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THE USE OF SEISMIC REFRACTION AND ELECTRICAL TECHNIQUES TO INVESTIGATE GROUNDWATER AQUIFER, WADI AL-AIN, UNITED ARAB EMIRATES (UAE)

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Abstract

Twenty seismic refraction profiles, three Vertical Electrical Soundings (VES) and Three Electrical Resistivity Tomograms (ERT), using Wenner Array were acquired along Wadi Al-Ain, in order to study the aquifer's geometry, groundwater level and locate the promising sites for future drilling. The seismic velocities distribution analysis indicated that, there are three different zones ranging between (590 – <1400 m/s), (1400 – <1800 m/s) and (1800 – 5300 m/s). The obtained results show that the first low velocity values may indicate the unsaturated zone which is directly affected by the surface water that appears along the studied area. The second velocity range may reflect the water level at the saturated zone or the main aquifer. The third range of velocity reflects the lithological interfaces. The estimated depth to the unsaturated zone varies between 2 m to 7m. The depth to the saturated zone ranges between 10 m and 15 m. However, the lithological interfaces depths is detected clearly at 15 m to 25 m. This represents the gradual increase of seismic velocity layers with depth. This increase may be due to the dense formation which change vertically from alluvial to compacted sediments and then to limestone. The integrated seismic refraction profiles, VES and ERT results show that the aquifer is a Quaternary alluvial deposits aquifer, which consists mainly of gravels, sand and clay with average thickness of about 15 m or more and underlained by compacted sediments and limestone. The apparent resistivity of the aquifer shows a surficial resistive layer of dry alluvium with resistivity of 700 Ω.m then lower resistivities reach to 5 Ω.m, then increasing gradually with depth to about 566 Ω.m or more through 100 m thickness. ERT profiles also confirm the water depths, obtained from seismic refraction analysis. This integration confirms the existence of a fresh groundwater within this interval. The obtained results show that any future drilling for groundwater, a number of the VES positions may be considered as potential locations.

Keywords: Seismic Refraction, VES, ERT, Groundwater, Aquifer, Al- Ain

1. INTRODUCTION

The study area is situated in Al-Ain in the eastern part of Abu Dhabi, United Arab Emirates (UAE), near the border with the Sultanate of Oman and at the western margin of the Northern Oman Mountains (Ellison et. al., 2006) (Figure 1). Although Al-Ain is located within the arid desert belt of the world and characterized by drainage net formed as a result of the prevalence of humid climate during the Quaternary, it is one of the largest and ancient oases of the Arabian Peninsula due to the fresh groundwater supply which is derived from the Oman Mountains to the East (Hunting, 1979).

The seismic refraction method is an important geophysical method. It has been adopted to investigate the groundwater level in the study area, which has recently become very shallow in some part of Al-Ain. The objective of the seismic survey measurements is to confirm or not the assumption that the groundwater level can primarily be revealed by seismic refraction technique especially in the gravely-sands or silty clay areas, in which the groundwater level can be determined as a boundary of acoustic impedance (Galfi & Palos, 1970). Shallow seismic survey can be useful to be integrated with the Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT), in order to investigate changes in the groundwater level and to possibly locate the groundwater aquifer and promising sites for future drilling.

2. METHODOLOGY

Seismic Refraction method along with VES and ERT have been used to investigate the depth of the groundwater level and the subsurface layering in the study area.

