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Using Vertical Electrical Sounding for Locating Static Water Level and Geological Features in Aqaba Area, Jordan

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ABSTRACT

This study was carried out to assessing the groundwater potential and its quality, to explain the subsurface geological and structural conditions of subsurface geological layers and to support the geological, environmental studies. Vertical electrical sounding survey of an area begins with a number of the depth sounding using the four-point method. About 10 sounding were taken at different locations. In each single sounding, direct current is applied to the earth through current electrodes. The equipotential surface (surface of equal voltages) runs perpendicular to the current lines. There is also a potential distribution on the surface of the ground. The resistivity (ρ) of the subsurface geological layer was delineated from the surface potential reflects. Several faults have been detected by using the geophysical surveys. The layers have a resistivity values between 16 and 1840 ohmm are interpretative as superficial deposit. The resistivity values less than 23 ohmm indicate that this layer contains brackish water. The locations that have a very high resistivity more than 1984 ohmm could be the basement complex. The shallow aquifers existing at a depths ranging from 4 to 19 m and the relatively deep aquifers from 24 to 60 m below the ground surface. The results that obtained from the Vertical electrical sounding coinciding with the results that obtained from the borehole information and the previous works.

Key words: Aqaba, groundwater, geophysics, Jordan, vertical electrical sounding

INTRODUCTION

The direct current resistivity inverse problem was investigated for the first time in thirties of twenty century (Slichter, 1933). The geophysical study aims to construct an isoresisitvity map of seawater intrusion and the geological layers. The calibration of VES results with borehole data enabled us to established geological cross sections. These sections shed the geometry of the aquifer and estimate the vertical and horizontal configuration of the seawater intrusion (Kouzana *et al.*, 2009). The resistivity methods are used frequently in ore, in groundwater investigation, mapping of geological formations, in geotechnical and in environmental problems (Meju, 2002). The genetic algorithm simulation technique has been applied for solving the groundwater inverse problems with some demonstrated use in the area of parameter estimation (Jha *et al.*, 2006).

Wenner profiling, Pole-pole surveys, pole-dipole and dipole-dipole profiles and gradient maps are the different possible arrays as Schlumberger sounding. Many authors have observed the effect of nonlayered structures located in the vicinity of vertical electrical soundings (Queralt *et al.*, 1991).

Numerous consequences of unsustainable groundwater use are becoming increasingly evident owing to cover-increasing demand for water supplies and increasing pollution and they key concern is to maintain a long-term sustainable yield from aquifer (Todd and Mays, 2005).

In the groundwater view, the shallow alluvium aquifer remained to be the source of water supply in Aqaba until 1965. The salinity of water in this shallow aquifer increased and became unsuitable quality for household uses due increase in population and then increased pumping time. Encroachment of sea water also caused the rapid increase in salinity. It is possible to investigate the quality of groundwater by using appropriate geophysical methods and techniques. Use of geophysical methods for solving groundwater and environmental problem is becoming essential. The rapid development in the geophysical techniques is offering reliable to great variety of environmental problems.

There are direct and indirect of geophysical methods for determining the resistivity and thickness of the layer using Vertical Electrical Sounding (VES) data. Indirect inverse modeling methods involve type curves matching and forward algorithm for the interpretations of VES data which are widely used by practicing hydro geologists. Direct inverse modeling methods, as resistivity inversion by numerical algorithms, involve the minimization of error between the observed apparent resistivity and the computed one. These can be obtained by using traditional optimization technique such as the ridge regression technique and singular value decomposition technique as well as evolutionary optimization technique (Jha *et al.*, 2008).

Santos and Sultan (2008) summarized the resistivity values characterized the geological units. The resistivity values of gravel and sand increase with depth from 20 ohmm to greater than 300 ohmm. Fine and coarse sand formations are characterized by resistivity values ranging from 80 to 400 ohmm. While the resistivity values of clay varies between 1.4 and 20 ohmm and the erinaceous calcareous formation shows resistivity values ranging from 15 to 40 ohmm.

