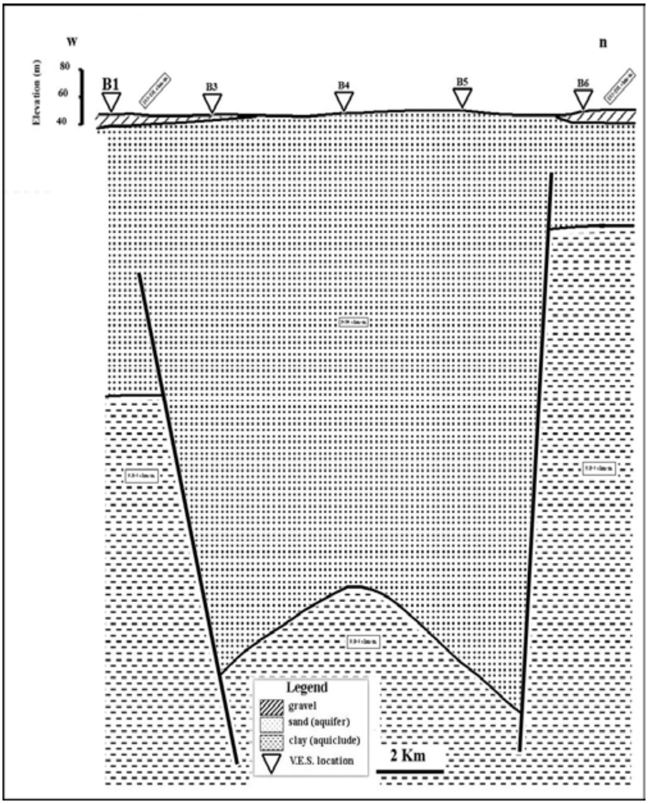

Fig. 4. Geoelectrical section for profile B.

Profile C (Fig. 5 and Table 1)

It is located south of profile B. It is covered by 5 VES's named C_1, C_2, C_3, C_4 and C_5. From the previous geological information and geoelectrial interpretation, we can conclude that:

A superficial geoelectrical layer covered the ground surface around V.E.S.'s C_1 and C_3. It is mainly from dry sand and gravel with relatively high electrical resistivity values (293-1200 ohm-m) and thin thicknesses (1.7-26.8 m).

The superficial geoeletrical layer is followed by Qena-Dandara complex (Prenile – main aquifer) from sand and thin clay lenses around VES.'s C_1 and C_3. While it can be regarded at the ground surface for the rest of this profile. It is characterized by relatively moderate electrical resistivity values (11-116 ohm-m) and depth range from 144 to 522 m. This depth decreases to the east and west directions as a result of two deep sited faults between VES's C_1 and C_2 and between C_3 and C_4. The maximum depth at the eastern direction ranges from 186 to 204 m. While at the western part a maximum depth of about 144 m.

The third geoelectrical layer (aquiclude) which is formed from clay or shale can be detected at the maximum depth of penetration with relatively low electrical resistivity values (2-10 ohm-m).

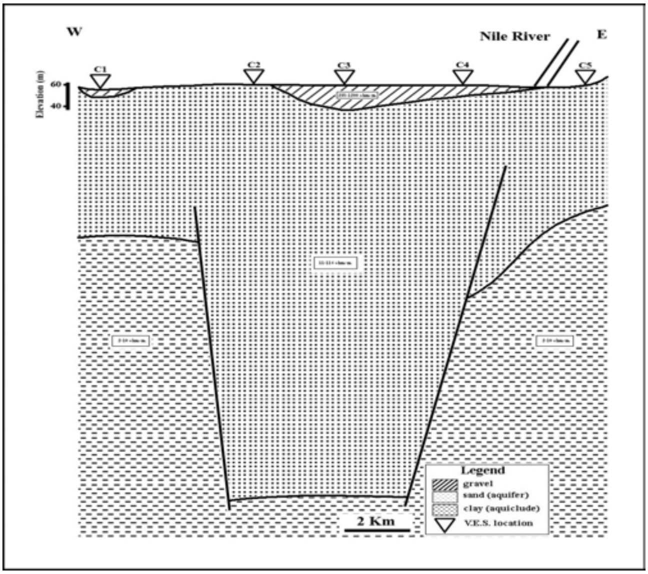

Fig. 5. Geoelectrical section for profile C.

