Geophysical Investigations for Groundwater in a Complex Subsurface Terrain, Wadi Fatima, KSA: A Case History

Mansour A. Al-Garni [1)]

[1)] Dept. of Geophysics, Faculty of Earth Sciences, King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT

Geological contacts in a complex subsurface terrain have favorable potentiality for groundwater; particularly in semiarid/or arid areas. Magnetic and DC resistivity surveys were proposed and conducted at Wadi Fatima for the groundwater exploration in this geologically complex media. Magnetic survey was used to delineate the basement structures which control the groundwater flow. On the other hand, DC resistivity profiling and sounding techniques were used to investigate and ensure the potentiality of the groundwater occurrence in the structurally complex basement.

Magnetic data were subjected to analytic signal analysis, where it showed clearly the complexity of the study area. Many magnetic contacts were delineated at the maximum amplitudes of the analytic signal curves. Two selected profiles along the Wadi have been quantitatively interpreted using analytic signal, spectral analysis, horizontal and vertical derivatives. These analyses delineate the geological structures that may accommodate the groundwater. DC resistivity profiling technique was used along one profile, to define the effect of the basement structures on the ground water distribution under this profile. On the other hand, Vertical Electrical Sounding (VES) was conducted at selected sites along the magnetic and DC profiles. Ground magnetic and DC resistivity techniques led to a better understanding of the study area. Thus, the integration of the obtained results from these two methods was successful to define new sites for drilling wells for the groundwater supply that would be at VES9 and VES7. It was recommended to conduct more detailed studies in the southwestern part of the study area.

INTRODUCTION

The study area lies in the northern part of Wadi Fatima (Fig. 1). The reduction of the precipitation on the area led to the water table lowering. Consequently, many wells, which had been productive, became dry and many trials to drill new producing wells failed. As the recharge became tremendously poor, the water table dropped down and the groundwater flow became almost controlled by the basement structures. Therefore, the present study was suggested to determine the more preferable location/locations to drill new wells for water supply.

In groundwater exploration in hard rock media, it is very important to delineate structures such as geological contacts, faults and joints. In Wadi Fatima, which lies within the Arabian shield, the groundwater potentiality is strongly controlled by the structures. Therefore, magnetic method was employed to delineate these structures, which are considered as a pre-requisite for groundwater exploration (Narasimha et al., 2005). DC resistivity methods have been conducted afterward at zones or sites suggested by the magnetic survey.

Exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media. In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement. The

Accepted for Publication on 15/4/2009.

magnetic materials within the weathered zones are reduced as a result of the weathering processes during the geological time. Hence, the depletion of the magnetic materials in the altered zones would reduce the susceptibility, which is a measure of the extent to which a material may be magnetized. Magnetic survey has been extensively used in groundwater exploration where delineating structures was the main target (i.e. Al-Garni, 1996, 2004a, 2004b, 2005; Al-Garni et al., 2005 and 2006; Hassanein et al., 2007).

Geolectrical technique has been widely used in groundwater exploration to correlate between the electrical properties of the geologic formations and their fluid content (Flathe, 1955; Zohdy, 1969; Flathe, 1970; Ogilvy, 1970; Zohdy et al., 1974). Many studies have been concentrated on the geometry determination of the aquifers (Robain et al., 1995, 1996; Cherry et al., 1996).

The electrical resistivity of a formation depends mainly on the salinity of its fluid content, saturation, aquifer lithology and porosity (Shaaban, 2002). This technique has been successfully used in the world to explore groundwater and its condition. The electrical resistivity technique is widely used also to estimate the depth and the nature of the alluvium, aquifer boundaries and its location (Young et al., 1998, Lashkaripour et al., 2005; Al-Garni, 2004a, 2004b, 2005; Al-Garni et al., 2005 and 2006; Hassanein et al., 2007). Furthermore, it has been used to delineate the fresh water/saline water interface (El-Waheidi, 1992; Yechieli, 2000; Choudhury et al., 2001); aquifer porosity (Jackson et al., 1978); water content (Kesseles et al., 1985); hydraulic conductivity (Yadav and Abolfazli, 1998; Troisi et al., 2000); transmissivity (Kossinski and Kelly, 1981); specific yield (Frohlich and Kelly, 1987); groundwater contamination (Kelly, 1976; Kaya, 2001). It is worth to mention here that the resistivity method limitation can be expected if the ground is inhomogeneous and anisotropic (Al-Garni, 1996; Matias, 2002).

GEOLOGY AND STRUCTURE

The study area is located within Wadi Fatima which is one of the main tributaries in the Jeddah-Mekkah region. The Wadi has a NE-SW trend with a downstream towards the SW and drains into the Red Sea.

Wadi Fatima is a major fault bounded graben with a length of about 50 km and a width up to 10 km at its SW end. The NE-SW major graben has an old faulting trend that is dissected by numerous NW-SE faults, related to the Red Sea tectonics. The latter trend intensively affects the rock exposures in the NW side of Wadi Fatima resulting in the formation of several mountainous horst blocks that are separated by graben-controlled wadies. The most prominent horst blocks are Gabal Abu Ghurrah, Gabal Mukasser, Gabal Daf and Gabal Shubairim, while Wadi Faj, Wadi Al Kur, Wadi Daf, Wadi Shobairim and Wadi Shoba are the main tributaries. The younger faulting trend also affects the SE flank of the wadi but to a less extent.

These mountainous horst blocks are built up of Precambrian slightly metamorphosed limestones, mudstones, sandstones and conglomerates (Fatima Formation) that rest unconformably on gabbroic, granitic, metavolcanic and metasedimentary rocks (Nebert et al., 1974). The Fatima Formation and older rocks are intruded by younger granites of Precambrian age that constitute large batholiths to the north of Wadi Fatima. The exposed basement rocks have undergone a highly complicated structural history as manifested by multiphase folding and thrusting, and intensive faulting and fracturing (Zakir and Moustafa, 1992).

Oligocene conglomerates, sandstones and red siltstones of the Shumaysi Formation are exposed in the graben floors as sporadic small tilted outcrops of little significance.

The extensive erosion of the Wadi Fatima flanks has produced broad alluvial fans and fluvial terraces composed of material washed out of the rock exposures. The fans have coalesced to form an almost continuous apron at the foot of the hills that spread out to form the fill of the main wadi trunk. The tilted Oligocene Shumaysi Formation is expected to constitute a part of the subsurface succession capping the basement rocks in the floor of Wadi Fatima.

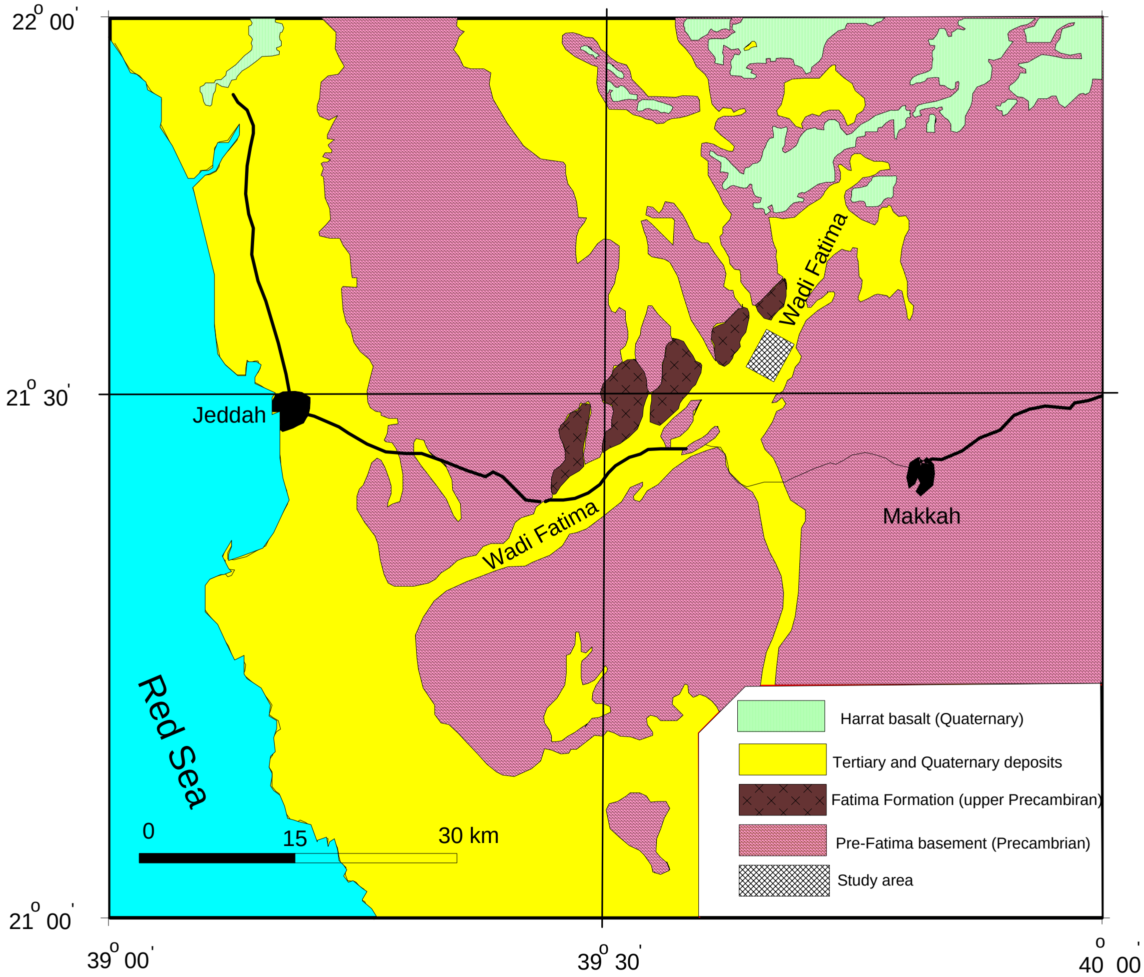


Figure (1): Geological map of the study area.

