International Journal of Water Resources and Arid Environments 2(4): 195-204, 2013
ISSN 2079-7079

Geoelectric Study for Water Well Location in the Campus of Taif University, Taif, Saudi Arabia

Ahmed A. Nigm

Nuclear Materials Authority, P.O. Box: 530 El Maadi, Cairo, Egypt

Abstract: The scarcity of surface water in the Arabian Shield led to concentrating the efforts of geologists and geophysicists in looking for new sources for water supply. The groundwater represents the most important target for these efforts. So, this study aims to explore the groundwater and to select the proper sites for drilling boreholes to feed the campus of Taif University with water. The geoelectric survey using Schlumberger configuration was applied in order to investigate the depth to the water table and thickness and configuration of the water-saturated zone. Therefore, thirteen vertical electrical soundings (VES) were conducted in the study area for this purpose. The geoelectric study proved the presence of groundwater at shallow depths in the weathered zone of the highly deformed and fractured granitic rocks and Quaternary sediments. The structural elements in the area led to the formation of down-faulted and uplifted blocks which may control more or less the groundwater movement. The depth to the water table in the area ranges between 6 to 8 m. The average thickness for the water-saturated zone is 18.5 m, while, it goes up to 22.2 m as shown from the measurements of the drilled borehole. The depth to the bed rock in the area reaches up to 12 m in the northern zone, 20 m in the southern zone and 28 m in the deepest middle zone. The results of geoelectric survey were compared and confirmed with that obtained from test borehole drilled at a promising selected site.

Key words: Geoelectric survey, Vertical electrical sounding, Water well, Groundwater

INTRODUCTION

The study area lies within the Arabian Shield at 18 km to the north of Taif Town, Kingdom of Saudi Arabia (KSA) between Longitudes 40° 28' 30.7" and 40° 28' 45.0" E and Latitudes 21° 25' 33.0" and 21° 25' 55.0" N (Fig. 1). The study aims to explore the groundwater in the area in the vicinity for supplying the University of Taif with water. So, it is important to determine the existence and potentiality of water as well as the depth to the water table and thickness of the water-saturated zone. Studying the geological and structural setting of the area could be helpful in interpreting the geophysical data, where the structural elements such as faults, fractures and joints may control the movement and storage capacity of the groundwater.

Taif area as a part of the Arabian Shield is characterized by shallow groundwater aquifers. However, it has many wadi (Dry Valley) systems, with vast area span, which collects water from the flash floods and

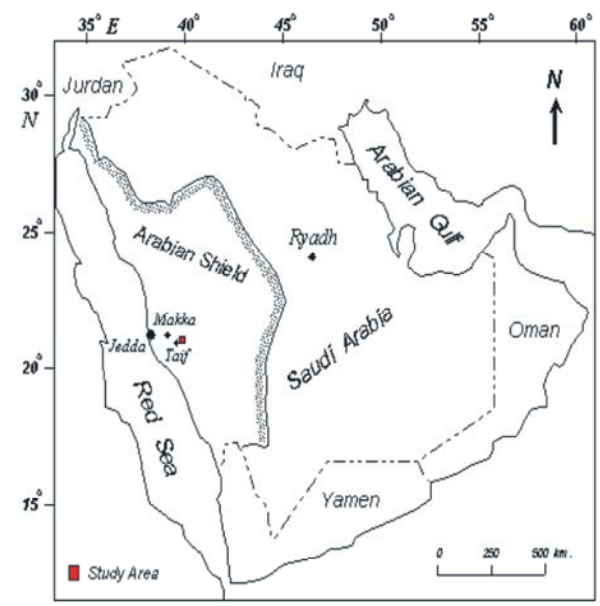

Fig. 1: General location map of KSA showing the location of Taif town

Corresponding Author: Ahmed A. Nigm, Nuclear Materials Authority, P.O. Box: 530 El Maadi, Cairo, Egypt.
E-mail: aanigm@yahoo.com.