Profile D (Fig. 6 and Table 1)

Profile D lies north of Al Azia and is covered by 8 vertical electrical soundings (D_1, D_2, D_3, D_4, D_5, D_6, D_7 and D_8). We can summarize the geoelectrical interpretation as follows:

A superficial geoelectrical layer, with thin thicknesses (0.5-16.8 m), is formed of gravel with relatively high electrical resistivity values (126-6270 ohm-m). It covers the ground surface of this profile.

The second geoelectrical layer is represented all over this profile (with exception around VES. D_2). It consists of sand with relatively moderate electrical resistivity values (16-175 ohm-m). It is considered as the main aquifer. It is located at the central part of this profile bounded by two deep sited faults (east of D_1 and west of D_8) with down thrown side toward the central part with maximum depth (105-292 m. While this depth decreases towards the eastern and western parts of this profile (9.9-14.4 m).

The third geoelectrical layer (aquiclude) may be located at the maximum depth of penetration along this profile. It consists of clay. It is characterized by relatively low electrical resistivity values (3-8 ohm-m).

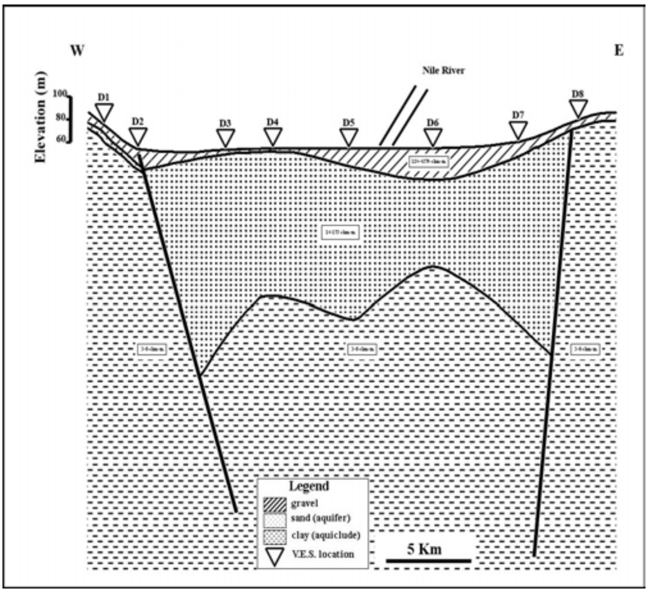

Fig. 6. Geoelectrical section for profile D.

Profile E (Fig. 7 and Table 1)

This profile passes through Mankabad city. It is covered by 6 vertical electrical soundings (E_1, E_2, E_3, E_4, E_5 and E_7). The geoelectrical interpretation with the help of geological information can be summarized as follows:

The ground surface of this profile is covered by a superficial layer which is formed of gravel (with exception at VES.'s E_4 and E_5). It is characterized by relatively high electrical resistivity values (223-2110 ohm-m) and thin thicknesses (0.55-20 m).

The second geoelectrical layer (aquifer) which consists of sand covers the ground surface of the area around VES.'s E_4 and E_5 or beneath the first geoelectrical layer at the rest of this profile. It is characterized by relatively moderate electrical resistivity values (13-95 ohm-m) and maximum depth ranges from 28.3 to 294 m. Its thickness increases at the central part of this profile as a result of two faults at the area east of VES. E_2 and west of VES. E_7 with down thrown side towards the central part.