The VES measurements in vicinity of the boreholes with the aim to get the layered resistivity model which obtained from interpretation constrained by the available geological data in the boreholes were carried out. The resistivity models at the boreholes would have then helped to interpret VES at the MRS sounding sites. The shallow depths of investigation for VES measurements are probably due to high conducting layers at relatively shallow depth (Wattanasen and Elming, 2008). A geoelectrical investigation is capable of mapping aquifer systems and thickness of that aquifers as well as groundwater quality (Todd, 1980; Fetter Jr, 1994).

The study area is the Aqaba region (Southern wadi Araba basin). Aqaba region area located at 87900 and 89000 North and 147000 and 158000 East (Palestine grid) as shown in Fig. 1. Tectonically Aqaba area lies within the tectonic plate boundary along the Arabian and African plate slide. This plate boundary comprises numerous and shot fault segments. The Gulf of Aqaba does not have a true shelf, it is submarine slopes are very steep. This is attributed to its origin as a down-faulted block forming a deep graben structure.

The main aims of this study are to assessing the groundwater potential and its quality, to explain the subsurface geological conditions and support the ongoing geological, environmental and hydrogeological studies. Therefore, it was anticipated that the results of the geophysical surveying will give many different important parameters as the subsurface geological features, thicknesses of the different lithological units, depth to the bed rocks and depth to the water table.

All surface geophysical methods measure some physical properties of rocks and fluids. Selection of appropriate geophysical method is determined by the required specific physical property and its contrast between adjacent rock units. Typical physical properties measures are electrical resistivity, electrical conductivity and velocity of elastic waves, gravity and magnetic fields.

