

Assessment of the Water Quality of the Quaternary Aquifer at El-Arish Area, Northern Sinai, Egypt Using Electrical Method

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Abstract: Thirty-six vertical electrical soundings were measured within the Delta of Wadi El-Arish area, Northern Sinai using Schlumberger configuration to elucidate the most probable hydrogeological factors affecting the salinity problem of the Quaternary aquifer in that area. The groundwater salinity of Quaternary aquifer eastern El-Arish area reaches to about 7500 mg/l of modern to sub-modern (old) evaporite dissolved groundwater. While the northern part of the aquifer (coastal zone) is characterized by fresh water and neither hydrochemical nor isotopic evidences of sea water intrusion are existed [1]. The measured vertical electrical soundings have been processed and interpreted, using Zohdy [2] and Fitter [3] one dimension automatic iterative programs. The initial model of interpretation is prepared using all available geological and hydrogeological information from the neighboring boreholes. The main result of the present study is the exploration of a large clay lens extending parallel to the shore line, which is suggested to be an important hydrogeological barrier to prevent the sea water intrusion and separating between the upper phreatic fresh water horizon (Holocene sand dune) and the lower confined to semi-confined salt water horizon (Pleistocene calcareous sand stone).

Key words: Salinity of Quaternary aquifer • VES's • Wadi El-Arish • Northern Sinai • Egypt

INTRODUCTION

The electrical method is considered as the most applicable geophysical technique in the field of groundwater exploration as well as delineation of subsurface succession. With the recent increasing interest in water resources, many survey projects relating to groundwater problems have been carried out by using this geoelectric method. It is well known that, the geoelectrical survey is a powerful and economic tool to investigate the properties of aquifer and to delineate the relationships between fresh and sea waters. The analysis of the vertical electrical sounding data, when accompanied by geological information, can permit the determination of groundwater types [4] and subsurface structural features of water bearing formations [5].

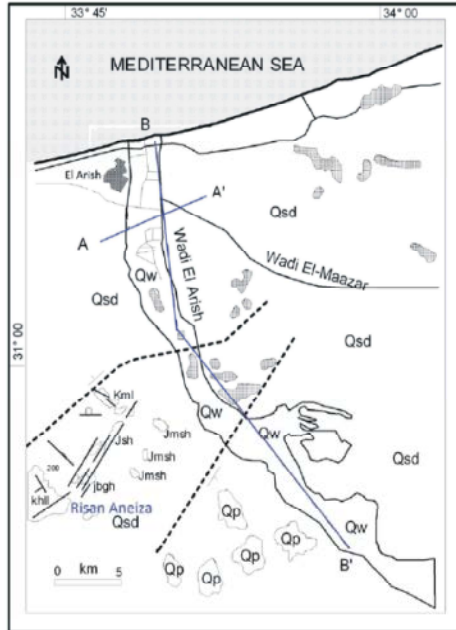
Geological and Hydrogeological Situation: The Sinai Peninsula is a continental sub-plate wedged between the African and Arabian plates. Sinai continental shelf is exposed in the South forming a landscape of high

dissected mountains of crystalline and metamorphic basement rocks. The basement complex is overlain by a sedimentary cover of different periods dipping gently to the North. The sedimentary succession begins with Paleozoic sandstone in the Gulf of Suez onshore to Holocene sand dunes in the Northern Sinai Mediterranean coastal zone. A detailed description and classification of surface and subsurface Tertiary and Quaternary deposits in the El-Arish area – Northern Sinai – is shown in Figure (1) and Table (1).

From the hydrogeological point of view, the Quaternary aquifer consists of four main water bearing formations (Figs. 2 and 3): Holocene and dune aquifer, Upper Pleistocene old beach aquifer, Gravel aquifer (Alluvium deposits) and Lower Pleistocene calcareous sandstone aquifer (Kurkar or Fagra). The differentiation in the lithological logs between sand dune deposits and old beach sand deposits is rather difficult. The old beach sand overlain by dune sand is assumed to be one of the prospecting aquifers in the area. The thickness ranges from 7 to 40m.

Legend:

Qsd: Quaternary sandstone and sheets



Qw: Quaternary wadi deposits
 Qp: Quaternary playa deposits
 Kml: Cretaceous, Malhah Formation (Albian-Aptian). Kaolinized sandstone, intercalated with mudstone, paleosol, conglomerate and fossiliferous limestone bands.
 Khll: Cretaceous, Halal Formation, (Cenomanian) Alternate beds of dolomite, dolostone, marl and clay. Commonly rich in fossils
 Inferred faults from gravity inversion
 Jmsh: Jurassic, Mashabbah Formation (Lower Liassic) crossbedded sandstone intercalated with clay beds, coralline limestone intercalated with calcareous clays and algal limestone
 Jsh: Jurassic, Shushah Formation. (Upper Liassic) banbrown, fine to coarse-grained sandstone with intercalations of carbonaceous clay.
 Cultivated area.
 Surface faults Cross section

Fig. 1: Geological map of El-Arish area (after Geological Survey of Egypt, [6]).