The study area is covered by Quaternary fan deposits and alluvial terraces as well as eolian sand and alluvial wadi filling materials. This layer is underlain by Tertiary sediments which are mainly related to Shumasysi Formation.

In addition, the study area is located within the Wadi Fatima, where the granite rocks are outcropped at the northern side of the wadi as dissected mountains. The granites are overlain by other successions of sedimentary and meta-sedimentary rocks. The meta-sedimentary rocks appear in the southern side of the Wadi (Fig. 1).

From the previous description of the geology of the region, it is obvious that Wadi Fatima runs through intensively deformed and highly fractured basement rocks. Accordingly, the groundwater is expected to be recharged through the Quaternary wadi fill deposits and also through faults and fractures in the bedrock.

It is difficult to investigate such geological model using DC resistivity alone. Therefore, ground total magnetic survey was suggested to outline the subsurface structural and lithological variations besides other geological, hydrological and geomorphological information, which were recorded, previously or during the study period, about the study area.

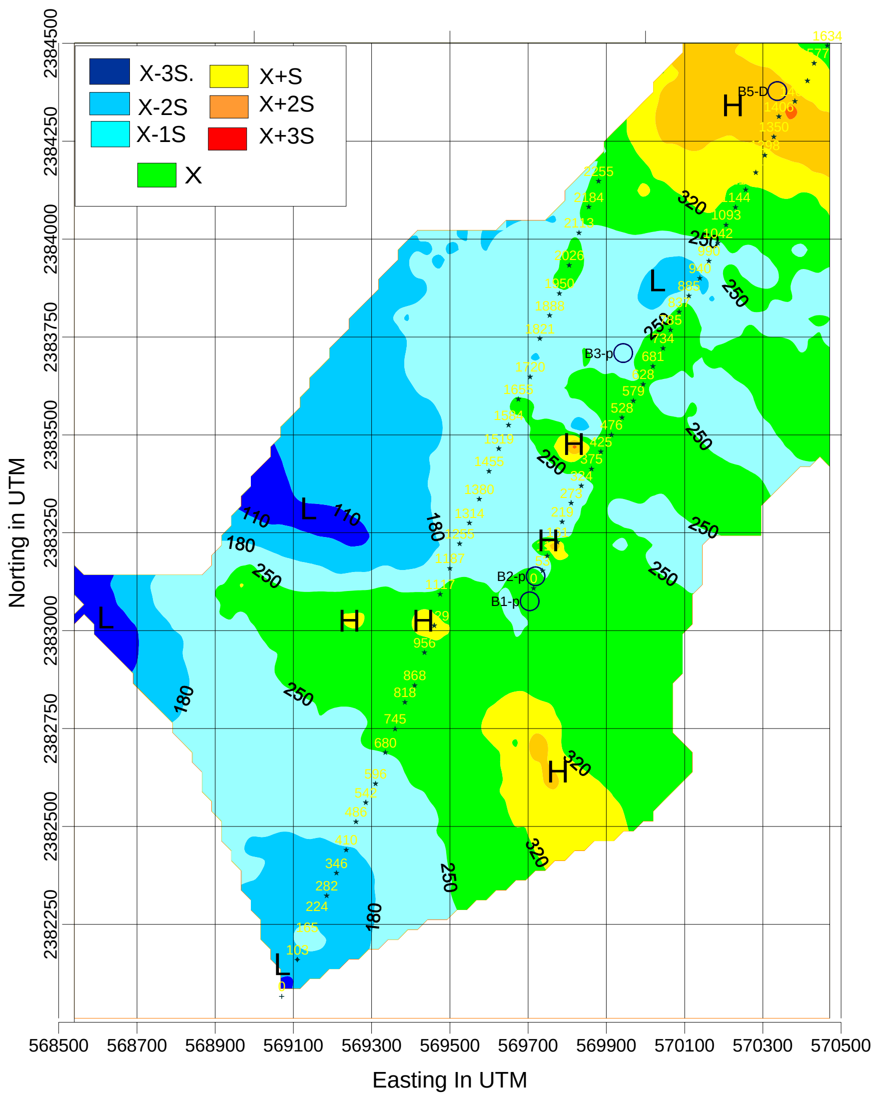


Figure (2): A semi-detailed total magnetic intensity map, using statistical analysis.

Geophysical Investigation Surveys

In the present study, ground magnetic and DC resistivity surveys were used for groundwater exploration. In this study, the deformation effect on the area as discussed before, makes the contacts interesting targets for mapping the structures which are favorable for groundwater exploration. Thus, magnetic and DC resistivity as proposed surveys were used: the magnetic survey for mapping the structures of basement rocks beneath the sedimentary cover, and DC resistivity survey to define the ground water saturated structures either in the sedimentary cover or inside the altered part of the sedimentary cover. Profiling and Vertical Electrical Sounding (VES) techniques were conducted at selected sides based on the results of the magnetic survey.

Magnetic Survey

A semi-detailed magnetic survey was carried out to understand and delineate the structures which could be the favorable targets to evaluate the groundwater potentiality within the study area. Sixteen magnetic profiles were conducted in different directions with spacing intervals ranging from 10 m to 20 m, where more than 1635 measuring points of observation were taken. These profiles have been chosen in such a way that they cross different main structural elements and subsurface geological contacts. Measurements were taken using two units of portable GEM 19 proton precession magnetometer providing a standard sensitivity of 0.2 nT/eHz and 1.0 nT absolute accuracy. One unit was used as a base station to record automatically, every 120 seconds, the diurnal variations of the earth geomagnetic field. The other unit was used to measure the total intensity of the magnetic field at each point of observations along the profiles. No magnetic storms were recorded during the periods of survey.

PROCESSING AND INTERPRETATION

The conventional statistical analyses of all the measured data were conducted and the results are shown in Table (1). These statistical results were used to draw the colored anomaly map. The minimum, average and standard deviations were taken into consideration. The minimum value was considered as a static level to be reduced from each individual data value. The standard deviation value was considered as an interval for constructing the semi-detailed total magnetic intensity map (Fig.2). This map is characterized by a low magnetic zone in the western side of the study area and a relatively high magnetic zone in the eastern side. These results suggested that the subsurface lithology and the structural setting at the eastern part of the area is different from that of the western one. Therefore, it can be expected that the wadi is running through two different rock successions, set around a main structural plain. In addition, the map obviously shows an E-W structure crossing the Wadi course.

The total magnetic intensity map has been subjected to the analytic signal algorithm (Fig.3). It is known that the maximum amplitude is exactly located over a magnetic contact (Nabighian, 1997; Sundararajan, 1983). It is evident that the study area is dominated by two main structures perpendicular to each other; namely: NE-SW and NW-SE (Red Sea trend). Figure (3) shows definitely NW-SE relatively high magnetic anomalies (Coded by H, Figure 2).

Table (1): Statistical results of the reconnaissance, total magnetic intensity data.

Stat. parameter	# of values	Min.	Max.	Mean	St. dev.
Value	1635	40153	40860	40392	70

Two NE- SW (P1 and P15, Figure 2) profiles were selected along the Wadi, crossing the main features. Regional anomaly was removed, using spectral analysis, followed by matching filtering procedure to enhance the magnetic anomaly and to obtain better trends, locations and disposition resolutions of the basement rock structures. The data were then interpreted to show the structural features of the magnetic contacts. Figures (6a and 7a) show the total magnetic field anomaly along profile 1 and profile 15, respectively. The logarithmic amplitude spectrum curves of profile 1 (Fig. 4) show two depth levels along the profile, the average depth level of the magnetic causative structures at 61.5 m and the deep-seated average depth level reaching 450 m. In profile 15, the shallow average depth level reaches 110 m and the deep-seated one about 608 m (Fig. 5). This ensures that the magnetic source is getting deeper as we go further west. The spectrum analysis of each profile helps determining the required parameters which are needed for matching filtering operations (Hassanein, 1994). Figures (6b and c) and Figures (7b and c) show the regional and residual anomalies of profiles P1 and P15, respectively.