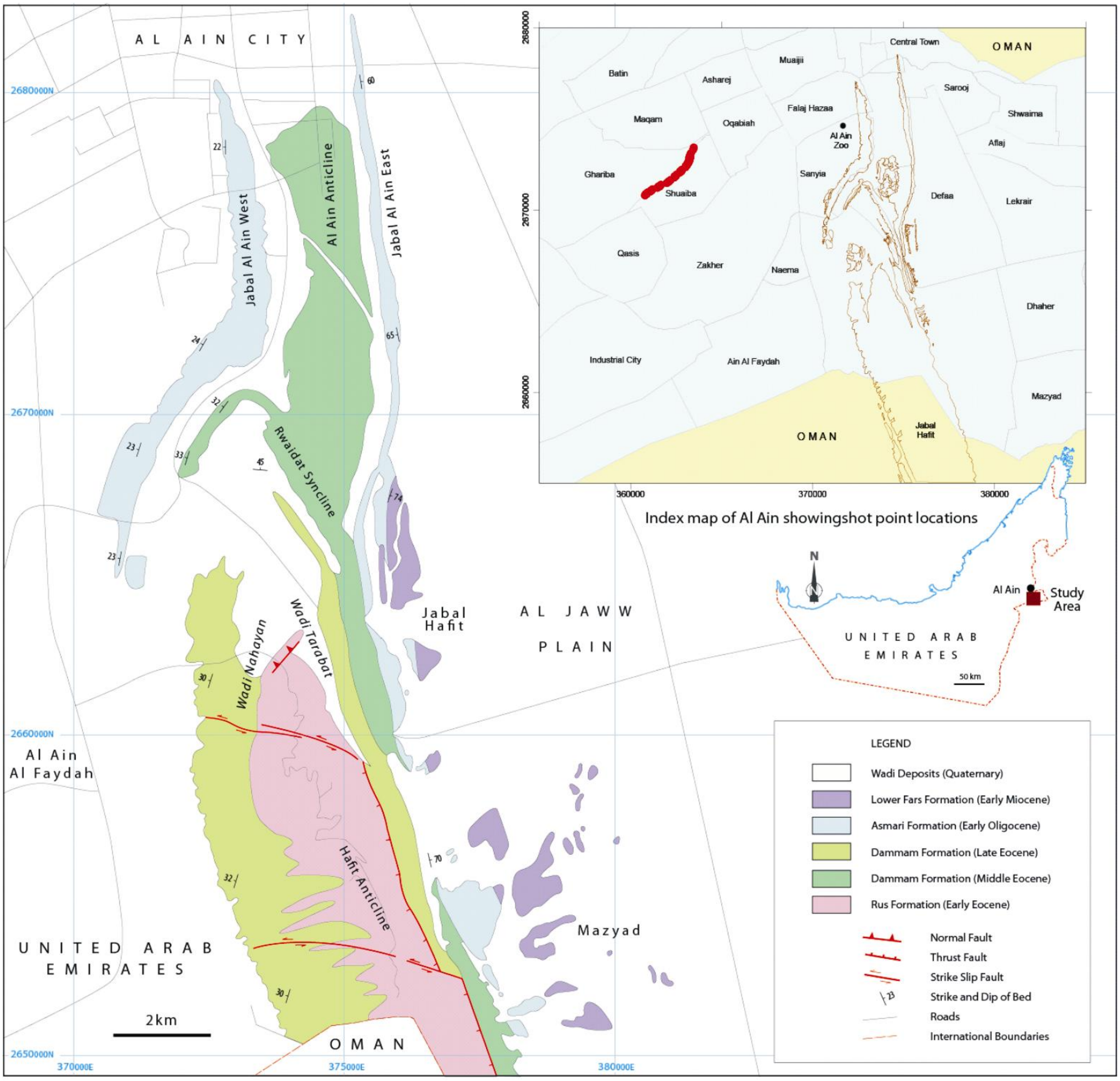


Figure (1): Geologic map showing the location of the study area (Ellison et al., 2006)

2.1. Seismic Refraction Method

Since in the case of differing elastic properties the groundwater level can be determined as a boundary of acoustic impedance, therefore, its level can be revealed by seismic refraction (Galfi & Palos, 1970). Seismic Refraction method uses seismic energy that returns to the surface after traveling through the ground along refracted ray paths. The first arrival of seismic energy to a detector offset from a seismic source always represents either a direct ray or a refracted ray (Reynolds, 1997). The compressional wave velocity increases with confining presure. The sandstone and shale velocities show a systematic increase with depth of burial and with age due to the effects of progressive compaction and cementation. For a wide range of sedimentary rocks, the compressionl wave velocity is related to the density, and well established velocity-density curves have already been published (Sheriff & Geldart, 1983). Hence, the densities of inaccessible subsurface layers may be predicted if their velocities are known from seismic surveys.