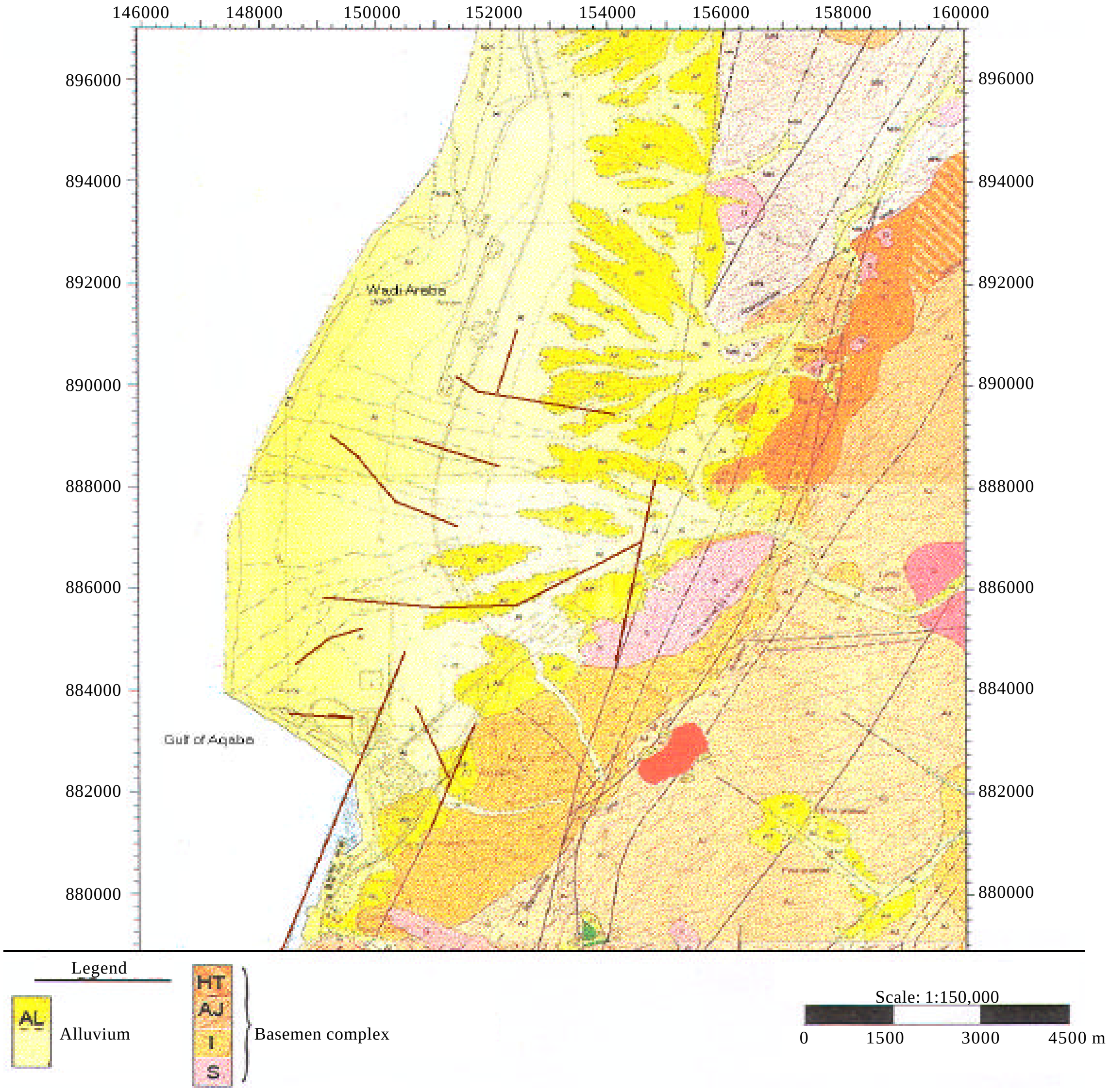

Fig. 1: Geological map showing the outcropping layers in study area and the locations of the VES geophones, the most of outcropping geological layers are alluvial, alluviums and sand (Modified after NRA 1988)

For above mentioned tasks, the Vertical Electrical Sounding (VES) method was selected for this study. VES was used for the determination of the different lithological units including their thickness and depth to the water table. It was used also to locate faults, dykes and other geological structures.

There are two major groups of rocks in the study area. The first group is the basement complex named Aqaba complex rocks and the second group is alluvial sediments.

Basement complex (Aqaba complex): This basement complex consists of granite, granodiorite and basic and acidic intrusive rocks pre-cambrian age. It extends from northwards of Saudi Arabia to Wadi Ram in south Jordan.

The basic intrusive are three sets of parallel dolerite dykes and the Acidic intrusive consists of porphyry dickes, aplites, pegmatites, felsities and quartz porohyries. The topographic of the basement is characterized by rugged mountain.

Alluvial sediments: The exposed alluvial deposits in the wadies and on the north and eastern shores line consists of rounded, weathered granitoid clastic. Wadi sediments consisting of unsorted sand and gravel which graded shores wards to beach sand and up slope into alluvial, mud flat sediments occur northwest of airport. A lagoon deposit (Pleistocene) occurs close to the shoreline.

MATERIALS AND METHODS

Materials: Electrical sounding techniques have been used effectively for shallow prospecting. The resistivity method provides information on subsurface geology such as the depths to the water saturated zones and the clay layers that confine the aquifers. Furthermore, electrical sounding are accurate in the detection of buried channels. It shows great variations in resistivity values across the axis of the channel due to the lateral changes in grain size of the deposits. But it shows small variations are observed in the parallel direction.

Methods: Vertical electrical sounding survey of an area begins with a number of the depth sounding using the four-point method. There are done in selected locations in the field, depending on the objective, a net or profile-arrangement is used. The spacing of the sounding points may also be varied. In each single sounding, direct current is applied to the earth through current electrodes. The equipotential surface (surface of equal voltages) runs perpendicular to the current lines. There is also a potential distribution on the surface of the ground. The surface potential reflects the resistivity (ρ) of the geological layer beneath it. The physical dimension of specific resistivity is ohm meter (ohmm).