Horizontal and vertical derivatives of the residual magnetic anomalies have been computed for the two profiles (Figs. 6d and 7d). The horizontal derivative shows the difference in magnetic value at a point relative to its neighboring point, while the vertical derivative shows the change of magnetic values with depth. These derivatives are sensitive to rock susceptibility near the ground surface rather than at depth. The amplitude of the analytic signal, which shows the precise location of structures and boundaries of causative targets along the two profiles, was computed too. The peaks along the computed analytic signal curve correspond to magnetic contacts (Nabighian, 1972; Sundararajan 1983). Figures (6d and 7d) show the amplitude of the analytic signal along profiles P1 and P15, respectively. It is worthy to mention here that the analytic signal and the spectrum of magnetic anomaly can be explained as follows:

If a magnetic anomaly is represented by $f(x)$ and its Hilbert transform by $H(x)$, then the complex analytic signal can be expressed as (Narasimha et al., 2005):

$$asc\,(x) = f\,(x) - i\,H(\mathbf{x}) \qquad (1)$$

Therefore, the amplitude of the analytic signal will be expressed as:

$$asa\,(x) = [\,f^2(x) + H^2(x)]^{1/2} \qquad (2)$$

The Fourier spectrum of a magnetic anomaly can be expressed as:

$$F(\omega) = |F(\omega)|\,.\,e^{i\varphi(\omega)} \qquad (3)$$

where $|F(\omega)|$ and $e^{i\varphi(\omega)}$ are the amplitude and phase spectrum, respectively, and ω is the angular frequency expressed in radians/meter. The logarithmic amplitude of the spectra, $[\log|F(\omega)|]$, is used for depth determination (Figs. 5 and 7). The amplitude of the analytic signal determines thoroughly the magnetic anomaly variations along the orthogonal axes, which define exactly the locations of structural features and boundaries. The peaks indicate the bodies/contacts along the two profiles as shown clearly. Analytic signal of profile 15 shows that the intrusion is also deformed. Interpretation of both total intensity magnetic anomaly map (Fig.2) and the 2-D analytical signal map (Fig. 3) as well as the results of the processing of the obtained data along the two profiles P1 and P15 indicate that the area along the Wadi is inhomogeneous. A set of NE-SW trended structures is shown along the main strike of the Wadi. In addition, another set of structural trend NW-SE across the main strike is also shown. Figure 2 shows roughly these two sets of structural trends, but the 2-D signal analytical map (Fig. 3) shows structures with higher resolution as lineament traces which represent the boundaries of these structural zones. Also, the response of these structures is represented as structural zones outlined across the extension of P1 and P15 as curves of regional, residual, horizontal derivative, vertical derivative and analytical signals. Figure (7) shows eight of these zones along profile P15.

DC RESISTIVITY SURVEY

DC resistivity was conducted using two different techniques, namely profiling and VES. The profiling technique was conducted using Wenner array and VES by using Schlumberger array. Both techniques were applied using EL-REC-T resistivity meter.

The present study was planned to obtain the subsurface information about the lithological conditions, structures and the underground water distribution. Therefore, the DC resistivity survey was conducted along a profile starting from the upstream to the downstream, across the main structures which preclude the water flow.

DC resistivty profiling was carried out along NE-SW profile, parallel to the Wadi strike and along its axis (Fig. 8). This survey was done along the extension of the magnetic profile to correlate the subsurface structural variations with the groundwater occurrences. Wenner array was used to measure the DC resistivity at 15 points with 100 m interval to investigate the average resistivity of the upper 50 m of alluvium deposits along this profile. The resistivity curve of these measurements is shown in Figure (9).

The VES technique is considered as the most effective technique for groundwater exploration. It is used to investigate the vertical variations of resistivity under the wadi surface. Therefore, nine selective locations were chosen in the study area, three of them (VES1, VES2 and VES3) were at locations where the resistivity is minimum along the conducted profiling survey. The other six locations of the VES were selected at (VES4, VES5, VES6, VES7, VES8 and VES9) according to the results of the hydrological investigation and the interpretation of the ground magnetic survey (Fig. 8).

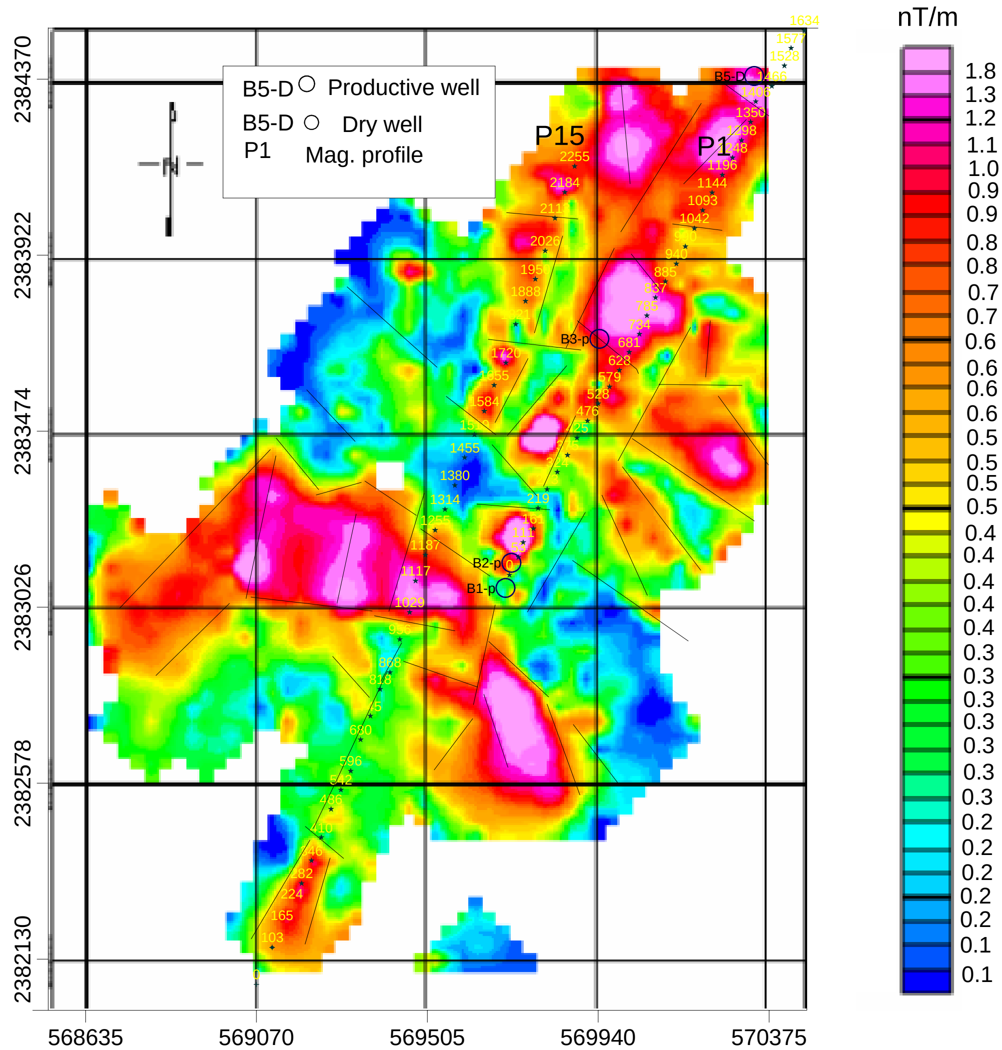


Figure (3): The 2-D analytic signal of the total magnetic intensity field, using Hilbert transform.

PROCESSING AND INTERPRETATION

Profiling Survey

Figure (9) shows the resistivity variations under this segment of the Wadi surface. Usually, the lowering of resistivity indicates that at the measured depths, the terrain is partially or totally saturated with water. Therefore, the resistivity curve outlines roughly the distribution of the underground water zones under the profile. The Figure shows that the resistivity values vary in the northern part of the Wadi. They decrease at locations 450, 750 and 1350 m, starting from the northwestern side. This indicates that the sedimentary cover in the northern part is fully or partially saturated with water. The resistivity values at the SW part of the profile decrease gradually as we go to the south which is the downstream direction, where the alluvium is getting thicker.

To emphasize the vertical limits of the lower resistivity zones which were recorded along the profiling survey, Vertical Electrical Sounding (VES) technique was used.