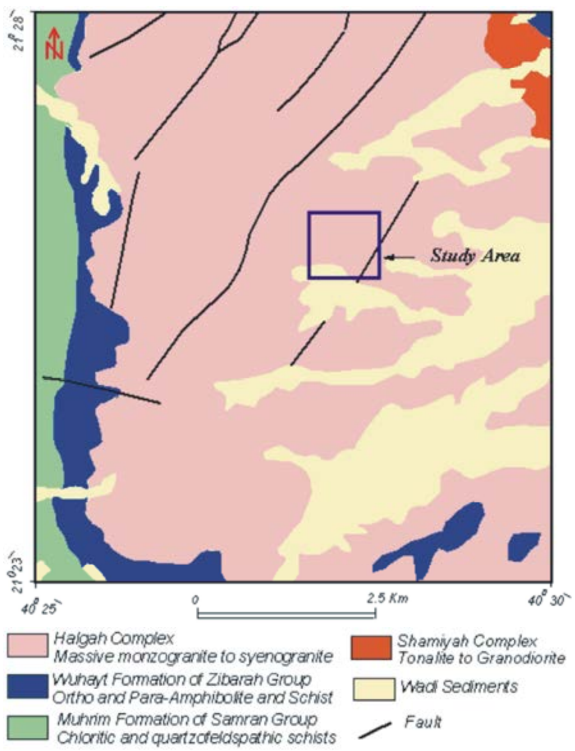

Fig. 2: General geology of the study area and surroundings

stores it within the sediment (sand, pebbles) and the weathered Basement rocks. The groundwater aquifers in the study area are respectively low compared with groundwater aquifers in deep aquifers of Arabian troughs. The main source of groundwater in the study area is rainfall. The highest average rate of seasonal rainfall is during May period (175 mm/year) while the lowest average rate is during July period, which reaches to 1.74 mm/month.

Regional Geology: The study area lies within Makkah quadrangle, west of the Arabian Shield. Generally, it characterized by the presence of numerous exposed rock masses of granitic type and the wadi deposits occupy the rest of the area (Fig. 2). Halgah Complex covers the majority of the area and its vicinity which is formed of massive monzogranite and synogranite. These rocks are composed of medium to large grains of plagioclase and quartz, as well as porphyry of biotite, amphiboles, muscovite and minor chlorite. The wadi sediments are of Quaternary age and compose of a mixture of sandy grains with different sizes, gravel and boulders as the products of weathering processes of the preformed granitic rocks. These types of sediments are capable of accumulating the groundwater with considerable amounts. The thickness of these deposits ranges from 1 m to several meters.

Hydrogeological Background: The yield of water from fractured rocks is dependent upon the frequency and interconnectedness of flow pathways [1]. Crystalline and metamorphic rocks, including granite, basic igneous rocks, gneiss, schist, quartzite and slate are relatively impermeable. Water in such areas is supplied as a result of jointing and fracturing.

Taif area as a part of the Arabian Shield is characterized by shallow groundwater aquifers. The area however has many Wadi systems, with vast area span, which collects water from the flash floods and stores it within the sediment (sand, pebbles) and the fractured faulted Basement rocks. The groundwater aquifers in the study area are respectively low compared with groundwater aquifers in deep aquifers of Arabian troughs.

Geophysical Survey: Geophysical methods provide efficient means of characterizing subsurface geology and hydrology [2]. The electric method is used in this study to measure the subsurface electrical properties in order to determine the subsurface resistivity distribution by making measurements on the ground surface. It aims to locate fracture zones, faults and depth to groundwater; depth to bed rock and other preferred groundwater applications. Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is greatly dependent on the degree of fracturing and the percentage of the fractures filled with groundwater and its type (i.e. fresh or saline). Thus a given rock type can have a large range of resistivity, from about 1000 to 10 million Ωm; depending on whether it is wet or dry. This characteristic is useful in the detection of fracture zones and other weathering features, such as in engineering and groundwater surveys [3].

Vertical Electrical Sounding: Resistivity surveys measure the composite electrical resistivity of the subsurface. Direct current is induced into the ground between two current electrodes A and B and the potential difference is measured between two potential electrodes M and N (Fig. 3). A resistance value is obtained by dividing the measured voltage by the induced current. Various survey-electrode-array configurations and data-processing techniques can be used to differentiate survey data into interpreted geologic sections [4].

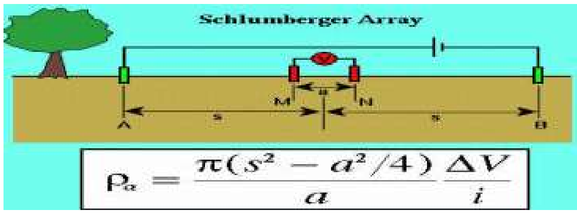

Fig. 3: Sketch diagram shows the Schlumberger electrode arrays

Table 1: Sounding locations in the study area.