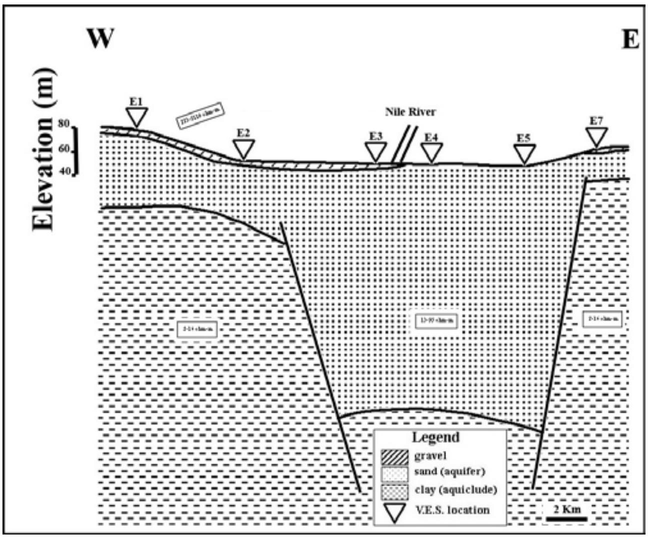

Fig. 7. Geoelectrical section for profile E.

At the maximum depth of penetration we can detect the third geoelectrical layer (aquiclude) which is characterized by relatively low electrical resistivity values (2-16 ohm-m).

Profile F (Fig. 8 and Table 1)

This profile runs from west to east direction. It is covered by 8 VES.'s (F_1, F_2, F_3, F_5, F_6, F_7, F_8 and F_9). The geoelectrical section indicates that:

The superficial geoelectrical layer is formed of gravel with relatively high electrical resistivity values (125-40400 ohm-m) and thin thicknesses (1.3-35 m). It covered the ground surface of this profile with exception at the area west of VES. F_3.

The second geoelectrical layer formed of sand (aquifer) is characterized by electrical resistivity values (9-174 ohm-m) and thicknesses range from 29.9 to 298 m or extends to the maximum depth of penetration at the area around V.E.S.'s F_5 and F_6 which is bounded by two faults with down thrown side towards the central part of this profile.

The third geoelectrical layer formed from clay (aquiclude) is represented at the area west of VES. F_3 to the maximum depth of penetration or with thin thicknesses at the area east of VES. F_7 (29.9-100 m) with relatively low electrical resistivity values (2-10 ohm-m).

The fourth geoelectrical layer is represented at the area east of VES. F_5 with relatively very high electrical resistivity values (950-3050 ohm-m). It is formed of limestone.

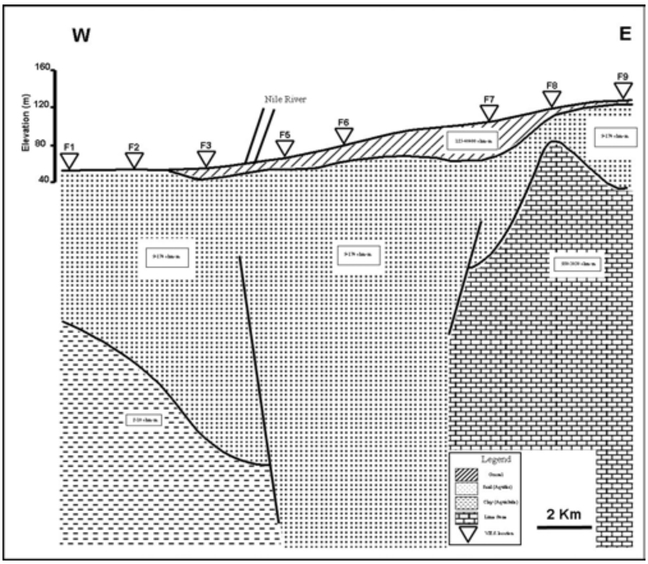

Fig. 8. Geoelectrical section for profile F.

Profile G (Fig. 9 and Table 1)

This profile exists at the extremely south east of the area under investigation. It is covered by 4 VES.'s G_1, G_2, G_3 and G_4. The geoelectrical section indicated that:

The upper most geoelectrical layer formed of gravel mixed with sand. It is characterized by electrical resistivity values ranging from 6 to 773 ohm-m and thin thicknesses (0.5-16.8 m).