Twenty Seismic refraction profiles have been acquired in the study area. The profiles' extensions were 120m. Forward and reverse seismic shooting were carried out with geophone interval of 10 meters, using the multi-channel ES 3000 seismograph with 12 geophones and a sledge Hammer energy source with approximate energy of 98 Joules of one shot. The accuracy of time measurement is about 10^{-4} sec. The shot points locations in the study area are as shown on the map (Figure 2).

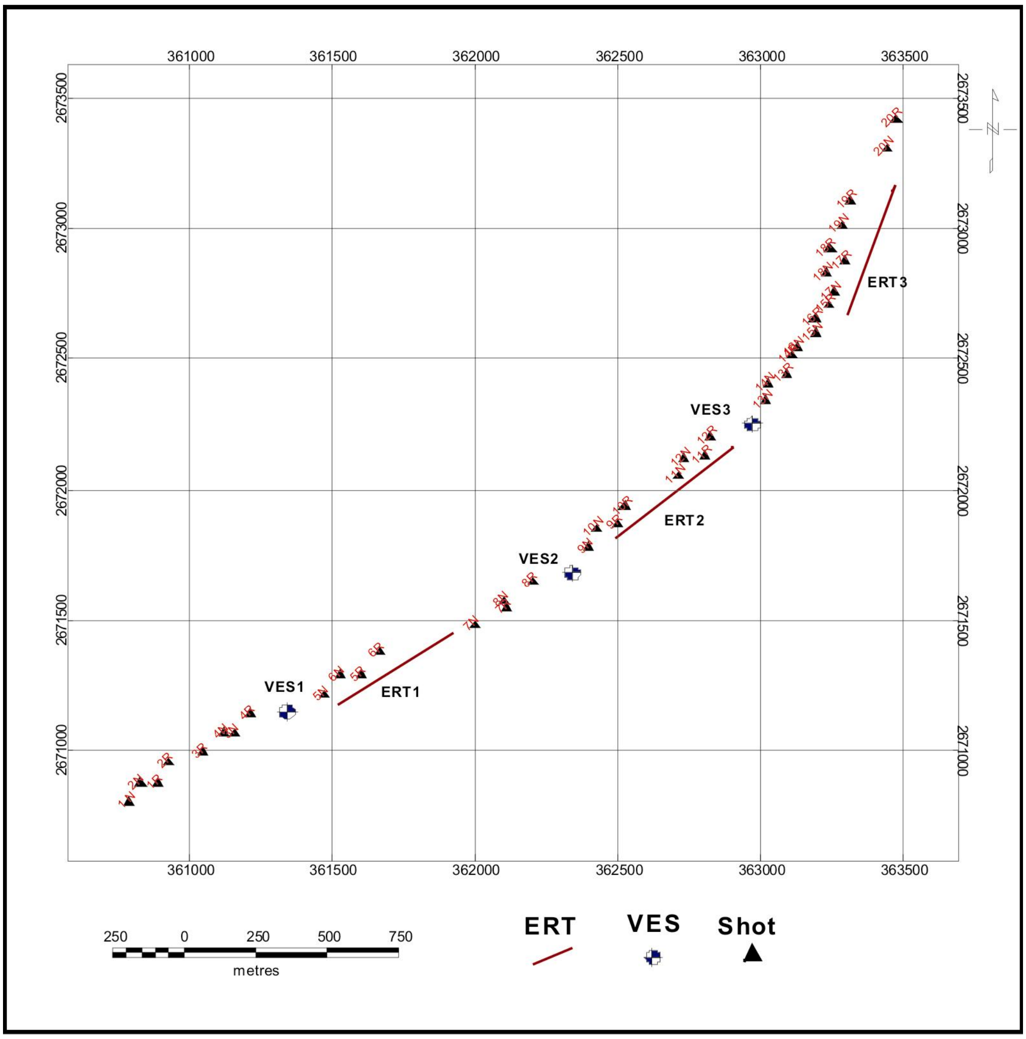


Figure 2: Location map of seismic shots, VES and ERT profiles

The seimogram is the main result of the field work. It represents the analog recording of the received signals. The recorded seismic traces reflect the responses of the subsurface interfaces. The most important first arrivals are the direct and refracted waves, received by the geophones. Some of the recorded traces have been noisy or bad traces, even after applying filtering techniques during the processing stage which had been carried out to enhance signal/noise ratio. These bad or highly noisy traces are killed or deleted from some of the shot records. Figure 3 shows an example of the tweleve traces of the recorded seismograms. These plots have been constructed using Seismodule, Pickwin and SeisOpt softwares. The first arrival picks are taken and tabulated, the time-depth graphs are plotted and the plotted points are best fitted to reflect the layers interfaces and estimate the seismic velocities. The seismic velocities are calculated from the slope of the fitted lines on the time-distance curve (Figure 4). Two parameters are usually used to quantify the layer thickness. The first of these is referred to as the cross-over distanc (X_c), which simply refers to the offset at which the headwave becomes the first arrival. The second commonly used parameter is called the zero-offset time (intercept time t_o). By measuring X_c or t_o, in addition to the seismic velocities of the first and second layers (V_1 & V_2), the thickness of the layer (h) can be computed using the following equations (Reynolds, 1997).