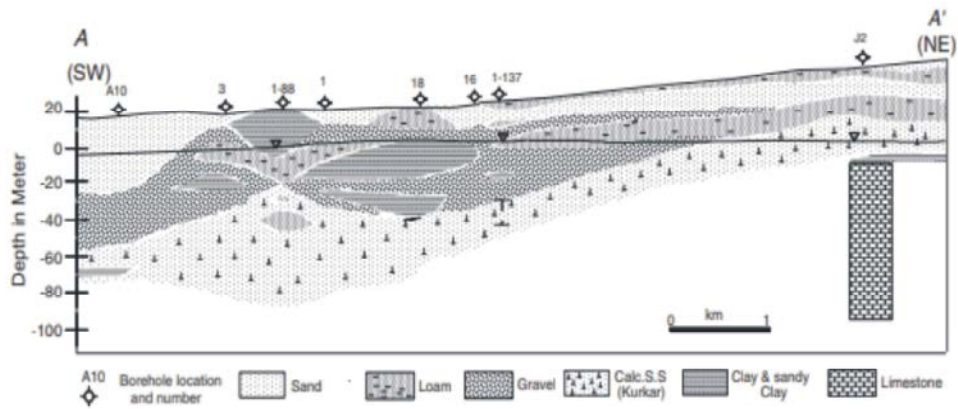


Fig. 2: Hydrogeological cross-section (A-A')

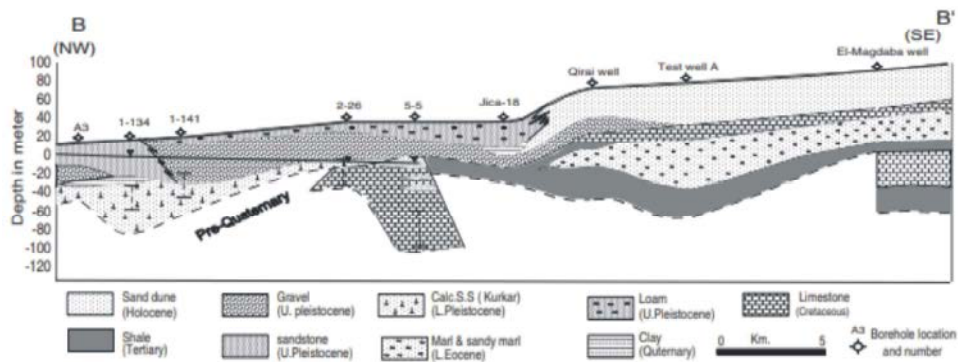


Fig. 3: Hydrogeological cross-section (B-B')

Table 1: Sedimentary succession of El-Arish-Rafah area (modified after different authors).

Age		Lithologic description			Thickness (m)	Locality	Geologic history and environment		
Quaternary	Holocene	Sand dunes: - Loose, fine to coarse ,rounded to sub-rounded, well sorted quartz grains mixed with carbonates.			Variable	Covered almost the study area	Aridity condition		
		Modern beach deposits Loose sand &hard sand cemented by calcium carbonates			Variable	El-Arish-Rafah coastal plain	Formed under warm water condition		
		Holocene wadi filling: Loam, sand, clay, silt with calcarous materials (mudflates)			5-25	Channel of Wadi El-Arish	Wadi El-Arish lowered its level and formation of alluvial terraces		
		Salt marsh deposits: Evaporites mixed with detrital materials, eolian sand and clay.				Sabkhat El-SheikhZuwied			
	Pleistocene	U	Old beach deposits: Sands intercalated with clay &silt			10	Abu-Sagal and El-Sheikh Zuwied		
			Alluvialdeposits	U	Medium to coarse grain sands and silt	13	Along Wadi El - Arish and its tributaries		
		M		Sand and calcarous clay	10	Fluvimarine condition			
		L		Gravels, coarse sand, calc. clay	43				
		L	Kurkardeposits	U	Sandstone , loamy sand (red bed)	20-30		Continental conditions, developm-ent of landmasses	Greatupheavalmovementinthe endofPliocene continuous to
				L	Coarse to medium calcareous sandstone with occasionally content of shell fragment	5-40	Subsurface (wells of the study area)	Marine condition	
Tertiary	Pliocene	U	Limestone with pebbles , cobbles, gravel of chert , coarsequartz grains and shell fragments			2-5	In Awlad Ali area (Surface) In almost all wells (Subsurface)	Shallow marine and inner neritic to littoralenvironme-nt	
		L	Yellow and grey sandy marl . salty and gypsiferous form an isolated hill standing amidst the channel of Wadi El-Arish			20 (Surface) 300 (Subsurface)			
	Miocene	U	Gypsum deposits			Few cms. to 40m.	R3 El-Arish (Subsurface) South Gabal Yelek (Surface)	Forming the ancesstor of Wadi El-Arish	Upheaval
		M	Dark green sticky clay			47 minimum	(Subsurface) in many wells	Submergence	
		L							
Mesozoic	Cretaceous	U	Chalk, marl, limestone			Not defined	Recorded in few wells in Rafah, Lehfin and El Tawila		
		L	Nubian sandstone interbedded with limestone and shale			Not defined			