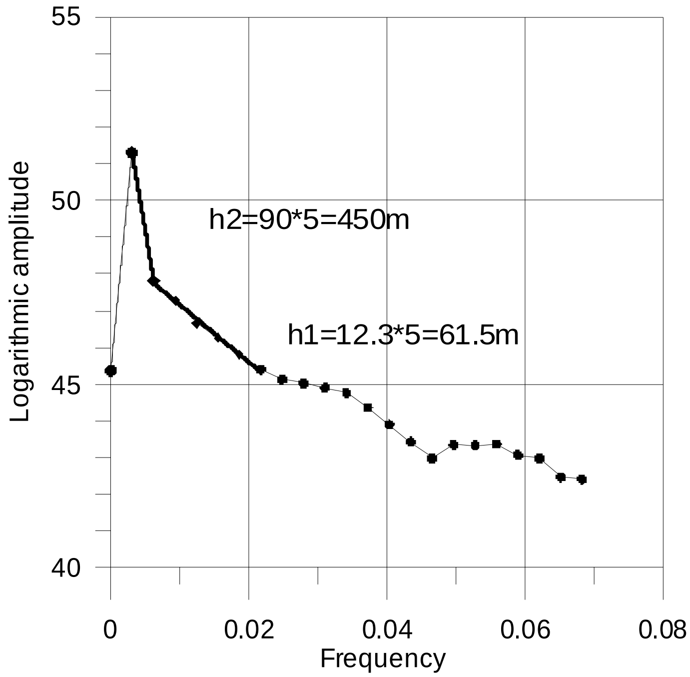


Figure (4): Logarithmic amplitude spectrum of profile (P1).

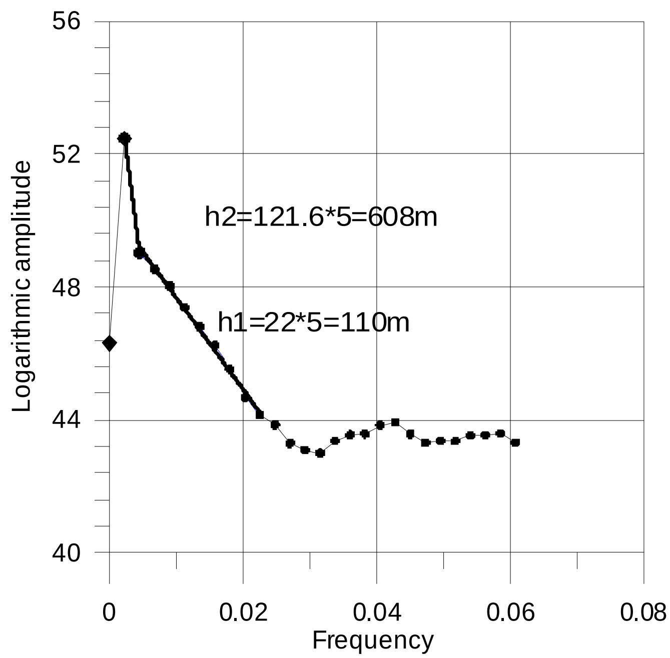


Figure (5): Logarithmic amplitude spectrum of profile (P15).

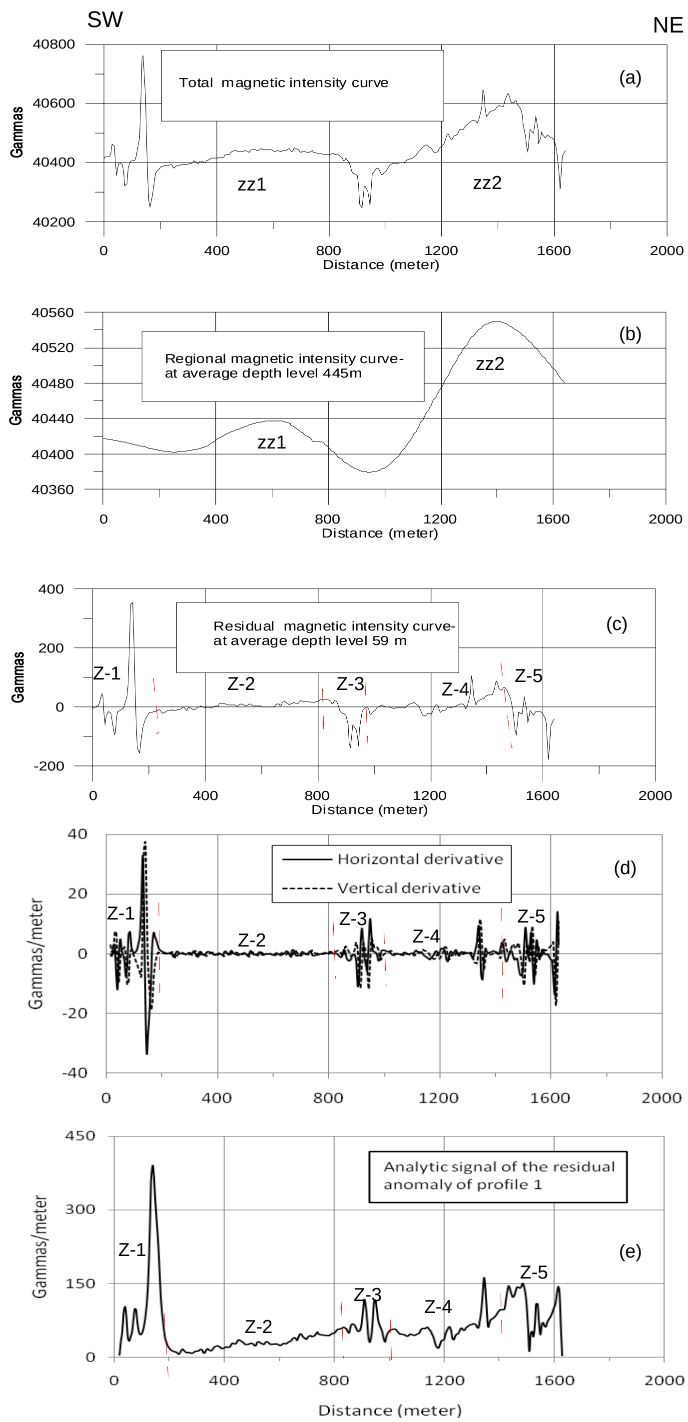


Figure (6): (a) vertical magnetic anomaly (P1), (b) regional magnetic anomaly, (c) residual magnetic anomaly, (d) horizontal and vertical derivatives of the anomaly and (e) the amplitude of the analytic signal of the magnetic anomaly.

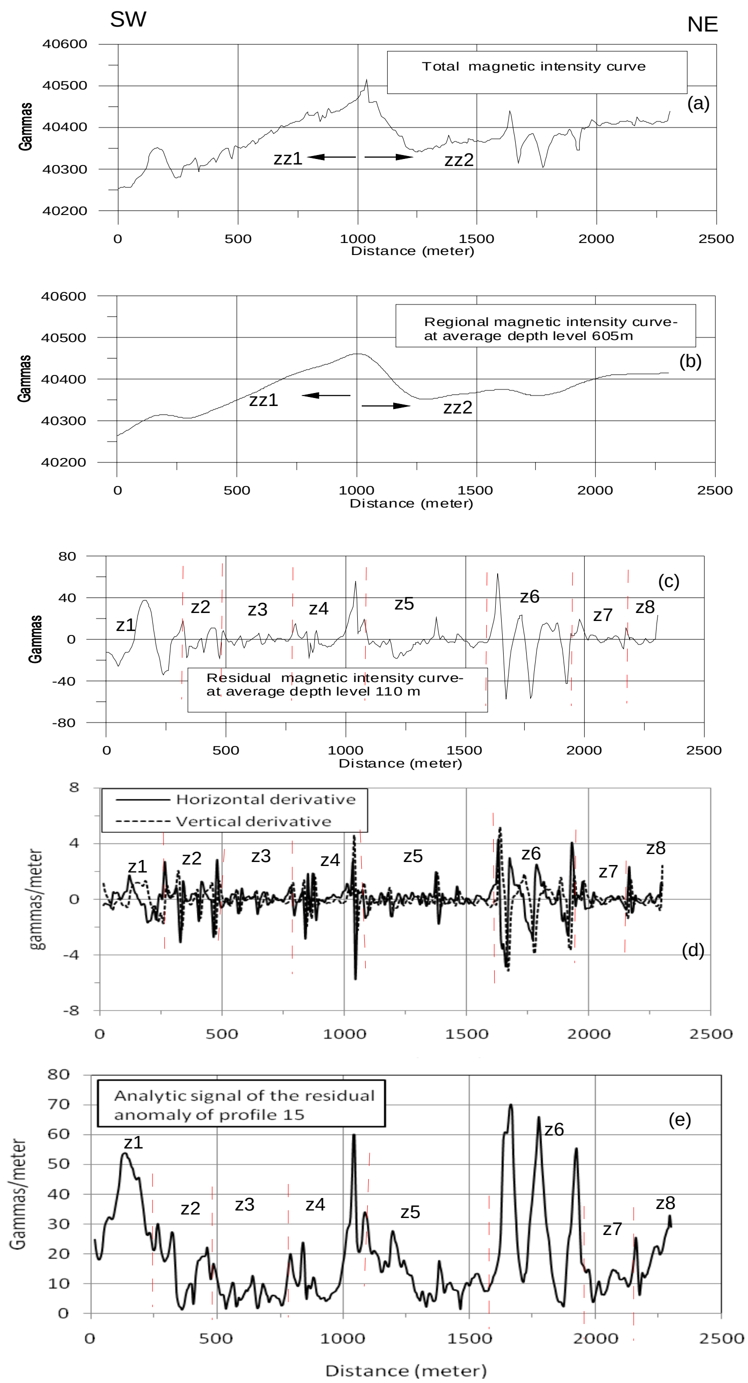


Figure (7): (a) vertical magnetic anomaly (P15),
(b) regional magnetic anomaly,
(c) residual magnetic anomaly,
(d) horizontal and vertical derivatives of the anomaly and
(e) the amplitude of the analytic signal of the magnetic anomaly.

