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Electrical Resistivity Tomography, an Assessment Tool for Water Resource: Case Study of Al-Aroub Basin, West Bank, Palestine

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ABSTRACT

This study aimed to characterize the nature of the shallow subsurface infiltration areas (3-18 m) and to understand the link between water storage transfer and the characteristics of the chalky formation, usually considered as aquitard (non acquifer) by applying the Electrical Resistivity Tomoraphy (ERT) technique. A multi-electrode geo-electrical survey was carried out at AL-Aroub area, West Bank, Palestine to map the electrical resistivity distribution. Electrical Resistivity Tomography (ERT) method is based on the measurements of electrical resistivity along a profile, where a series of electrodes are regularly placed. The interpretation of two dimensional (2D) pseudo-sections showed the existence of a continuous dominated moderate layer ($90<\rho_a<130$ Ωm) accompanied with an upper clayey layers (<30 Ωm). Meanwhile, the heterogeneity of the shallow subsurface layers is evident; the later result permits to explain the groundwater circulation within the fractures existed in the chalky geological formations. These results are highly correlated with the existed dug wells located at the study area.

Key words: Chalky formation, underground water, electrical resistivity, exploration, Al-Aroub

INTRODUCTION

Water is considered as one of the vital elements all around the world. Due to several strong factors as the over exploitation, water resources are steadily decreasing in Palestine during latest years. Overall average annual rainfall was recently estimated at 409 mm in central and 275 mm in the South of Palestine (Alatout, 2000). The agriculture is an essential economical source for a large number of regions inhabitants. In this area, springs has played an important role in providing a source for drinking and agriculture (Associates, 2002), while the asymmetry of rainfall during the year, the characteristic of the geological formation, the topographical nature of mountains and the increasingly demand of water supplies can lead to the lack of water resources during dry seasons (Sbeih, 1996).

Traditionally, drilling techniques are used in the study area as an adequate solution for water exploration; these techniques are expensive without depending on scientific processes. Geological information are expected to be lost during drilling operations and might not be recovered as water circulation modification (Guerin, 2005). Whereas, geophysical techniques are known as non-destructive investigations and ideally be used as a tool to resolve problems related to the earth and its environment.

Due to the lack of data, this study aims presenting the results of the first geophysical surveys applied at Wadi Al-Aroub, in order to characterize the nature of the surface and subsurface of infiltration zones by using the electrical method, a total of 15 Electrical Resistivity Tomography (ERT) profiles have been conducted with different electrode array configurations. This geophysical method has been employed to explore the zone which contains several springs and drilled wells at different depths and to describe water flow by determining the geometry of geological structure around these selected points.

However, this study aims to understand the link between water storage, transfer and the characteristics of the geological formation: chalk, usually considered as aquitard (non-aquifer).

Groundwater is considered as the main water source in West Bank, Palestine (Fig. 1). This reservoir is recharged mainly by rainfall. According to Qannam (2003), the average annual rainfall recorded at Al Arroub Meteorological Station for the period 1953-2001 is 607.1 mm, taking into consideration the considerable variations in the quantity of the annual rainfall from year to year.

Surface geophysical methods are qualified as reliable and non-destructive tools which are employed to collect subsurface field data quickly. Despite these powerful tools in collecting field data and different ways of interpretation, these collected data can be very useful as an indication of the nature of structures or phenomena that we are looking for.

In this study, geophysical survey was carried out at the Al-aroub Camp located at the Northeastern direction of Hebron District (Fig. 1). Different array configurations were used and compared: (Wenner, Schlumberger, Dipole-dipole and Pole-dipole) with two and three meters electrodes spacing to map groundwater in different shallow structures. The objective of the geophysical prospecting is to locate the circulation of subsurface water flow within certain geological formation; a heterogeneous geological formation.

MATERIALS AND METHODS

Electrical Resistivity Tomography (ERT) is a widely applied method to demonstrate measurements as high resolution 2D pseudo-sections; these pseudo-section images represent the distribution of subsurface electrical resistivity. Applied geophysical techniques are being increasingly used in various domains to solve problems related to environment and engineering (Pellerin, 2002; Corriols and Dahlin, 2008) and locating shallow cavities, fractures, fissures and explaining groundwater flow (Al-Tarazi *et al.*, 2006; Auken *et al.*, 2006).