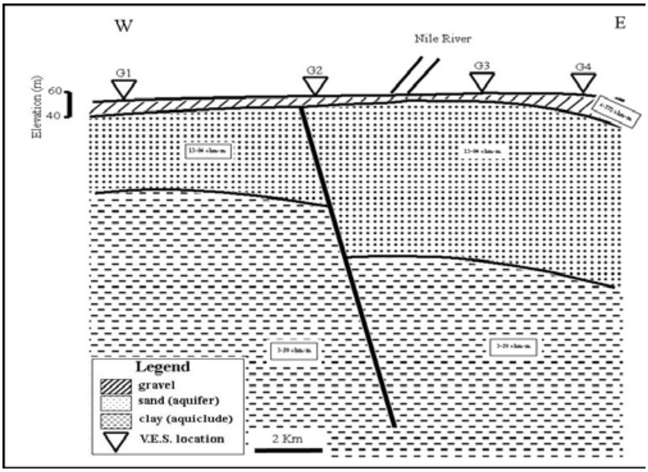

Fig. 9. Geoelectrical section for profile G.

The second geoelectrical layer (aquifer) is characterized by relatively moderate electrical resistivity values (13-84 ohm-m). It is formed of sand with depth ranging from 74.2 to 150 m.

The third geoelectrical layer is represented at the maximum depth of penetration with relatively low electrical resistivity values (3-20 ohm-m). It mainly consists of clay (aquiclude).

Hydrogeology Setting

Aquifer System

The Quaternary aquifer is composed of graded sand and gravel with thin interbeds of clay, the aquifer reaches a thickness of approximately 200 meters and is highly productive. It occupies much of the Nile valley and is covered by a Holocene silty clay layer, which acts as an aquitard. Groundwater in this aquifer is present under semi-confined conditions (Said, 1981).

Recharge and Discharge

The aquifer system is recharged mainly from seepage of water from irrigation canals and percolation of excess irrigation water from the fields. Recharge rates from irrigation water seepage vary according to the thickness of the clay layer and the drainage system conditions. The recharge rate from irrigation is about 1 mm/day. There is a lateral recharge occurs by seepage from the Nile (backwater curve zone).

Discharge from the aquifer takes place along the river course. Groundwater extraction by wells is another important discharge component (RIGW/IWACO B.V., EMGR.; 1997).

Groundwater Flow

Groundwater heads fluctuate around the year, within a range of a few centimeters to more than one meter. The general flow direction is from south to north. Main deviations in the flow direction occur near the Valley fringes, where groundwater flow is directed from the reclamation areas to the Quaternary aquifer. Deviations are also found near the Nile river reclamation areas to the Quaternary aquifer. Deviations are also found near the Nile river, where groundwater flow is directed either towards the river (base flow of groundwater) or from the river (infiltration of Nile water to the aquifer). In these areas the flow direction is perpendicular to the main flow direction; from or towards the river Nile. Figure 10 represents the hydrogeological cross section at Wadi Al Asyuti area (RIGW/IWACO B.V., EMGR.; 1997).

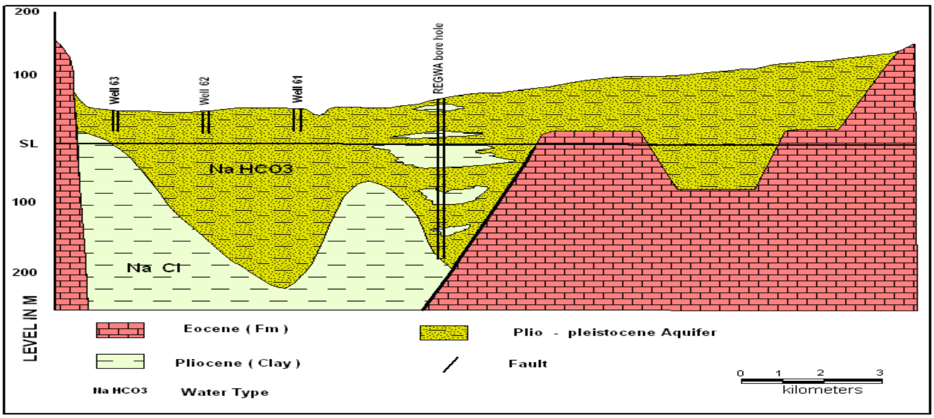

Fig. 10. Hydrogeological cross section of Wadi Al Asyuti (after RIGW/IWACO B.V., EMGR.; 1997).