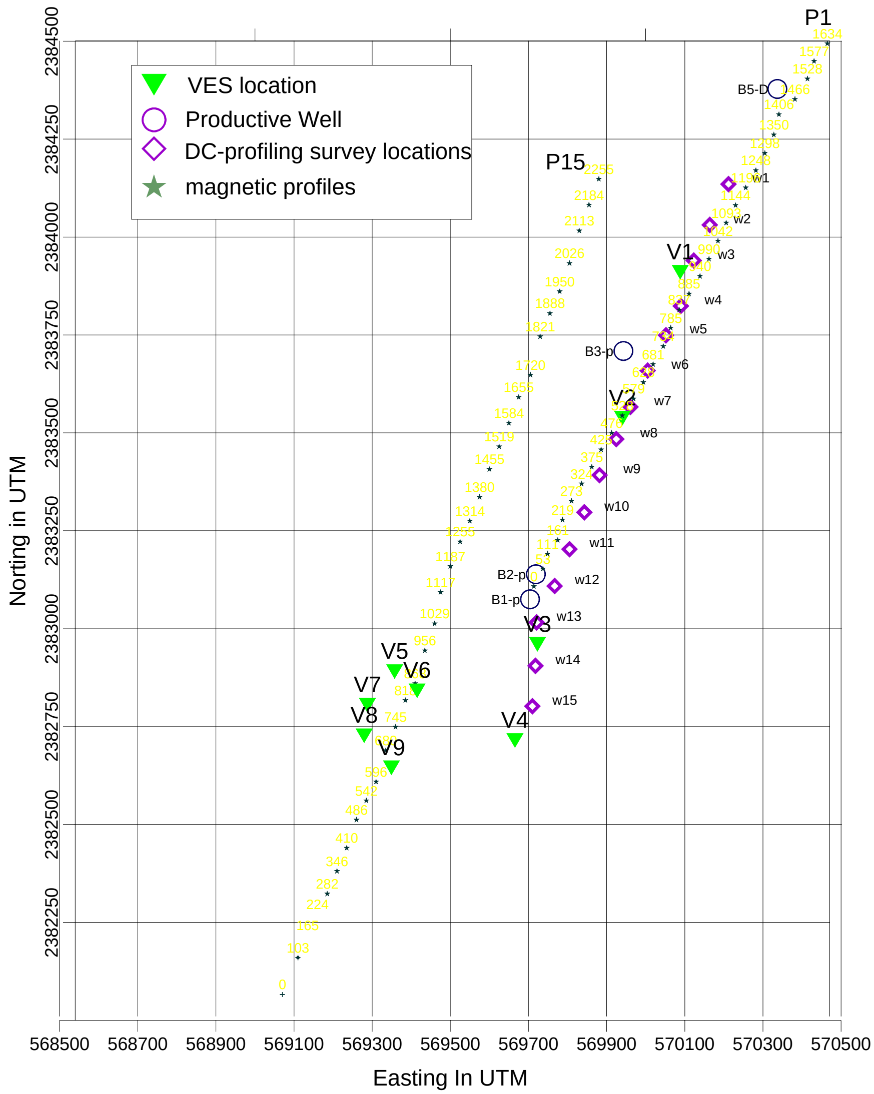


Figure (8): Locations of geophysical surveys.

Vertical Electrical Sounding

The VES measurements provided a series of apparent resistivity *(ρ_a)* values as a function of electrode spacing (a resistivity sounding curve) at each site. The variation of apparent resistivity indicates the existence of zones of contrasting resistivities. The sounding curves were smoothed and digitized to produce continuous seven *(ρ_a)* readings per decade of half the electrode spacing. Accordingly, VES was applied at 4 sites (VES1, VES2 , VES3 and VES4) along and at the extension of the profile (P1). Field and digitized data are represented as resistivity curves by log-log graphs (Fig. 10).

The digitized data of the reduced field curve were inverted and interpreted using the inversion technique developed by Zohdy (1975 and 1989) to obtain the equivalent layer models (n-layered model). The most recent software (Res2dinv) was used for optimizing data correction and interpretation (Fig. 11). This model consists of a number of horizontal geoelectric layers comparable with the number of measurements, which describe the sounding curves.

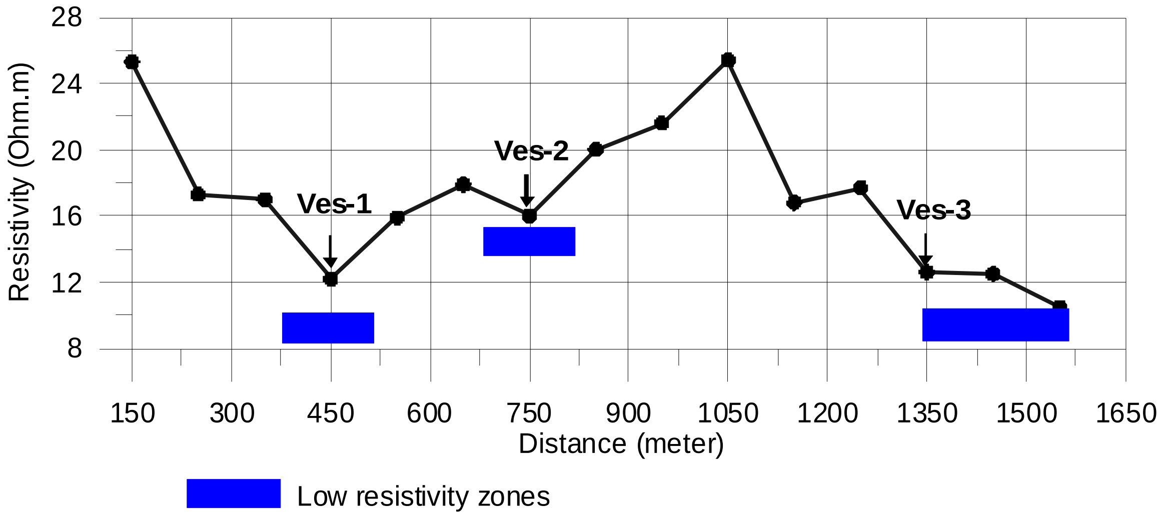


Figure (9): Resistivity profiling curve and vertical electrical sounding, along profile P1.

It is known that the resistivity of a formation largely depends on the moisture content and on the physical and chemical properties of the saturating water. After the analysis of the field VES data recorded at each location, the variations of the resistivity values with depths were correlated with the geological succession of the area under study. It is noted that this area, being part of the Arabian Shield, is composed of basement rock beneath the sedimentary cover. Alluvium deposits represent the upper part of the sedimentary cover as a result of weathering. Therefore, the resistivity of this part of alluvium varies from 1 to more than 1000 ohm.m. Beneath this part, there are semi-permeable beds with different grain size, suitable for water accumulation according to the water table equilibrium.

Figure (10) shows the apparent resistivity field and smoothed curves of the data obtained at 4 sites. These curves indicate that the resistivity is decreasing with increasing depth. This shows that the surface of highly resistant basement rocks is still deeper than the maximum depth penetrated by the available system, especially with increasing the clay content of certain alluvium layers. The alluvium cover may be overlying low resistivity beds, rich in clay content. The alluvium cover can be classified further into different ranges of thickness; the upper part is highly resistant and unsaturated with water, while the lower part has lower resistivity values which correspond to zones partially or totally saturated with wate. This is shown in Figure (11) which illustrates the interpreted subsurface geoelectric layering models considered to be under the VES1, VES2, VES3 and VES4, which were conducted along the NE-SW profile (P1). The results determine the depth of the lower resistivity part of alluvium section which increases in the SW direction (the downstream direction). These depths are 15m under VES1 and VES2 and about 30 m under VES3. The indications of the presence of groundwater saturation zones were observed under VES1 where the resistivity values were less than 50 ohm.m and decreased to less than 21 ohm.m under VES4. The thickness and resistivity values of the groundwater saturated part under VES4 suggested to continue the exploration in the SW part of the study area.

The correlation of the results of DC profiling survey , interpretation of VES1, VES2, VES3 and VES4 with the results of ground magnetic surveys along profile P1 and the sites of the productive wells, show that the groundwater saturated zones are related to the boundaries of the structural zones. These zones usually get recharged during rainy seasons and return to dry otherwise. This may be due to that they lie in the upstream side with limited depth and thickness. Thus, it is expected to have southward more promising sites. Accordingly, five VES's were conducted at a selected zone in the southwestern part of the study where the available information highlighted the higher potentiality expectation of groundwater (Fig. 8).