The present geophysical survey was carried out at Wadi Al-aroub(South of West Bank) from April 2007 to August 2008. The purpose of using Direct Current (DC) electrical resistivity surveys is to determine the subsurface resistivity distribution of the ground. This distribution can be related to physical conditions such as lithology, porosity and degree of water saturation. Electrical Resistivity Tomography (ERT) technique is considered as a powerful tool in measuring the main physical property of the subsurface; electrical resistivity. This technique including the electrical resistivity field data provide an image representing the characterization of the content of geological feature and supply an overview about the lithology of the underground geological structures. Resistivity can be considered as a relevant parameter in environment investigations since a significant contrast in resistivity can be occurred between different geological formation caused by waste materials (Leroux *et al.*, 2007). The ERT techniques is capable to show changes in the electrical resistivity values of the compounds during a period of time, therefore it is applicable in detecting environmental pollution (Batayneh, 2005; Kaya *et al.*, 2007).

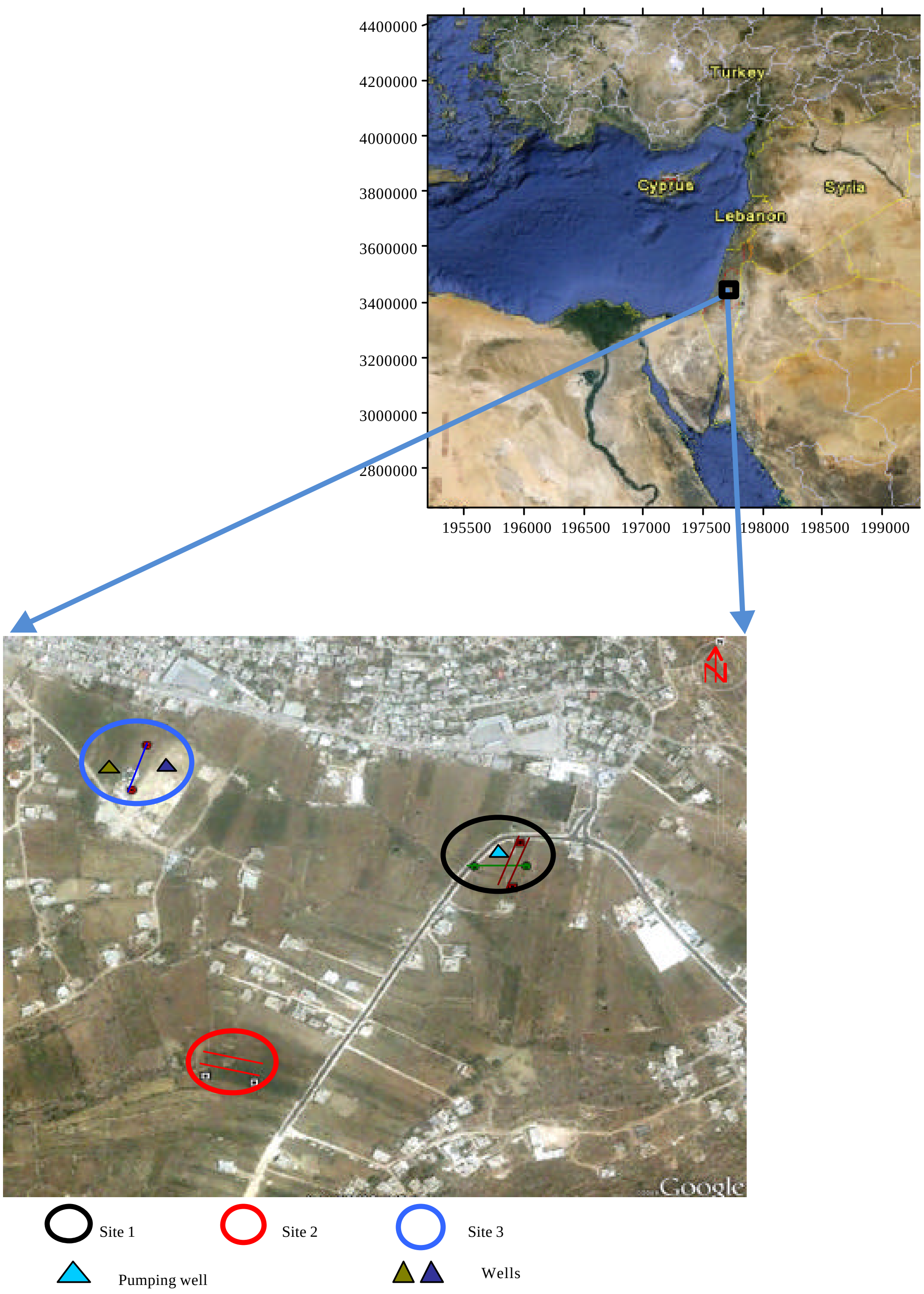

Fig. 1: Study location: Al-Aroub site

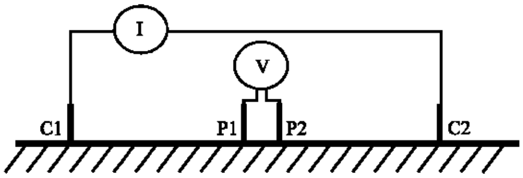

Fig. 2: Principal of resistivity measurements with a four electrode array

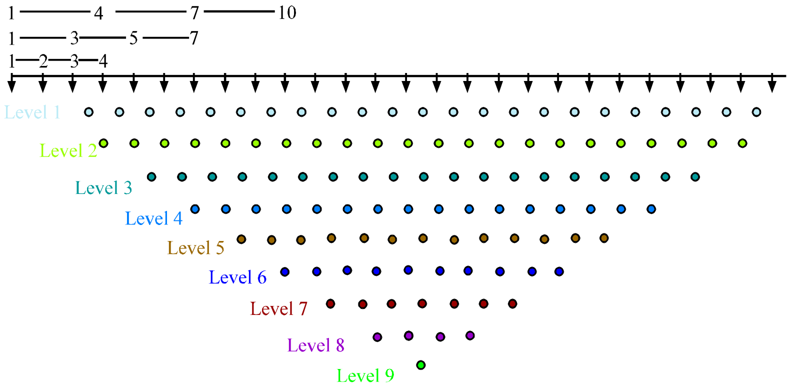

Fig. 3: A multi-electrode resistivity pseudo-section

The system is based on the injection of a known electrical current value in the ground (C1 and C2), then the potential distribution is measured (P1 and P2) along the survey line (Fig. 2).

More details about the Direct Current (DC) method, refer to Seidel and Lange (2008). Many multi electrode array configurations were employed to acquire more accurate measurements in which data resolution is improved (Fig. 3). Meanwhile, programs are used to eliminate the interference of natural and cultural noises, thus reliable data can be extracted to be interpreted in good manners. Geophysical techniques related to Earth's exploration are viewed as cost effective, rapid and non destructive useful tools.