$$h = t_o V_2 V_1 / 2 (V_2^2 - V_1^2)^{1/2} \qquad (1)$$

$$h = X_c/2 \quad (V_2 - V_1/ V_2 + V_1)^{1/2} \qquad (2)$$

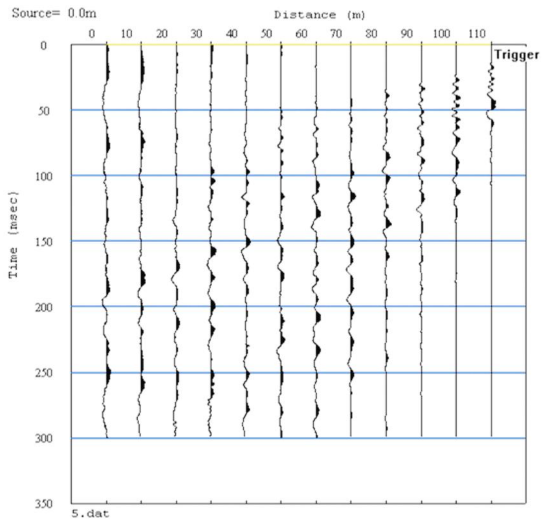


Figure 3: Recorded seismogram (Reverse Shooting) shot No.6

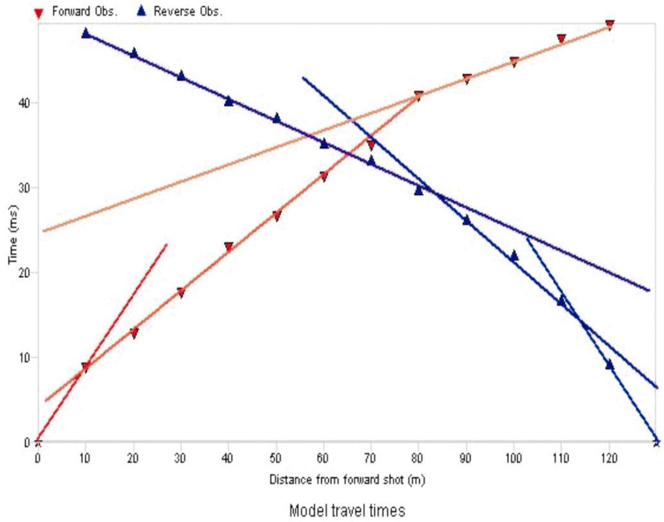


Figure 4: Time-Distance curve of shot point No.6

2.2. VES and ERT Method

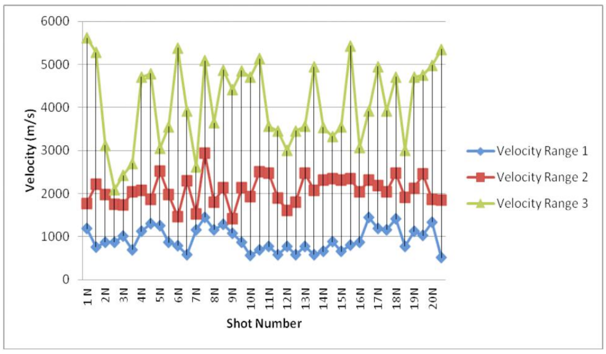
The electrical methods in general include different techniques and instruments depending on the nature of the method used in prospecting. For more details about these different techniques refer to Musset and Khan 2000, Reynolds 1997 and others. VES and ERT surveys are used to map areas with moderately complex geology. VES Resistivity measurements are one of the simplest methods to be used in geophysics. By putting two electrodes into the ground and inducing an electric current through the ground a potential field is created. Two additional electrodes are used to measure the potential at some location. Increasingly deeper measurements are achieved by using a bigger separation between the current electrodes. Moving the current electrodes and the potential electrodes with the same distance (a) is named as the "Wenner" method. For this setup, a direct current was introduced into the ground through two current electrodes A and B. The potential electrodes M and N were inserted in the ground between the outer current electrodes A and B, where the potential difference was measured across these two potential electrodes. By measuring the current (I) between the two current electrodes A and B and the associated potential difference (V) between the potential electrodes M and N, the apparent resistivity (ρ_a) was computed by the following equation:

$$\rho_a = 2\Pi \text{ a } V/I \qquad (3)$$