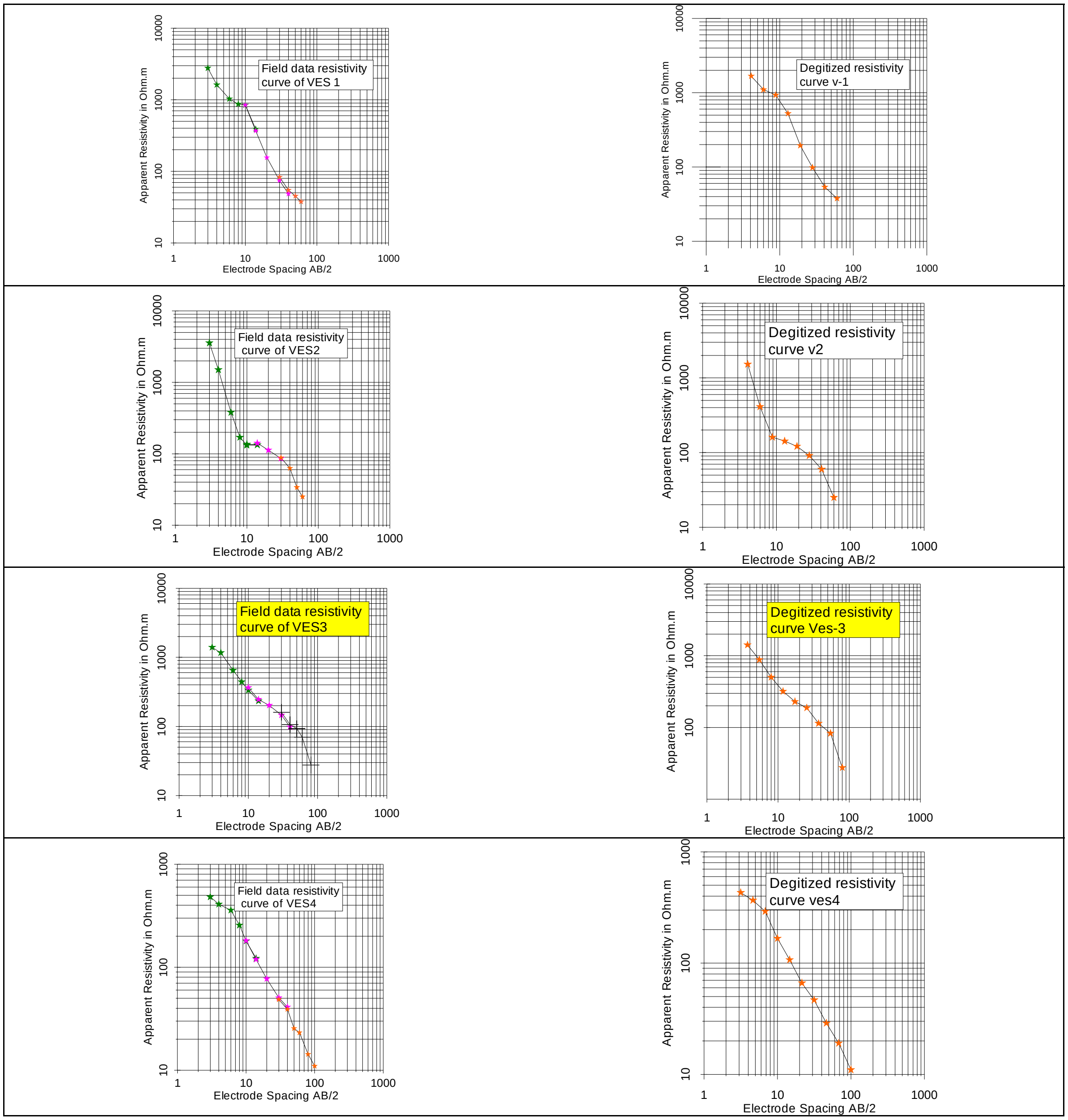


Figure (10): Field and digitized apparent resistivity data curves of the 4 VES's.

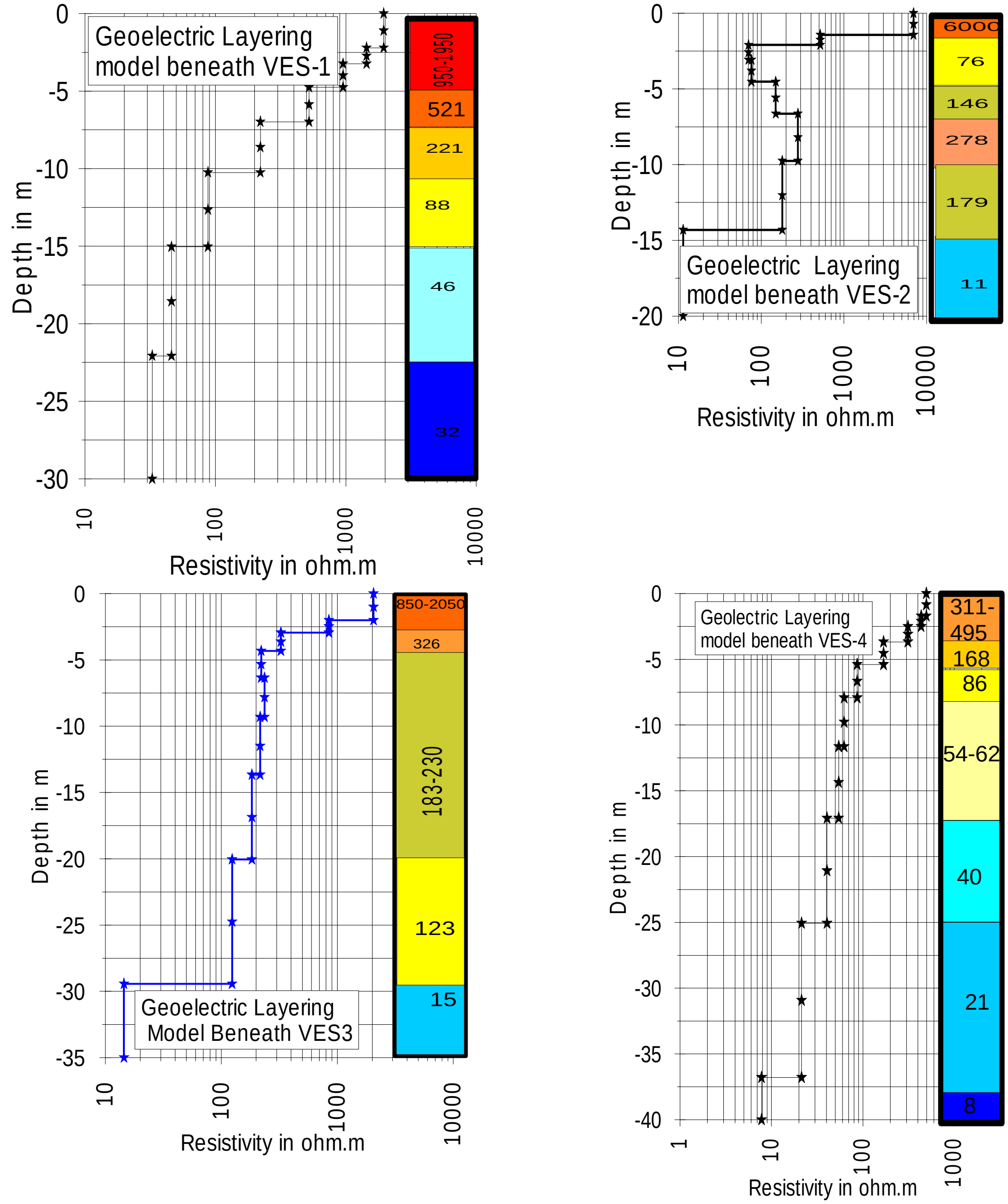


Figure (11): The interpreted n-layer models at VES1, 2, 3 and 4(Fig.8).