Resistivity (ρ) can be determined from the current (I) flowing through the ground between the current-electrodes A and B and the voltage (V) is measured between the potential-electrodes M and N (Fig. 2).

The calculate resistivity in independent of the contact resistance's at the electrodes. If I is the current between A and B and V is the voltage measured across M and N, then the apparent resistivity (ρ_a) is given by the following equation:

$$\rho_a = K\ V/I \text{ ohmm} \qquad (1)$$

where, K is a constant, depending on the spacing AB and MN of the current and potential-electrodes, respectively.

In the case stratified material, between layers of different electrical resistivity. The resistivity the current preferentially travels in the highly-conductive layers. The current lines are refracted at interface depends quite strongly on the distance between the two current-electrodes A and B. When the values for resistivity (ρ_a) are plotted on a log-log paper against AB/2, the so-called sounding graph is obtained. In practice, at a single sounding point, measurements are taken at different electrode-spacing AB, varied by moving the current electrodes A and B to different positions. There are different types of electrode configurations each type is used for a special purpose. For the purpose of this study, the Schlumberger configuration was used one in electrical

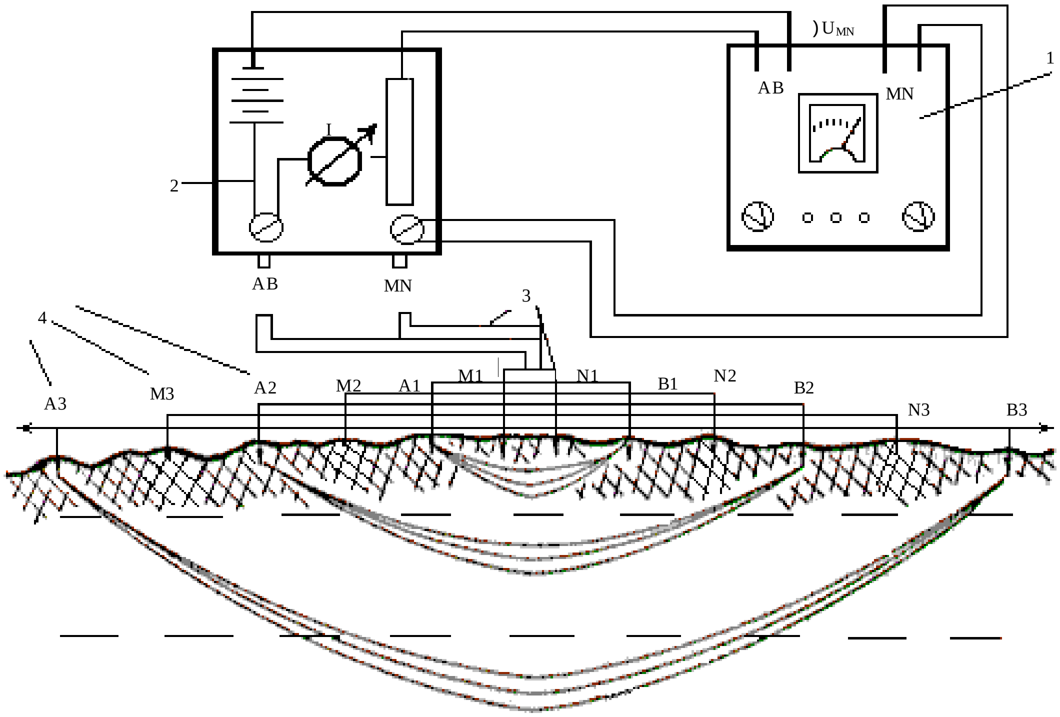

Fig. 2: Scheme of the vertical electrical sounding (VES) device: (1) Auto-canceller, (2) Commutator for electrodes AB and MN, (3) Netted wires for different distances among electrodes AB and MN and (4) electrodes

prospecting. Four electrodes AMNB are placed along a straight line on the earth surface. The distance between the potential electrodes (M, N) is relatively small as illustrated in the following schematic diagram.