Field work and data processing: Investigation surveys were conducted in accessible places and consisted of several Electrical Resistivity Tomography (ERT) profiles in parallel and perpendicular directions. Various electrode array configurations; Schlumberger, Wenner and Pole-Dipole have taken place for acquiring data field.

A Syscal junior resistivity meter (IRIS Instrument) with two multi nodes and a remote control multiplexer (RCM) have been employed to acquire field data. Thirty two copper electrodes were used throughout, both for transmitting current and measuring the potential distribution along line surveys. Several inter electrode spacing have been used to match *in situ* conditions and achieving several Depth of Investigation (DOI). Field measurements have been analyzed using software programs: Prosys, X2ipi (Robain and Bobachev, 2002) and Res2DInv (Loke, 2006) have been used to perform the acquisition, data processing and the models inversion of 2D resistivity pseudo-sections. Least square inversion by a Quasi-Newton method has been employed (Loke and Barker, 1996) to achieve apparent resistivity inversion pseudo-sections.

RESULTS

The representative inverse models will be demonstrated for three locations at the study area. The interpretation of these 2D models provides the following results:

Site 1: Parallel and perpendicular profiles have been conducted around a water pumping location where the ground water feeds this location from the south and south-western direction due to the topographical effect. The pumping location (Fig. 1) is surrounded by ERT profiles covering the EW direction and the NS directions towards the eastern direction. Figure 4 demonstrates the more representative profiles.

Two of the most representative profiles taking the NS directions spaced by 5 m. are shown here, where these profiles represent a region where the geological formation do not allow water to be circulated within the different type of formation due to their characteristics.

The inverse model (P1NS) demonstrates an altering upper layer of 0.5 m. of thickness. The second layer is consisted of a high resistivity structure (>300 Ωm) located from the middle towards the Northern direction and owning 8 m of thickness, while the Southern side consists of low and high resistivity structures; clayey (<30 Ωm) and hard limestone (<300 Ωm). The third layer represents a low resistivity structure dominated at the left bottom part of the profile (<30 Ωm) with a maximum thickness of 6 m.