The ERT surveys are usually carried out using a large number of electrodes, connected to a multi-core cable. A laptop together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. The apparent resistivity data was collected by the two dimensional DC-resistivity system, then inverted to create a model of the subsurface resistivity that approximates the true subsurface resistivity distribution (Loke & Barker, 1996). This inversion is carried out using Res2dinv software, which uses an iterative smoothness, constrained least-squares method (Loke & Barker, 1996). The resistivity models were used to generate synthetic apparent resistivity data. The resistivity models were adjusted and simplified to qualitatively match the field data inversions. Resistivity models helped to constrain interpretation of the field data inversions to identify locations and orientations of anomalies.

3. RESULTS AND DISCUSSION:

The results obtained from the shot records and interpretations indicate that the minimum seismic velocity range of 590 – <1400 m/s, was observed in the unsaturated weathered material above the water level. The zone of saturation has a velocity range of 1400 – <1800 m/s or a slightly higher, while in the underlying weathering rocks the range is from 1800 – 5300 m/s. This velocity range may represent the beds' interfaces (Figure 5). It is noticed that, refracting velocity at water level is lowest when the water level is at the shallowest depth. When the water level drops closer to the top of the saturated zone, refracting velocities are observed to increase. However, as the water level drops close to the saturated zone, it may become undetectable. The water level at the unsaturated zone and the saturated zone are presented in Figure 6.