Figure 2a and b are the current electrodes (M and N) are the potential electrodes (O, o) are the mid points (a) is the half distance between the current electrodes (A, B) (b) is the distance between the potential electrodes (M, N), where, AB≥5 MN.

The distance the resistivity in terms of the electrical field (E) rather than the potential deference (ΔV) can be obtained from the following equation:

$$\rho = \pi\ (AB/2)^2.\ E/I \qquad (2)$$

where, E = lim and (ΔV/MN)/MN = electrical field.

MN is the distance between the potential electrodes. The above equation shows that the Schlumberger apparent resistivity (ρ_a) is a function of a signal distance-variable (AB/2).

The specific electrical resistivity of rocks and the electrical conductivity of a sediment is essential electrolytic and consequently depends on the nature amount and concentration of the electrolyte in the voids of the sediments.

High conductivities and thus low specific resistivity are typical of sedimentary layers bearing large amount of water with a high electrolyte concentration. In this case the presence of pore spaces, Joints and fractures in sediment is clearly essential. Clayey sediments are relatively good electrical conductors. Because of they consist of very fire grains having the highest porosity and the lowest permeability. So, groundwater remains in the tiny pores of the clays. It is difficult to distinguish between clayey sediments and unconsolidated sediments bearing water with a high electrolyte concentration from resistivity values only. In both cases, the electrical resistivity lies approximately within the range of 1-50 ohmm. Additional information is required in this case. However, in most sediment, the resistivity is essentially dependent on the percentages of clay and marley, so that resistivity values are indicative of grain size of the sediments. Dry rocks with no clay component show very high resistivity values (≥1000 ohmm).

In general, for conducting resistivity measurements in the field, a power source, electrical, cables and reefs and current meter and voltmeter for measuring the current and voltage.

The resistivity equipment which was used in the study area, is SYSCAL R1 which is a high quality general purpose. Early resistivity equipment capable of conducting accurate measurements over a wide range of conditions was used. IRIS instruments, a famous French geophysical instrumentation company, develop it. SYSCAL R1 is high-power automatic resistivity meter for DC electrical survey applied to groundwater and structural geology investigations. The SYSCAL R1 includes a transmitter and receiver within one single compact box. The maximum output voltage is 800 volts peak to peak. The stored in the internal memory is up to 1000 readings. Each reading includes current, voltage, Self-potential (SP), resistivity, chargeability and spacing. It includes also automatic digital stacking to enhance the signal to noise ratio with a maximum of 250 stacks and resolution of 1 μV for measuring low amplitude signals. The SYSCAL R1 measures ground resistance from 1 ohmm up to 1000 K ohmm.

RESULTS AND DISCUSSION

Geoelectrical cross sections: Results of the electrical soundings are shown in three cross-sections of Fig. 3a-c.

Geoelelectrical section 1: This cross section as shown in Fig. 3a, represents the correlation between VES 38, 39, 37, 40 and 42 along this cross section; three layers of different resistivity have been observed. The thickness of the top layer reach a maximum value of about 12 m. The resistivity