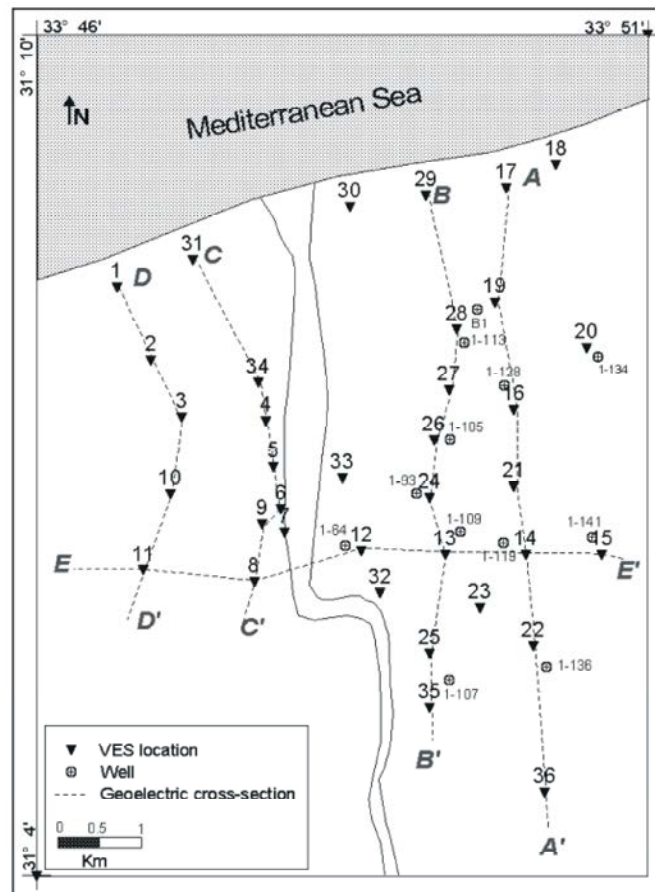


Fig. 4: VES and well location map.

Considering the subsurface conditions, the three water bearing horizons are hydraulically connected and no significant difference has been recorded between their piezometers, so they resemble as one aquifer. Quaternary aquifer in El-Arish area has been highly extracted (52000m³/day) by the extensive pumping rates through about 147 pumping wells.

Present Study: The main aim of the present study is the delineation of the different geoelectrical layers through a hydrogeological interpretation of vertical electrical sounding VES (electrical drilling). Thirty-six vertical electrical soundings were measured in El-Arish area, northern Sinai using Schlumberger configuration.

The location of these VES's is shown in Figure (4). Apparent resistivity is a function of a singledistance variable ($AB/2$), which is 500m in the present study. The advantages of the Schlumberger array are that, it has a large probing resolving power, less affected by lateral homogeneity, detects deeper depths and is more economic. The measured parameter is the apparent

resistivity which is a combination of potential, currents and electrode geometrical factors and would equal true earth resistivity if the earth is uniform (isotropic) [7].

The used instrument is a DC resistivitymeter-GGA31 (Bödenseewerk-Germany) with a microprocessor and RS-232 interface. The resistivity meter consists of two main units and some accessories. The two units are L-unit (power unit) and M- unit (measuring and control unit). The accessories are NI-CD batteries, calibrating resistors, single-core insulated cables (100-1000 m), battery charger and unpolarizable, light, impact resistant high quality steel current and potential electrodes of 50 cm length.

Interpretation: Interpretation is the process in which we determine the layering parameters of the model that describes the geoelectric properties of the earth, which is called inverse problem. The parameters of the geoelectric layer are; resistivity, thickness, longitudinal conductance, transverse resistance. These parameters are determined by interpretation of vertical electrical sounding (VES)