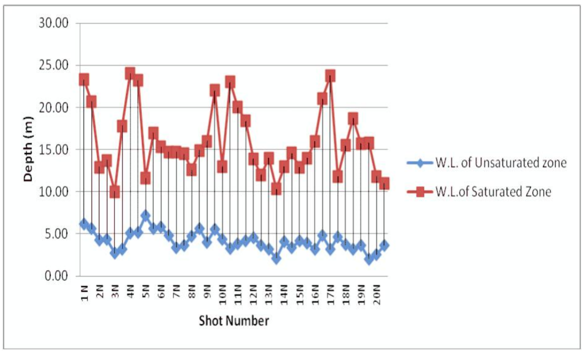


Figure 5: Seismic velocity distribution of the study area. Figure 6: Water Level detected from Seismic Refraction

The VES results indicate that the apparent resistivity of the aquifer reflects first a surficial resistive layer of dry alluvium with resistivity of 80 Ω.m, then lower resistivties which reaches to 15 Ω.m and after that increasing gradually with depth to about 566 Ω.m or more through 100 m thickness.

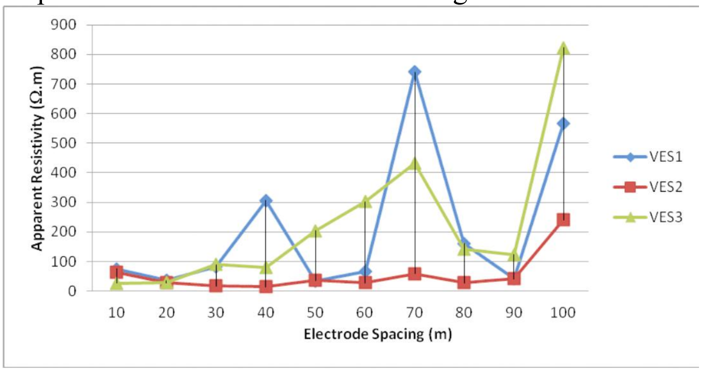


Figure 7: Electrode spacing versus apparent resistivity

ERT profiles show a highly resistive zone (indicated by the red and deep brown colors) which is attributed to the existing of surfacial layer with resistivity reaches to 700 Ohm.m. The basal claystone and siltstone formation exhibit lower resistivity as shown in some places at the deeper depth. This zone has resistivity of less than 5 Ohm.m probably due to salinity increase with depth. The lateral variations of lithological units are recognized along ERT1; reflecting the stratigraphical complexity of the area. The depth of the groundwater, indicated by the deep and light blue colors, is due to the presence of the groundwater, indicates that the water level is at 2m to 4m depth and reaches to about 6 m at certain locations in ERT1. However, ERT2 and ERT3 show a depth range of the groundwater between 10 and 13m respectively (Figures 8 a,b & c).