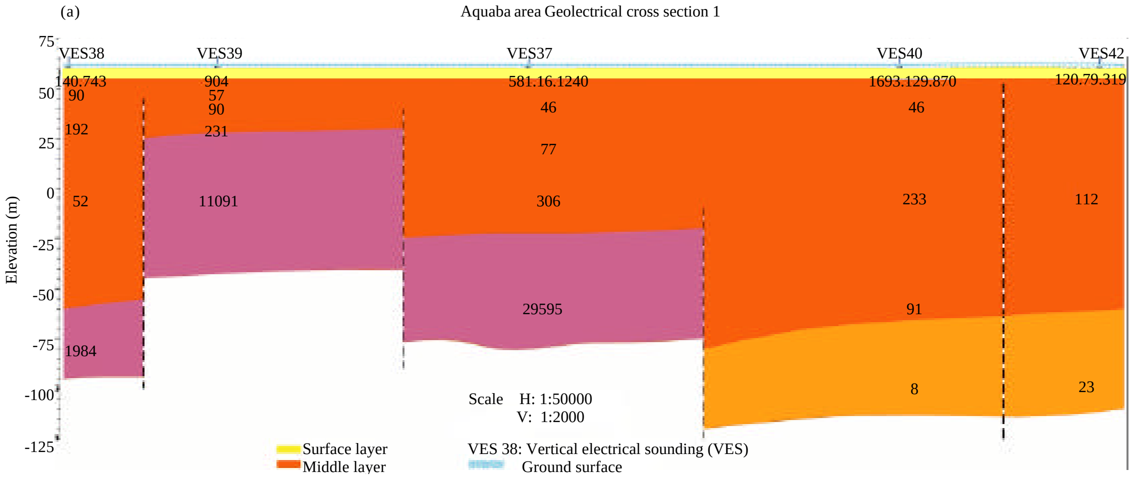

Fig. 3(a-c): Continue

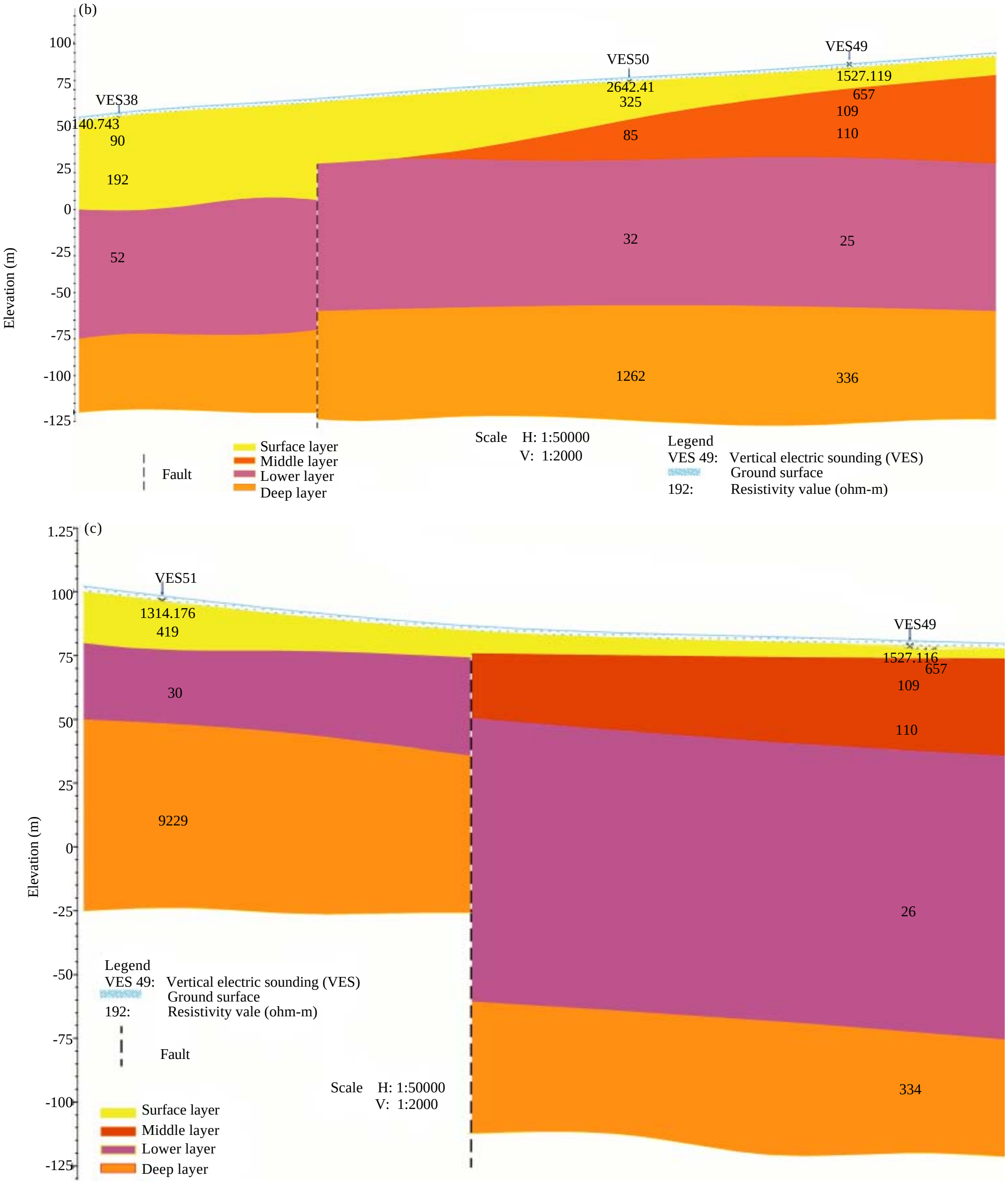

Fig. 3(a-c): (a) Cross section 1 of the vertical electrical sounding at the study area shows the faults as dashes black lines, the resistively of the geological layers as numerical numbers in ohm-m, the different colors denote to the different geological layers and the VES locations, (b) Cross section 2 of the vertical electrical sounding at the study area shows the faults as dashes black lines, the resistively of the geological layers as numerical numbers in ohm-m, the different colors denote to the different geological layers and the VES locations and (c) Cross section 3 of the vertical electrical sounding at the study area shows the faults as dashes black lines, the resistivity of the geological layers as numerical numbers in ohm-m, the different colors denote to the different geological layers and the VES locations values range between 16 ohmm up to 1840 ohmm. This layer is interpretive as superficial deposits consisting of alluvium. Resistivity of the second layer ranges between 46 and 306 ohmm. The maximum thickness of this layer is about 135 m below VES 40. This layer is subdivided into three sub-units. The resistivity value of the upper unit is about 126 ohmm or less. The second one is located beneath VES numbers 38, 39, 37 and 40 that has resistivity values ranging between 192 and 306 ohmm. While the third unit has resistivity values of 91 ohmm that located beneath VES 40 and resistivity value of 52 ohmm that located beneath VES 381. The third layer contains brackish and saline water beneath VES 40 and 42 the top of this layer is reached at a depth of about 140 m. The resistivity value of this layer is less than 23 ohmm beneath VES 40 and 42. Where the value is very high (more than 1984 ohmm) beneath VES 38, 39 and 37 which could be the basement complex. Several subsurface faults were detected along this section.