VES No.	VES Coordinates Latitude (N)	Longitude (E)	VES Location (UTM) N	E
1	″54.7 ′25 °21	″43.5 ′28 °40	2370657	653245
2	″40.5 ′25 °21	″31.5 ′28 °40	2370226	652909
3	″37.5 ′25 °21	″32.9 ′28 °40	2370133	652949
4	″36.6 ′25 °21	″36.9 ′28 °40	2370107	653067
5	″45.9 ′25 °21	″34.2 ′28 °40	2370393	652985
6	″45.4 ′25 °21	″32.2 ′28 °40	2370379	652928
7	″41.5 ′25 °21	″33.5 ′28 °40	2370258	652967
8	″51.4 ′25 °21	″35.9 ′28 °40	2370562	653032
9	″52.4 ′25 °21	″32.2 ′28 °40	2370592	652925
10	″35.5 ′25 °21	″36.1 ′28 °40	2370074	653045
11	″45.8 ′25 °21	″34.4 ′28 °40	2370393	652992
12	″45.7 ′25 °21	″38.6 ′28 °40	2370388	653111
13	″45.9 ′25 °21	″34.2 ′28 °40	2370391	652978

An apparent resistivity is calculated from a resistance value and geometric factors that account for the electrode spacing configuration.

In the present study, resistivity measurements were made with Schlumberger array configurations [5]. This array remained as one of the best arrays for depth sounding among the different array configurations. The main application of this array is to explore the groundwater aquifer occurrences and to determine the depth to bed-rock. In this method, the center point of the electrode array remains fixed, but the spacing between the electrodes is increased progressively to obtain more information about the deeper sections of the subsurface (Fig. 3).

The Vertical Electrical Sounding (VES) survey was conducted at 13 sites distributed in the study area (Table 1 and Fig. 4). The VES specifications were selected as seven measurements per decade to obtain excellent data continuity, while the half current electrode spacing (AB/2) started from one meter to 140 meter. The equipment used in the present study is a D. C. resistivitymeter model CAMPUS-Ω.

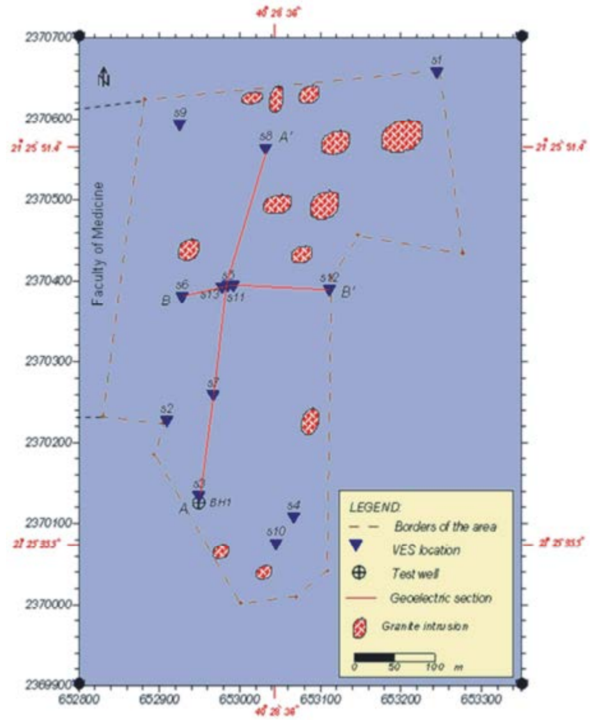

Fig. 4: Layout map of the study area

Data Analysis and Processing: From the field data, the apparent resistivity (ρ_a) is plotted versus AB/2 on log-log paper. Among the advantages of the log-log plot is that it emphasizes near-surface resistivity variations and suppresses variations at greater depths. This is important, because interpretation of the results depends largely on the small variations in resistivity occurring at shallow depths. In addition, the basement complex or the presence of an electric basement is readily determined on the log-log plot by a 45° sloping straight line [6].

The field data have been interpreted through successive interpretation steps. Feeding the field data to the PC represents the first step, in order to get the n-layer model. The interpretation of the VES'es was obtained through using an automatic interpretation multi-layer computer program [7]. Based on these interpretations, the parameters ñ (resistivity) and h (thickness) of a geoelectric model, thought to be closer to reality, were estimated. The resultant multi-layer models for each sounding (Fig. 5a) represent the initial models used for feeding the Resist layering program [8] and to construct the subsurface true resistivity contour sections. The layering models of Resist program (Fig. 5b) were used to reduce the layers into 4, in order to build up a geoelectric model.