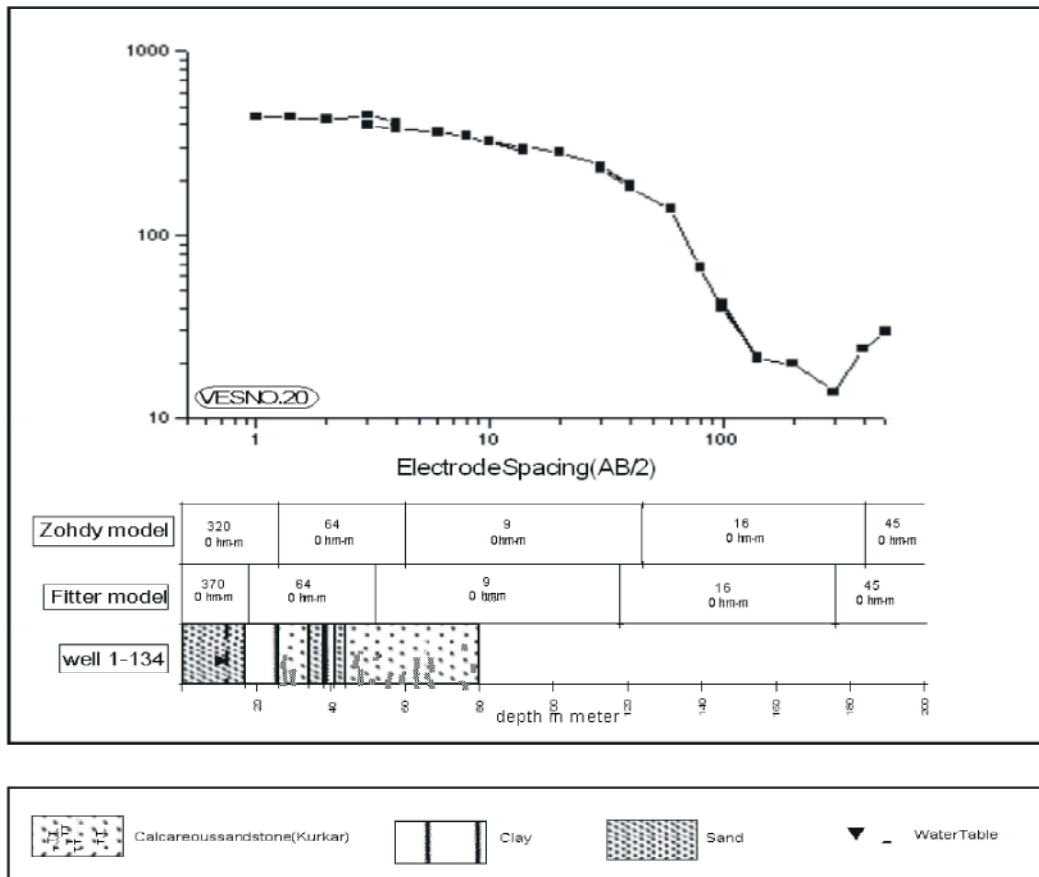


Fig. 5: Results of VES No. 20 by Zohdy [2] and Fitter [3] Programs comparing with the neighboring well No. 1-134.

curves. A correct interpretation requires that, two conditions are satisfied; first, the calculations must be precise; second, a reasonable geological concept or model must be incorporated in the interpretation process [8].

The automatic iterative interpretation method is used in the present study via using two 1D-interpretation programs: Zohdy [2] and Fitter [3]. Zohdy [2] is an automatic inversion process of resistivity sounding curves using least-squares optimization in which a starting model is adjusted successively until the difference between the observed and model is reduced to minimum. Fitter program after Gaal [9] is also an automatic interpretation procedure, but it differs from Zohdy's program in that it needs a previously prepared initial model. The initial model is prepared depending on the lithology and thickness of the different lithologic units in the boreholes which are very close to the location of the measured vertical electrical soundings. The input model is used to generate an initial theoretical curve, then the theoretical curve is compared to the observed one. If the matching is not good or exceeds certain values given

previously to the program, a new theoretical curve is calculated after changing the depth or the resistivities of the geoelectrical layers by certain amounts. Accordingly the program runs until a good agreement with a minimum RMS is achieved. The greatest advantage of this method is that, the use of a true geological model as initial model avoids the problem of equivalency.

The resulting final interpreted models from Zohdy [2] and Fitter [3] and their neighboring boreholes are studied for all VES's. For example Figure (5) shows the observed apparent resistivity curve and its interpreted models of VES No. 20 compared with the neighboring borehole No. 1-134.

Geoelectric Cross-sections: The most plausible resulting resistivity models that agree best with the known geological and hydrogeological structures of the boreholes are used to construct the geoelectrical cross-sections. It must be taken into consideration that, there is a large difference between the geological bed and the geoelectrical layer. The geological bed is defined by its

lithology, while the geoelectrical layer is a tabular body differing from its surroundings in resistivity and polarizability. A geological bed and geoelectrical layer need not to be identical and frequently are not. In some cases a resistivity method is able to separate a geological bed into several geoelectrical layers, whereas in other cases an entire geological complex appears as a single geoelectrical layer. Accordingly, the surfaces separating individual geological beds need not correspond to boundaries between physically homogenous layers [7].

Five geoelectrical cross-sections are constructed in the study area as shown in Figures (6, 7, 8, 9 and 10). The location of these geoelectrical cross-sections are illustrated in figure (4). Examination of the geoelectrical cross-sections indicate that, the geoelectrical succession of the area under investigation could be classified into three geoelectrical layers. The first layer is the surface dry layer, which is characterized by high resistivity values reaching up to 1000 Ohm-m in VES No. 24. This geoelectrical layer is continuous and horizontally extended in cross-sections C-C' and D-D', that are located in the western zone of the studied area or dissected and absent in cross-sections A-A' and B-B' in the east of the studied area.