P2NS pseudo-section shows almost the same features found in P1NS with changes in the values of the resistivity, in which it increases in a side and decreases on the other side. It can be clearly obvious that the second layer becomes thinner and their resistivity values decrease to reach values around 100 Ωm at the Western direction.

Site 2: Figure 5 demonstrates the inverse models of two ERT profiles which have been conducted in parallel separated by 5 m. These profiles are presented from East to West direction. P1EW inverse model shows fours inclined layers of different resistivity and thickness values. A conductive layer can be easily found at the surface of the profile with a maximum depth of 1 m. While, this layer disappears a little bit towards the Western direction, where the second and the third inclined layers appear at the surface directly. A four meters low resistivity (20-32 Ωm) layer is located between two high resistivity layers. The second layer and the fourth layers own higher resistivity values which range from 70 to 160 Ωm.

Site 3: Figure 6 demonstrates the inversion model of a pole dipole electrode array configuration. ERT profile shows a recognizable low resistivity layer located at shallow depths, its resistivity values

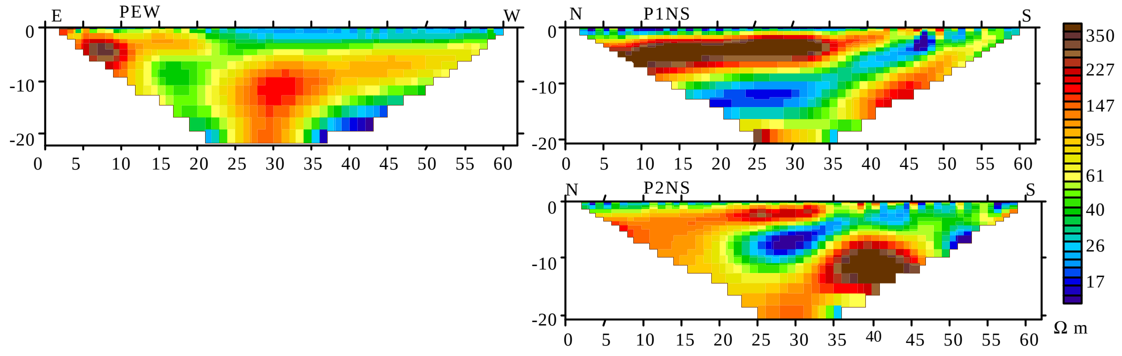

Fig. 4: Inverse models of different directions at site 1

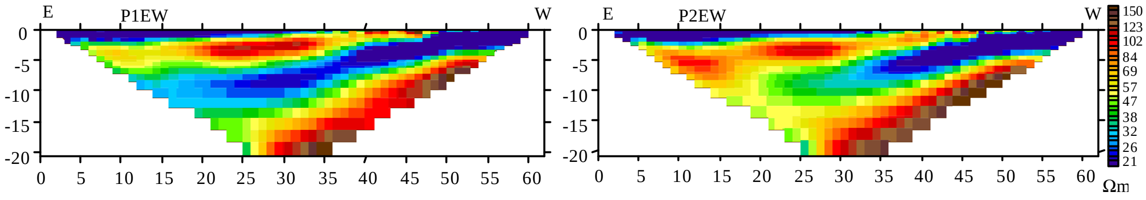

Fig. 5: Inverse models of parallel ERT profiles of site 2

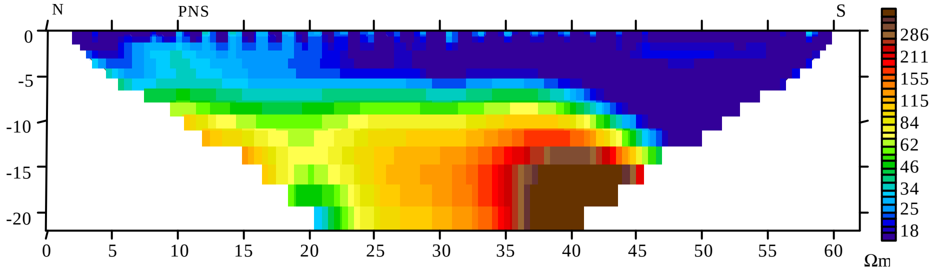

Fig. 6: Pole-dipole electrode array configuration at site 3

are lower than 25 Ωm and having 8 m of thickness in which its thickness is increased towards the southern direction. While a high electrical resistivity structure can be clearly obvious along the profile starting from 10 m in depth till the bottom of the profile. Resistivities range between 15 Ωm for a clayey layer to more than 320 Ωm for hard limestone. The present profile is located between two drilled wells (near home 18 m and near the school 10 m).