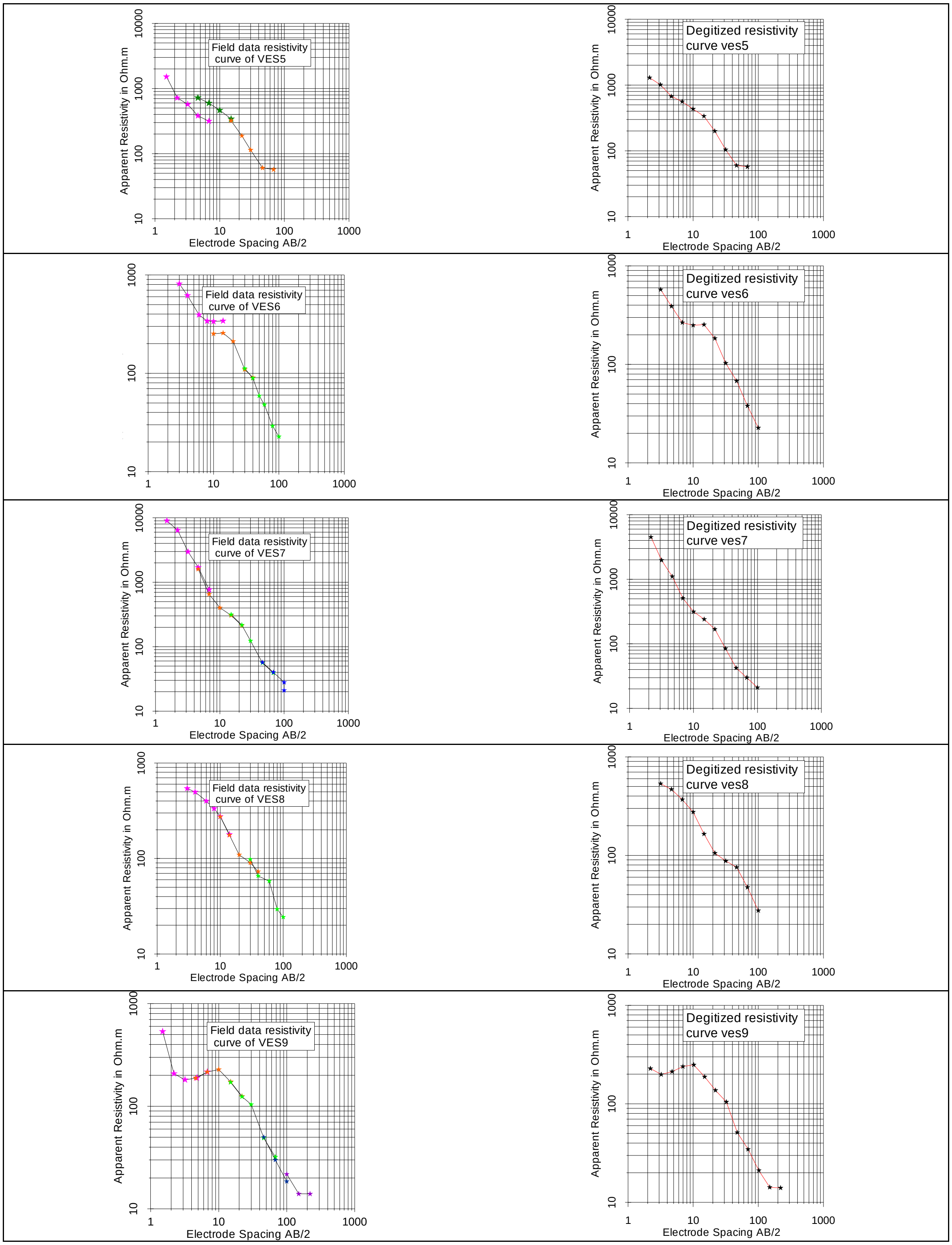
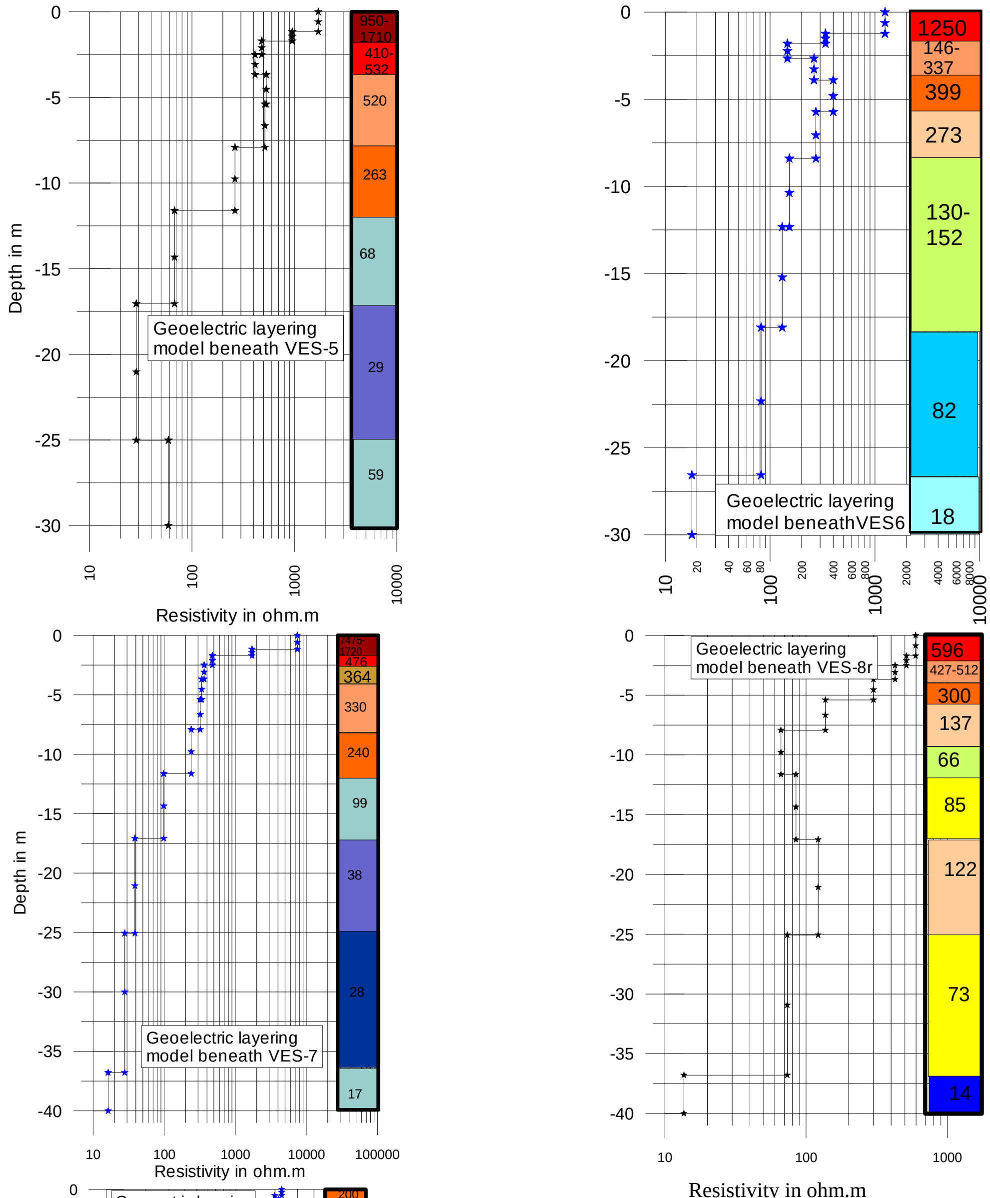


Figure (12): Field and digitized apparent resistivity curves of the acquired data from the 5 VES's at South west zone (Fig. 9).



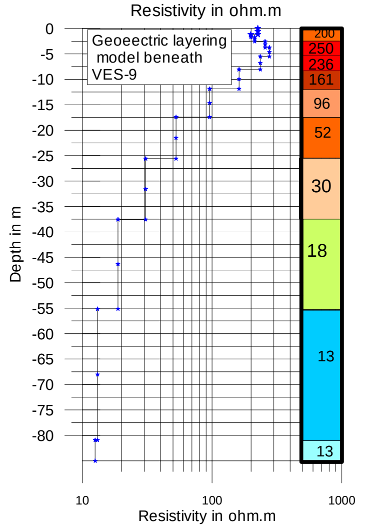


Figure (13): The interpreted n-layer models of VES5, 6, 7, 8, and 9(Fig.9).

Figure (12) shows the field data and the smoothed curves of the apparent resistivity obtained at five sites (VES5, VES6, VES7, VES8 and VES9). The interpreted subsurface geoelectric layering models achieved under these VES's (Fig. 13) show that the layers under the sites VES5, VES6 and VES8 are characterized by their relatively high resistivity values; therefore, these locations are not considered as suitable locations for drilling. The resistivity values of layers under VES 7 and VES 9, show a continuous decrease of resistivity with increasing depth. Under the VES of site 7, there is a low resistivity layer which starts from the depth of 7 m and continues in resistivity decreasing with depth to 40 m. The resistivity values range from17 to 38 ohm.m which indicates that a suitable probable groundwater potential exists under this site. Also, through the layers under the VES9, the resistivity ranges between 14 and 26 ohm.m, starting from the depth of 26 m down to 90 m. Thus, this decrease in resistivity is most probably related to the degree of saturation. The layer with 14 ohm.m resistivity is mostly correlated to the productive layers at the study area.

The quantitative interpretation of the VES shows that most of the potential occurrences of groundwater are located south and southwest of the intrusion. Therefore, the recommended sites for drilling would be in the order: VES9 and then VES7. The recommendation for further studies would be in the southwestern part of the area to find the most favorable and preferable sites for drilling.