The resistivity distribution map of the first geoelectrical layer is shown in Figure (11). The thickness of this layer varies from 2m at VES No. 31 to 113m at VES No. 10. From the geoelectrical properties of this layer (resistivity and thickness), its geographical distribution and its matching with information of neighboring boreholes it is concluded that, this layer is corresponding to the surface dry sand dune bed that is distributed mostly in the western part of the studied area.

The second geoelectrical layer is characterized by low to middle resistivity values (10-220 Ohm-m.) and is corresponding to the water bearing aquifer. It is referred to the conductive layer which will be discussed in detail later.

The third geoelectrical layer is characterized by low resistivity and large thickness (Fig. 12). This layer correlates well with the salty lower horizon of the Quaternary aquifer, which is either calcareous sandstone (Kurkar), as in wells No. 1-64, 1-141, 1-128, 1-119 and 1-113 or a gravel horizon, as in well No.1-109 or gravel and kurkar horizon, as in well No.1-107.

From the geology of the study area, the Quaternary aquifer is underlain by a Miocene clay bed of large thickness. Accordingly, the large thickness of the third

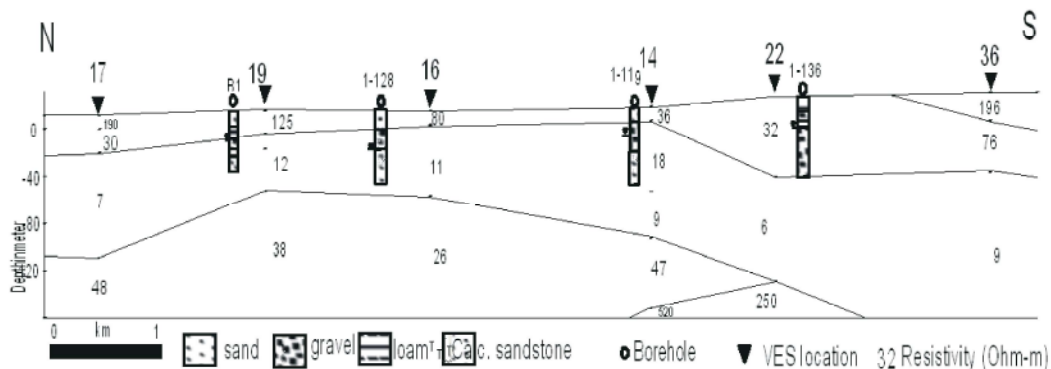


Fig. 6: Geoelectrical cross-section (A-A')