DISCUSSION

The geoelectrical results allow us to verify the efficiency of the ERT in determining the boundaries between different geological layers. Geo-electrical pseudo-sections for the selected investigated sites show essentially local lithology changes especially towards the Eastern direction. The chalky formation was the interest of this study due to its characteristic in permitting water to circulate through fractures existed in such geological formations.

The geomorphological study carried out at the same area shows that the topography has more effect on the drainage, where the main effect of topography is in the W-E direction, while that of structure is mainly in the NNW-SSE direction and to some extent in the N-S direction (Qannam, 2003). The present results added more details about the vertical and horizontal variations at different direction for the study area.

The inverse model P-EW represents successive layers. A conductive layer is found at the upper surface, starting from the middle towards the Western direction. This layer can be interpreted as a clayey layer clearly found at the surface. The inverse model (P-EW) shows recognizable layer (80-130 Ωm) along the profile starting from 1 m to a 20 m in depth, where this layer appears at the surface of the eastern part of the profile. This layer is fractured and filled by another low resistivity (35-50 Ωm) structure at the left bottom part. This dominated layer located not far from the pumping location allow to delineate a hypothesis that groundwater flows within this geological layer especially at the centre of the P-EW 2D pseudo-section.

A recognizable high electrical structure is well identified at the right bottom part with 10 m of horizontal extension and 8 m of vertical extension. Whereas, the intermediate conductive layer is reduced and concentrated at the centre of the model, with some extension towards the Southern direction. The existence of such geological features at the NS direction; low resistivity (<30 Ωm) and higher resistivity (>300 Ωm) structures allow to guess that it forms as underground barrier preventing water to feed regions in the Eastern direction. This information can be used to explain the non existence of water within the structures situated at the Eastern direction, where lot of wells have excavated for tens meters of depth without finding water. The extracted geological formations from the borehole were of hard limestone (Site 1, Fig. 4).

By comparing the results of the first profile (P1EW) with its parallel profile (P2EW) in site 2 (Fig. 5), it is obvious that the geological features have not been changed regarding the layers but the inverse model demonstrates a significant change in the value of the resistivity where there is a trend increase in the resistivity values of each layer, especially the conductive layer sandwiched between higher resistivity layers. An increase of the resistivity values is obvious towards the North Eastern direction. The latter layers can be interpreted as clayey layers for the low resistivity, while high resistivity structures can be considered as porous chalky limestone geological formation. The resistivity ranges between 70 and 120 Ωm can be a good indication about the water flow within these formations due to the lithology changes.

While, the inverse model of site 3 (Fig. 6) shows almost an intermediate horizontal interface (40-55 Ωm) between low resistivity values in the upper part and highest resistivity values at the bottom especially towards the southern direction. The thickness of this intermediate thin layer is about 2 m. The existence of a structure at the lower bottom of the profile ($85<\rho_a<155$ Ωm) can explain the existence of water in this porous chalky formation, knowing that a drilled well is found at 5 m far from the middle of the profile.

The electrical method was reliable for underground water studies (Lashkaripour *et al.*, 2005; Alile *et al.*, 2008). In present study area, the link of water storage and the chalky geological layer was well identified which explains the existence of water at certain locations and the absence at other near places. The electrical resistivity tomography has defined clearly the probable location of water presence by determining the thickness of the geological layers (Corriols and Dahlin, 2008).

CONCLUSION

The Electrical Resistivity Method (ERT) known as a valuable technique in characterizing the underground layers has been used during the survey carried at Al-aroub site. The more representative results taken at different locations in the study area have been discussed. A dominated moderate layer have been detected at the three locations (90-120 Ωm) with different thicknesses due to the topographical effects, these layers have been accompanied all the time with a clayey layers (<30 Ωm) more found in large thickness at the lowest point of the wadi, while these clayey layers disappear towards the surrounded mountains and the eastern direction of the site.

Areas of continuous moderate resistivities indicate good probability of providing water at certain places, where many wells were found in the area with 18 m in depth, thus predicting the existence of water in this layer. Meanwhile, the heterogeneity of the shallow subsurface layers allows the explanation of groundwater circulation within certain geological formations and preventing this circulation within other formations. The profiles show that the feeding of the Al-Aroub basin could happen by the infiltration of water through porous and fracture chalky limestone beneath the upper clayey layer. In order to well mapping this wadi by demonstrating a three dimensional (3D) model, more surveys will be held in the future with other geophysical method and in correlation with hydrogeology studies.

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