CONCLUSION

Investigation for groundwater in complex basement structures in an arid/semiarid area such as Wadi Fatima is a difficult task. Since these structures control the groundwater flow and are more favorable sites for the groundwater accumulation, magnetic and DC resistivity were conducted at Wadi Fatima to locate them and to understand more clearly the nature of the study area.

The magnetic survey showed an intrusive body crossing the Wadi and that it is highly fractured. DC resistivity, on the other hand, was conducted at sites recommended by the magnetic survey. The results clearly show that the downstream part of the study area (southwest) is the most preferable and favorable location for drilling and for further detailed studies. VES9 and VES7 sites show higher potentiality of the groundwater occurrence. Hence, they are strongly recommended locations for drilling.

ACKNOWLEDGEMENTS

This project was sponsored and supported by Wadi Fatima Poultry Co. Ltd. The author wishes to thank El-Shaikh Aabed Zaini for his support and providing all the facilities to implement this study. Also, I would like to thank Prof. Hamdy Hassanein and Mr. Fadlallah Farouq for their suggestions to improve the manuscript, and the staff members of Geophysical Dept., King Abduaziz University for their help in the field.

REFERENCES

Al-Garni, M.A. 1996. Direct current resistivity investigation of groundwater in the lower Mesilla Valley, New Mexico and Texas: MS Thesis, Colorado School of Mines, 120p.

Al-Garni, M.A. 2004a. Schlumberger sounding and magnetic survey in Wadi Al-Damm, Makkah Al-Mukarramah, Saudi Arabia, *Journal of Petroleum and Mining Engineering (JPME),* 7: 45-60.

Al-Garni, M.A. 2004b. Application of magnetic and electrical geophysical methods in exploration of groundwater resources of Wadi Malakan, Saudi Arabia, *Journal of King AbdulAziz Univeristy: Earth Sciences*, 16: 67-93, Saudi Arabia.

Al-Garni, M.A. 2005. Investigating the groundwater occurrence in Wadi Rahjan and its potential contribution to Ain Zubaida using magnetic and electric methods, KSA, *Journal of King AbdulAziz Univeristy: Earth Sciences*, 18: 23-47, Saudi Arabia.

Al-Garni, M.A., Hassanein, H.I. and Gobashy, M. 2005. Ground-magnetic survey and Schlumberger sounding for identifying the subsurface factors controlling the groundwater flow along Wadi Lusab, Makkah Al-Mukarramah, Saudi Arabia, *Journal of Applied Geophysics*, 4: 59-74, Egypt.

Al-Garni, M. A., Hassanein, H. and Gobashy, M. 2006. Geophysical investigation of groundwater in Wadi Lusab, Haddat Ash Sham Area, Makkah Al-Mukarramah, *Arab Gulf Journal of Scientific Research*, 24 (2): 83-93.

Choudhury, K., Saha, D.K., and Chakraborty, P. 2001. Geophysical study for salain water intrusion in a coastal alluvial terrain, *J. Apllied Geophy.,* 46: 189-200.

El-Waheidi, M.M., Merlanti, F. and Pavan, M. 1992. Geoelectrical resistivity survey of the central part of Azraq plain (Jordan) for indentifying saltwater/freshwater interface. *J. Applied Geophy.,* 29: 125-133.

Frohlich, R.K. and Kelly, W.E. 1987. Estimates of specific yield with geoelectric resistivity method in glacial aquifer, *J. Hydrol.,* 97: 33-44.

Flathe, H. 1955. Possiblities and limitations in applying geoelectrical methods to hydrogeological problems in the coastal areas of north west Germany, *Geophysical Prospecting*, 3: 95-110.

Flathe, H. 1970. Interpretation of geoelectrical resistivity measurements for solving hydrogeological problems, in Morely, E. W. (ed.), Mining and Groundwater Geophysics: Geological Survey of Canada Economic Geological Report no. 26: 580-597.

Hassanein, H. 1994. Geophysical study of El Missikat radioactive mineral prospect, Central Eastern Desert, Egypt, M.Sc. Thesis, Cairo University,156p.

Hassanein, H., El-Kaliouby, H. and Al-Garni, M.A. 2007. The use of DC-resistivity to outline the subsurface hydrogeological and structural setting beneath a proposed site for subsurface dam building, Makkah Al-Mukarramah, Saudi Arabia, *Journal of King AbdulAziz Univeristy: Earth Sciences*, 18: 117-138.

Jackson, P.N., Taylor, S.D. and Stanford, P.N. 1978. Resistivity-porosity-particle shape relationships for marine sands, *Geophysics*, 43: 1250-1268.

Kaya, G.K. 2001. Investigationg of groundwater contamination using electric and electromagnetic methods at open waste-disposal site, a case study from Isparta, Turkey, *Environ. Geol.,* 40: 725-731.

Kelly, E.W. 1976. Geoelectric sounding for delineating ground water contamination, *Ground Water*, 14: 6-11.

Kesseles, W., Flentge, I. and Kolditz, H. 1985. DC geoelectric sounding to determine water content in the salt mine asse (FRG), *Geophysical Prospecting*, 33: 446-456.

Kossinski, W.K. and Kelly, W.E. 1981. Geoelectric sounding for predicting aquifer properties, *Ground Water*, 19: 163-171.

Lashkaripour, G.R., Sadeghi, H. and Qushaeei, M. 2005. Vertical electrical soundings for groundwater assessment in southeastern Iran: a case study, *J. Applied Geophy.,* 5: 973-977.

Matias, M.J.S. 2002. Square array, isotropy measurements and resistivity sounding interpretation, *J. Applied Geophy*., 49: 186-194.

Nabighian, M.N. 1972. The analytic signal of two dimensional bodies with polygonal cross-section, its properties and use of automated anomaly interpretation, *Geophysics*, 37: 507-512.

Narasimha, M.C., Srivinas, Y. and Sundararajan, N. 2005. Structural analysis of magnetic anomalies across Gondwana Outliner near Tiruvuru, Krishna District, Andhra Pradesh, *J. Ind. Geophys. Union*, 9: 21-28.

Nebert, K., Alshaibi, A. A., Awila, M., Bounny, I., Nawab, Z. A., Sharief, O. H., Sherbini, O. A. and Yeslam, A. H. 1974. Geology of the area north of Wadi Fatima, Kingdom of Saudi Arabia. Center for Applied Geology, *Ministry of Petroleum and Mineral Resources Bull.* (1): 31.

Ogilvy, A.A. 1970. Geophysical prospecting for groundwater in the Soviet Union, in Morely E. W., (ed.), Mining and Groundwater Geophysics: Geological Survey of Canada Economic Geological Report no. 26: 536-543.

Robain, H., Braun, J.J., Albouy Y. and Ndam, J. 1995. An electrical monitoring of an elementary watershed in the rain forest of Cameroon, Proceedings of 1st Environmental and Engineering Geophysics Meeting, Torino, Italy, 411-414.

Robain, H., Descloitres, M., Ritz, M. and Yene Atangana, Q. 1996. A multiscale electrical survey of a lateritic soil system in the rain forest of Cameroon, *J. Applied Geophy*., 34: 237-253.

Shaaban, F. 2002. Vertical electrical for groundwater investigation in northwestern Egypt: a case study in a coastal area, *J. African Earth Sci.,* 33: 673-686.

Sundararajan, N. 1983. Interpretation techniques in exploration geophysics using Hilbert transform, PhD Thesis submitted to Osmania University, India.

Troisi, S., Fallicos, C., Straface, S. and Migliari, E. 2000. Application of kriging with external drift to estimate hydraulic conductivity from electrical resistivity data in unconsolidated deposites near Montato Uffugo, Italy, *Hydrogeol. J.,* 8: 356-367.

Yadav, G.S. and Abolfazli, H. 1998. Geoelectric soundings and their relationship to hydraulic parameters in semiarid regions of Jalore, northwestern India, *J. Applied Geophy*., 39: 35-51.

Young, M.E., de Bruijin, R.G.M. and Al-Ismaily, S. 1998. Reports: exploration of an alluvial aquifer in Oman by time-domain electromagnetic sounding. *Hydrogeol. J.,* 6:383-393.

Yechieli, Y. 2002. Fresh-saline ground water interface in the western Dead Sea area. *Ground Water*, 38: 615-623.

Zakir, F.A.R. and Moustafa, A.R. 1992. Structural setting of Gabal Abu Gurrah Area, Wadi Fatma, West-Central Saudi Arabia. *Journal of King Abdul Aziz Univrsity*, 5: 177-200.

Zohdy, A.A.R. 1969. The use of Schlumberger and equatorial soundings in groundwater investigations near El Paso, Texas, *Geophysics*, 34, 713-728.

Zohdy, A.A.R. 1989. A new method for the automatic interpretation of Schlumberger and Wenner sounding curves, *Geophysics*, 54: 245-253.

Zohdy, A.A.R., Eaton, G.P. and Mabey, D.R. 1974. Application of surface geophysics to groundwater investigation, U.S.G.S. Techniques of Water-Resource Investigation, Book 2.