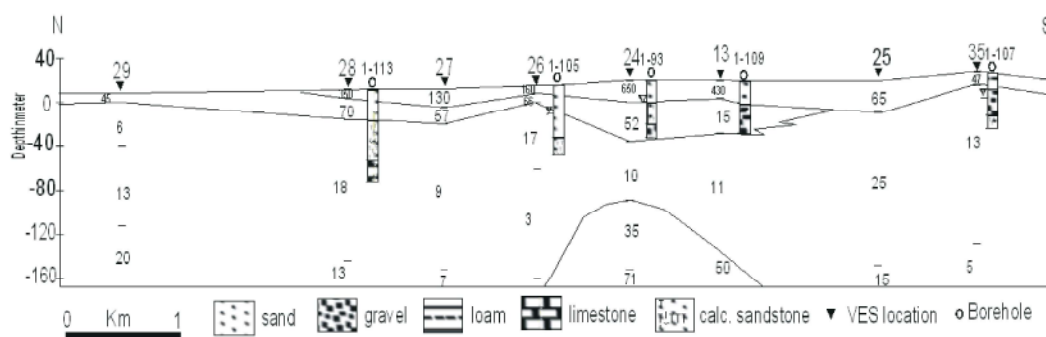
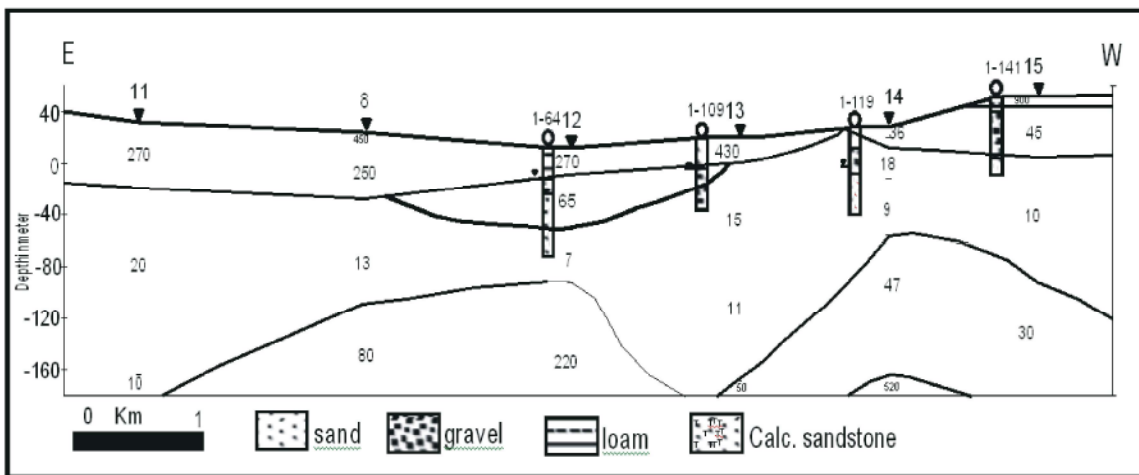
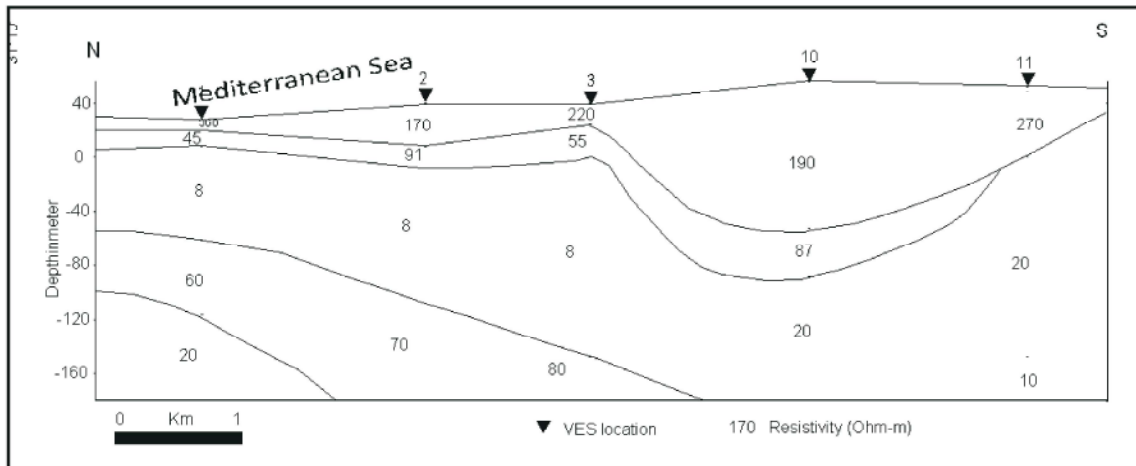
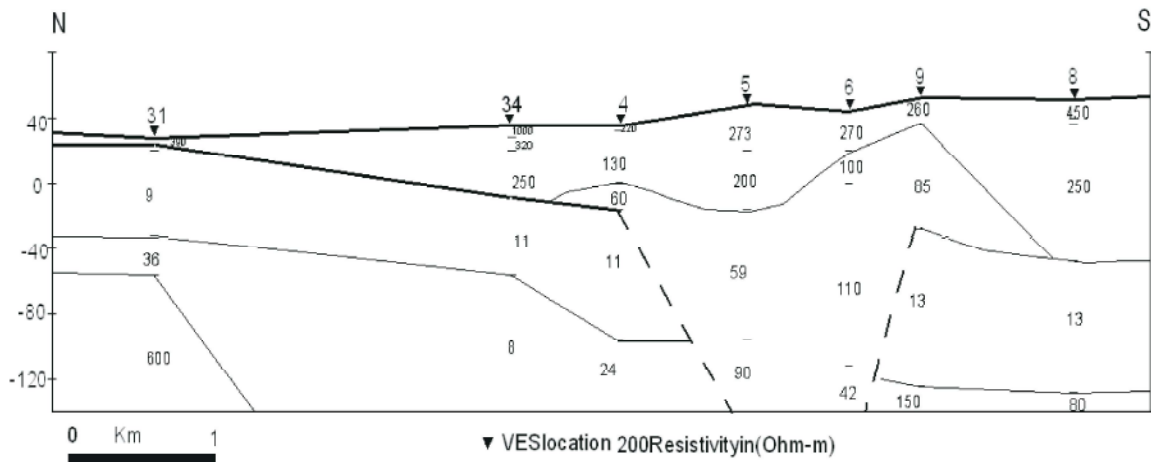


Fig. 7: Geoelectrical cross-section (B-B')