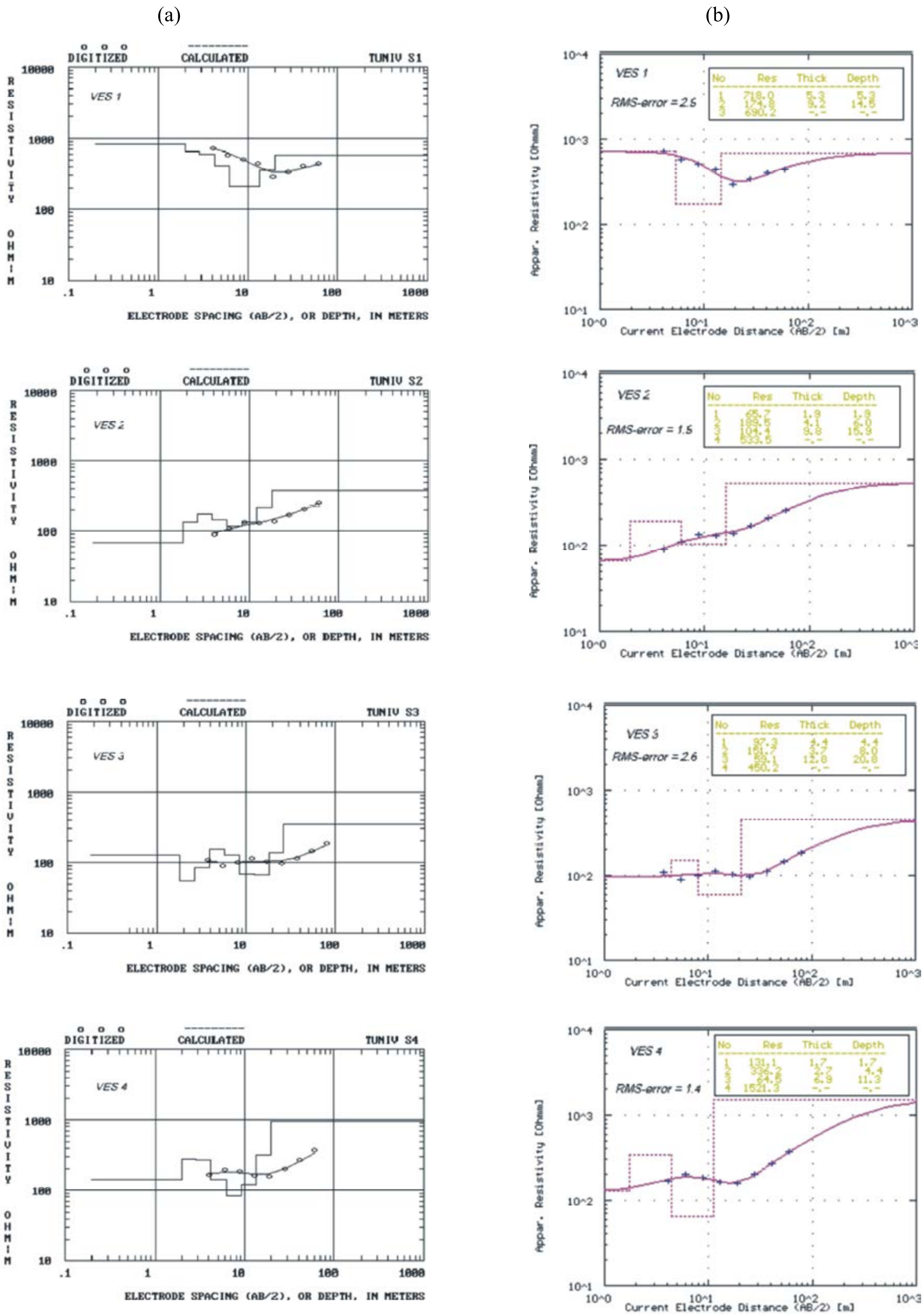

Fig. 5: Continued

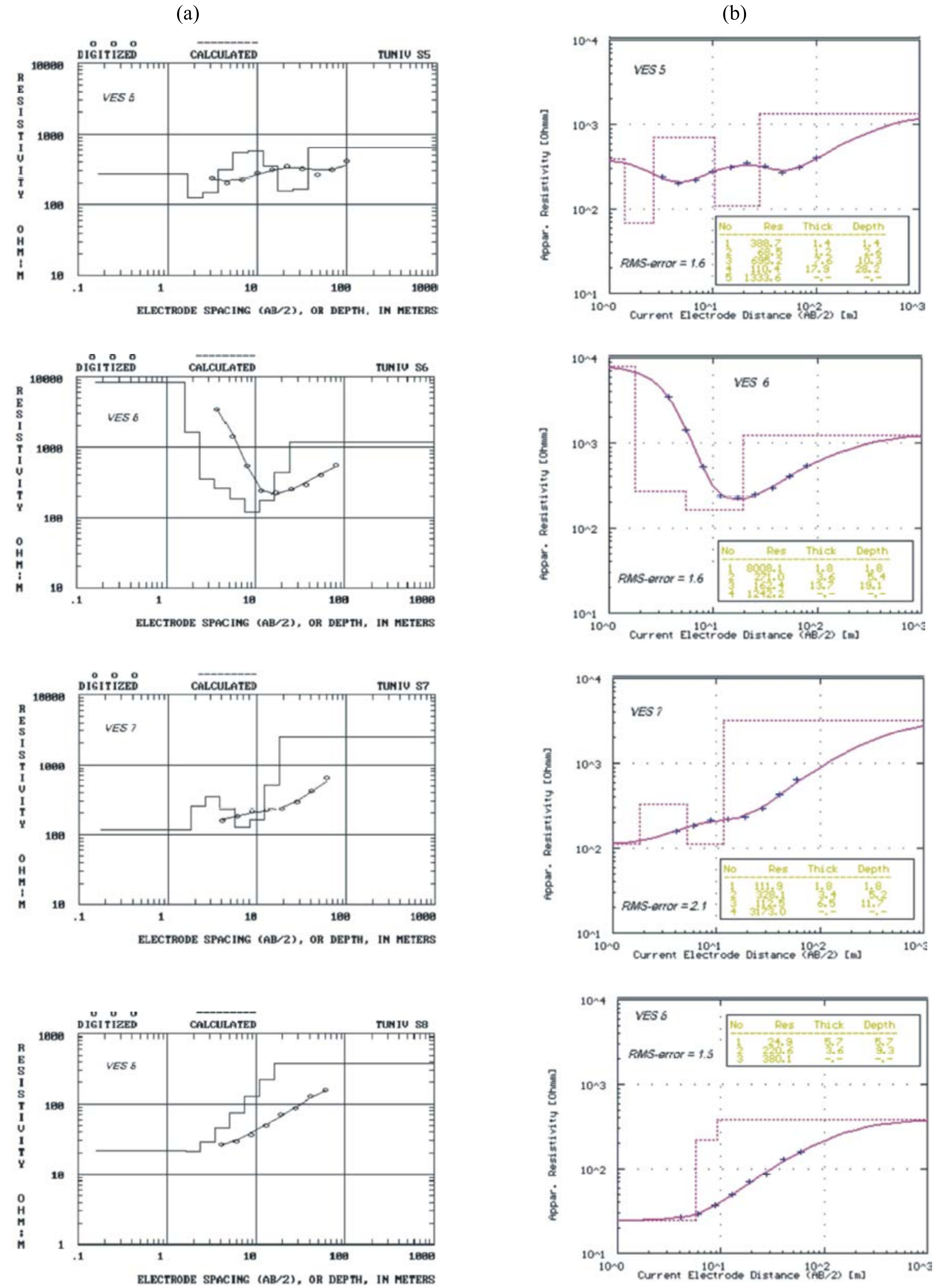

Fig. 5: Continued