Geoelectrical cross section 2: This cross section (Fig. 3b) correlates the soundings VES 38, 50 and 49. Along this section, four layers of different resistivity were observed. The top layers have a maximum resistivity of 2642 ohmm below VES 50. It is interpretive as superficial deposits consisting of dry alluvium. The thickness of this layer ranges from 15 m beneath VES 49 to 50 beneath VES 38. Resistivity of the second layer varies between 85 and 110 ohmm and its located beneath VES 50 and 49, where it is missing beneath VES 38. Its thickness ranges from 15 m beneath VES 50 m and up to 42 m beneath VES 49. The third layer has resistivity values less than 52 ohmm where its average thickness is about 85 m. The fourth layer has high resistivity values it ranges between 336 and 1262 ohmm. It is interpreted as a basement complex and it occurs at a depth of about 125 m beneath VES 38. One subsurface fault was detected along this cross section between VES 38 and VES 50.

Geoelectrical cross section 3: This cross section (Fig. 3c) correlates the soundings VES 49 and 51. Resistivity values along this section are interpreted as three layers. The top one has a maximum resistivity of 1527 ohmm below VES 49 and a maximum thickness of about 22 m below VES 51. This layer is interpreted as superficial deposits consisting of dry alluvium. Resistivity of the second layer ranges between 26 and 110 ohmm. Its thickness is about 140 m and 30 m beneath VES 49 and 51, respectively. The third layer has relatively high resistivity (the resistivity is about 334 ohmm or more). The top of this layer occurs at a depth of 55 and 150 m beneath VES 51 and 49, respectively. It is interpreted as a basement complex. One subsurface fault was detected along this cross section. Figure 3c shows the VES cross section 3 at the study area.