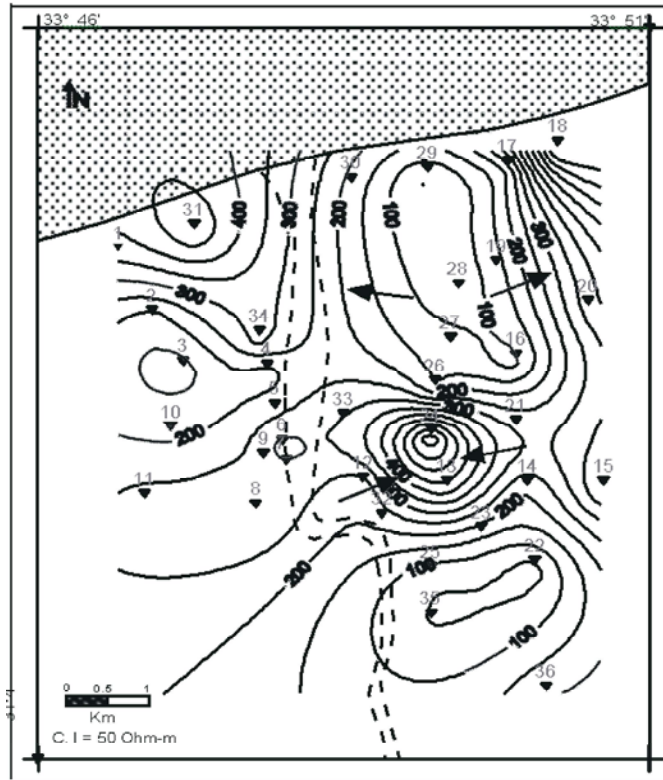


Fig. 11: Resistivity map of the first geoelectrical layer.

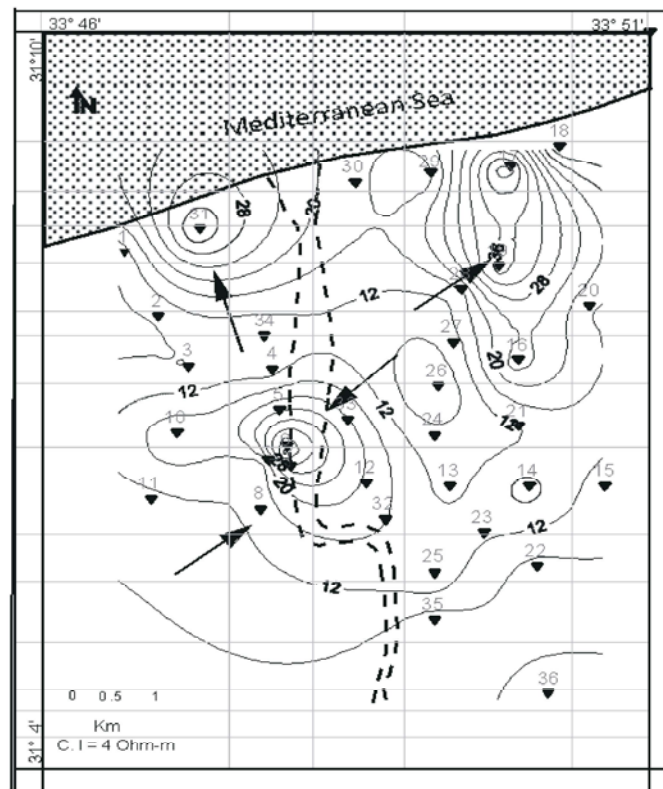


Fig. 12: Resistivity map of the third geoelectrical layer.

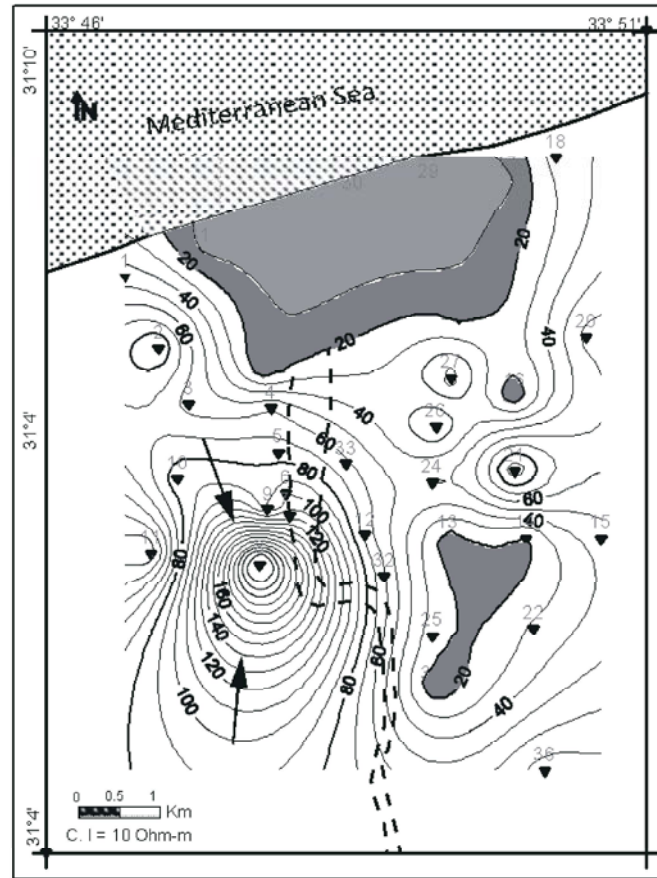


Fig. 13: Resistivity map of the conductive (second) layer.

geoelectrical layer could be subdivided into two geological beds. The upper one is the lower salty zone of the Quaternary aquifer and the lower one is the Miocene clay. The separation between them or the exploration of the lower surface of the Quaternary aquifer (which is a very important hydrogeological target) in this case using only VES is rather difficult.

The underlying geoelectrical layers are characterized by various resistivities, ranging from high to low. The absence of deep boreholes in the study area makes the interpretation of these deep geoelectrical layers rather ambiguous.