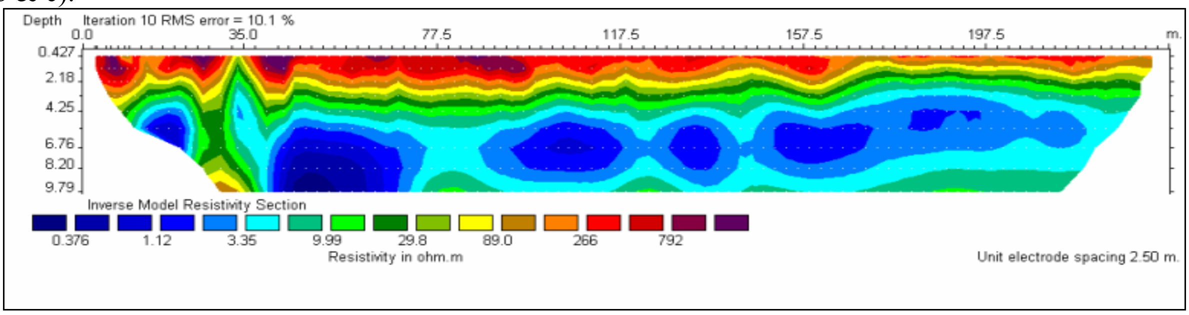


Figure 8a: ERT1 profile along the study area

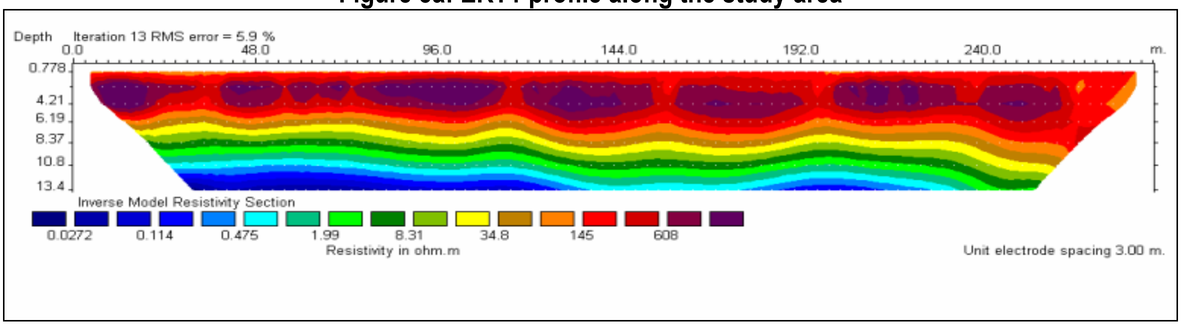


Figure 8b: ERT2 profile along the study area

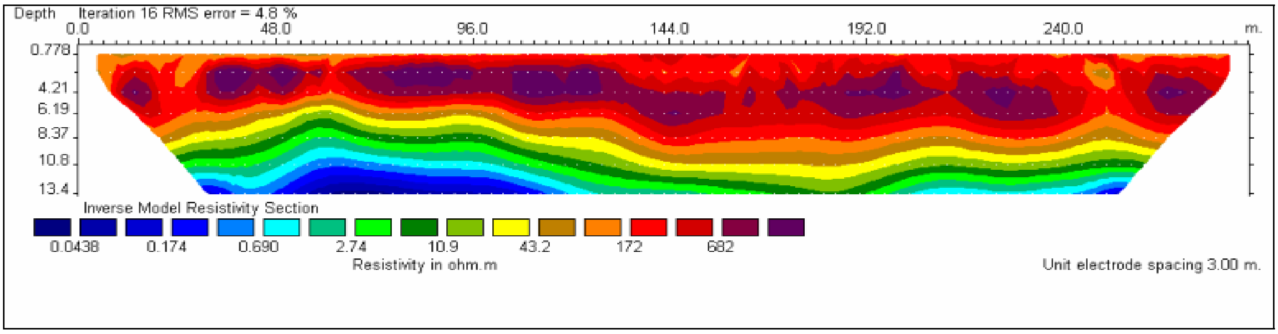


Figure 8c: ERT3 profile along the study area

4. CONCLUSION:

Seismic refraction, VES and ERT profiles along Wadi Al-Ain have been used to investigate the groundwater level and possible promising sites for future drilling. The results interpretation indicate that the aquifer is a Quaternary alluvial deposits aquifer, which consists mainly of gravels, sand and clay with average thickness of about 15 m or more and underlained by compacted sediments and limestone. The obtained measurements in the saturated zone indicate seismic velocities range between 1400 – <1800 m/s, while at the top of the capillary fringe zone it gives rise to another response indicated by a velocity range between 590 – <1400 m/s. The VES and ERT results have confirmed the water depth's estimate which have been detected by the seismic refraction method. The shallow water level at some locations is attributed to the perched water due to inflitration from the surface water along the study area. The geophysical techniques integration confirms the existence of a fresh groundwater within the interval between 2m to 13m. The obtained results show that for any future drilling for groundwater, a number of the VES positions may be considered as potential locations.

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