In addition to the geological structure, depth and thickness of the different lithological units, a good success has been achieved in detecting depths to the water levels and thicknesses of the saturated zones.

Close to the air port well, E 150.950, N 5888.450 VES No. 37 was conducted. A layer at 40 m depth with a resistivity of 77 ohmm the top of which is interpreted as the Static Water Level (SWL) of the groundwater in that site which is the real SWL measured in the well.

VES No 42 lies in the vicinity of the palm forest well No 2. The log of this well is shown in Fig. 4. The depth to the SWL in the site was detected at 10 m and the thickness of the saturated layer is 120 m. The SWL detected on this sounding coincides with the well information.

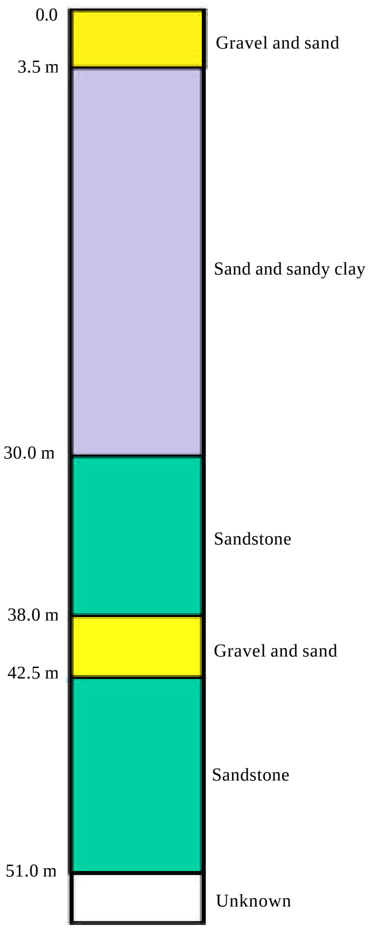

Fig. 4: Strip log show the subsurface geological layers of the well No. 2 (palm forest well) in Aqaba area

Generally the subsurface geological layers in the study area is described as the following:

00-25 m:	Course grained reddish to yellowish sandstone inter-bedded with gravel zones
26-27 m:	Sandy silt, very fine-fine grained, yellowish colour
28-34 m:	Unconsolidated sandstone, coarse to medium grained, Reddish-Brown colour
35-36 m:	Sandy silt, very fine-fine grained, reddish and yellowish colour
37-42 m:	Unconsolidated sandstone, coarse to medium grained, reddish colour
43-46 m:	Sand intercalated with gravel, flat lying terrace material, fine to coarse grained

There is a good correlation between the results have been obtained from VES in this study and the results obtained from the Ground Penetrating Radar (GPR) method that carried out by Slater and Niemi (2003). The locations of the faults that obtained in this study have been coinciding with the surface faults at the Aqaba area that were delineated by Garfunkel *et al.* (1981), Klinger *et al.* (1999) and Barjous and Mikbel (1990).

CONCLUSION

In this study Vertical Electrical Sounding (VES) survey were carried out at many different sites in the Aqaba area using the Schlumberger electrode configuration. The true layer resistivity and thickness values of different layers obtained from the VES data inversion were correlated with the available wells data. Based on this correlation, the types of layers present at different depths including water-Bearing formation (if any) were identified. It was found that the subsurface layer having a true resistivity in the range of 30-65 ohmm that indicates groundwater availability. On the other hand the true resistivity of aquiclude layers (i.e., unsaturated zones) varies from 8.4 to 2595 ohmm. Aquifers are available in the study area at depth ranging from 4 to 60 m below ground surface with a thickness of 4 to 30 m.

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