In the presented geoelectrical cross-sections no indications of shallow geological structures are clear, except for the geoelectrical discontinuity of the third geoelectrical layer in geoelectrical cross-section C-C' under VES's No. 5 and 6.

The Conductive Layer: The conductive layer or the second geoelectrical layer is characterized by low to medium resistivities ranging from 10 to 220 Ohm.m

(Fig. 13). From the horizontal distribution of resistivities, this layer could be divided into three zones. The first one has a very low resistivity (<20 Ohm.m) existing in two areas; The first is around VES's No. 31, 30, 29, 17 and 18 adjacent to the shore line and the second area lies within VES's No. 13, 14 and 35 to the east of wadi El-Arish main channel in the main delta. These very low resistive areas, especially that parallel to the shore line, may indicate salt water contamination or clay content. A comparison between the resistivity map of the conductive layer and the isopach and distribution map of the clay lenses within the Quaternary aquifer (Fig. 14) indicates a significant correlation. These two high conductive areas match well with the two large clay lenses.

The second resistivity zone ranges from 20 to 80 Ohm.m, existing in the northwest of the studied area between the two clay lenses. The third zone is located around VES's No. 6, 7, 8, 9 and 10 in the southwest of the studied area and is characterized by resistivities more than 80 ohm.m. Since the second and third zones contain no clay lenses, the proposed influencing factor is

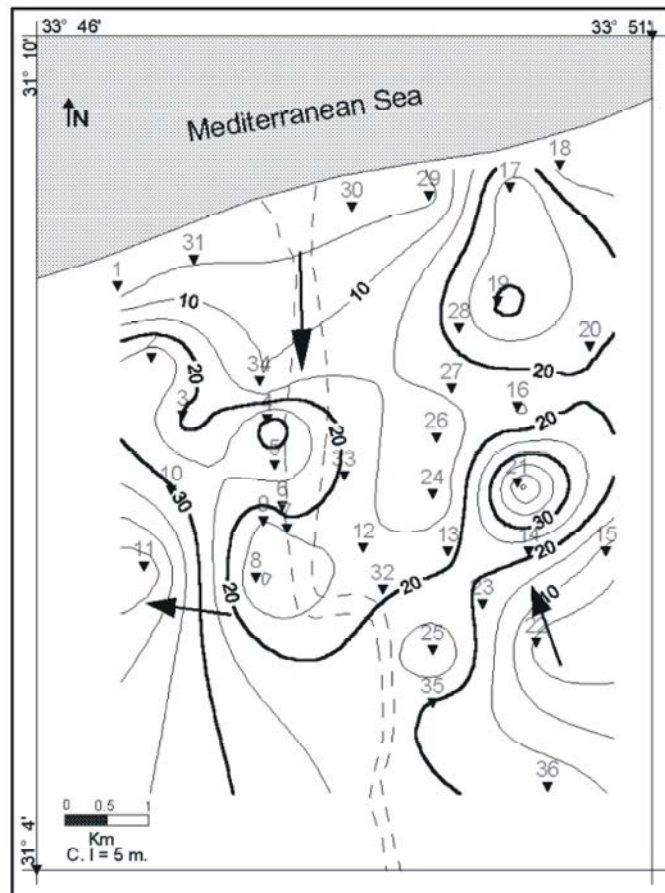


Fig. 15: Depth to the conductive layer map.

the groundwater salinity. The low resistivity to the East refers to high salinity and the high resistivity to the West refers to low salinity.

Figure (15) shows the depth to conductive layer, which could be divided into three zones. The first one is the major zone in the study area and is characterised by a depth ranging from 4m along the shore line to 20 m in the main delta. The second zone ranges from 20 m to 30 m forming the boundary of the first zone. The third zone is more than 30 m in VES's No. 11 and 21.

A comparison between the depth to conductive layer resulting from resistivity interpretation and the static water level in boreholes shows a good matching with a small difference due to the previously discussed hydrological reasons. There is a good matching between VES No.12 and borehole No.1-64 and VES No.13 and borehole No.1-109 in geoelectrical cross-section E-E', VES No.19 and borehole No.B1 and VES No.16 and borehole No.1-128 in geoelectrical cross-section A-A' and VES No.24 and borehole No.1-93

and VES No.26 and borehole No.1-105 in geoelectrical cross-section B-B'.

CONCLUSIONS AND RECOMMENDATIONS

The depth to the conductive layer ranges from 4m parallel to the shore line to about 30m southern and south-eastern the study area.

The large extended clay lens parallel to the shore line is suggested to be an important hydrogeological barrier to prevent the sea water intrusion and to separate between the upper phreatic fresh water horizon and the lower confined to semi-confined salt water horizon.

The recommended resistivity method for the exploration of lower surface of Quaternary aquifer would be the induced polarization, where IP signals disappear, when they enter saline water, since their high conductivity does not allow for any ion accumulation, but may grow or remain steady when going through clay beds [10].

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