Results and Conclusions

A superficial geoelectrical layer mainly covered the ground surface of the area under investigation with relatively high electrical resistivity values (105-40400 ohm-m) and varied depths (0.43-35 m). The wide ranges of the electrical resistivity values are due to dry nature and percentage of gravel and sand.

The second geoelectrical resistivity layer is supposed to belong to the Qena – Dandara complex (Prenile) that is formed of sand with thin clay lenses. This layer is considered as the main groundwater aquifer. It is characterized by relatively moderate electrical resistivity values (9-175 ohm-m.) and of maximum depth ranges from 9.9 to 522 m (reached to a maximum depth of penetration as in profiles C and the central part of profile F). It could be noticed that the maximum thickness of such aquifer layer is reached at the central part of all profiles. While it becomes thin at the eastern and western direction as a result of two deep faults with down thrown side towards the central part.

The third geoelectrical layer can be countered at the maximum depth of penetration with some exception as at VES A_5, B_5 and the central part of profile F. It is considered as the aquiclude (clay and silt) belongs to Pliocene age. It is characterized by relatively very low electrical resistivity values (0.6-15.5 ohm-m.).

Occasionally, the fourth geoelectrical layer can be countered at the maximum depth with relatively high electrical resistivity values (104-3050 ohm-m.) which may be attributed to the presence of highly fossiliferous limestone or marly limestone from Eocene age (Wadi El Asyuti Formation).

The area under investigation is affected by two faults mainly bounded the Nile Valley with down thrown side towards the central area. These faults are barrier for the groundwater at the central part.

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المسح الكهربائي لاستكشاف المياه الجوفية بمحافظة أسيوط بوادي النيل – مصر

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المستخلص. تقع منطقة الدراسة في جنوب وادي النيل بين خطي طول ١٠َ ٢٧° – ٢٠َ ٢٧° شرقًا وخطي عرض ١٠َ ٣١° – ٣٠َ ٣١° شمالاً وهي منطقة محافظة أسيوط. وتعتبر هذه المنطقة أكثر احتمالا للزراعة في كلتا الصحراء الشرقية والصحراء الغربية، وإحدى أكثر المناطق الواعدة للتنمية. إن المياه الجوفيّة إحدى أهم المصادر الضرورية لهذه المنطقة. ولقد تم عمل مسح كهربائي لمنطقة الدراسة بطريقة شلمبرجيربعدد اثنتين وأربعين جسة كهربية رأسية. والهدف الرئيسي لهذا المسح هو توضيح المعلومات الهيدروجيولوجية والتراكيب الجيولوجية المؤثرة على مسار المياه الجوفية.

من نتائج التحليل للجسات الكهربائية وجد أن: التتابع الجيوكهربائي لمنطقة الدراسة مكون من أربع طبقات. الطبقة العليا وتغطي سطح الأرض، وهي ذات مقاومة كهربائية عالية، وهي مكونة من الحصى. والطبقة الثانية مكونة من الرمل ذي المقاومة الكهربائية المتوسطة، وتعتبر الخزان الجوفي الخاص بصخور الزمن الرباعي، على أعماق تتراوح بين ٠.٤٥ إلي ٢٣.٢ مترًا. والطبقة الثالثة المكونة من الطين (الطبقة غير المنفذة للمياه) وهي ذات مقاومة كهربية منخفضة. وأخيرًا الطبقة الرابعة ذات المقاومة الكهربائية العالية وهي مكونة من الحجر الجيري.