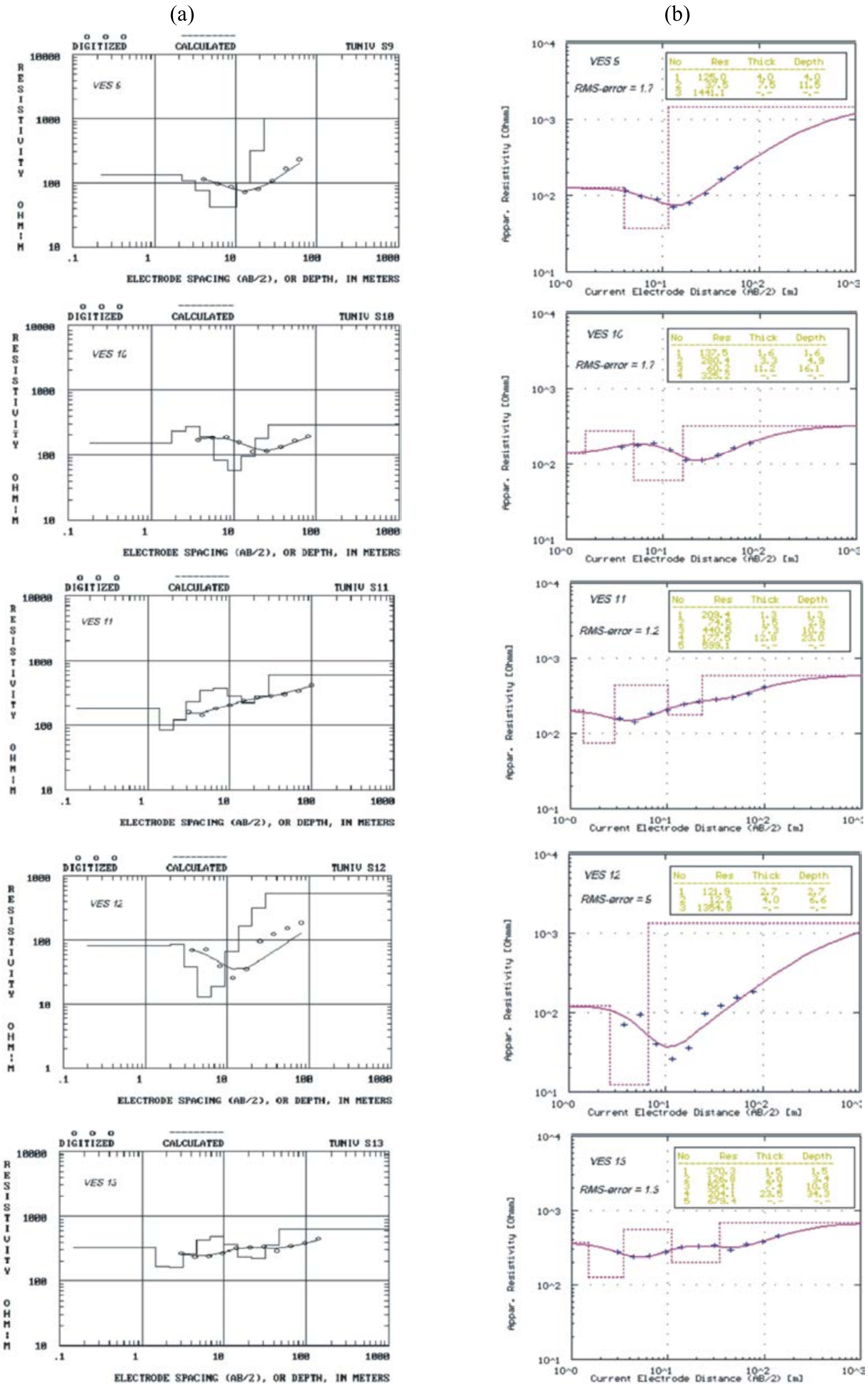

Fig. 5: (a) VES's multi-layer models using Ato program [7] and (b) the layering models using Resist [8]

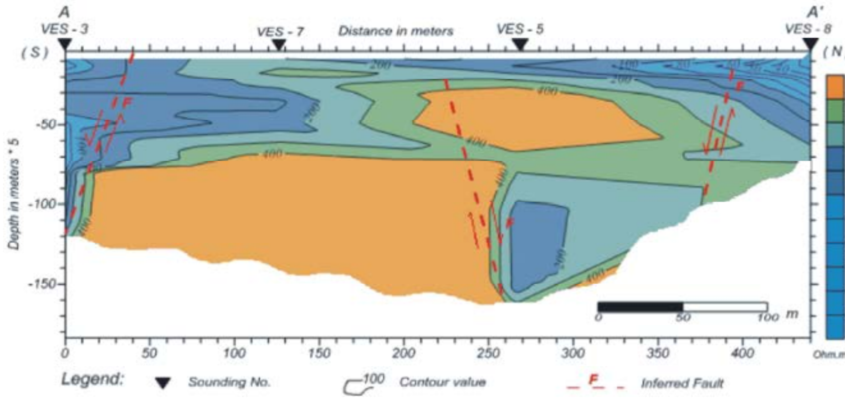

Fig. 6: Subsurface true resistivity contour section (A-A') through VES's 3, 7, 5 and 8

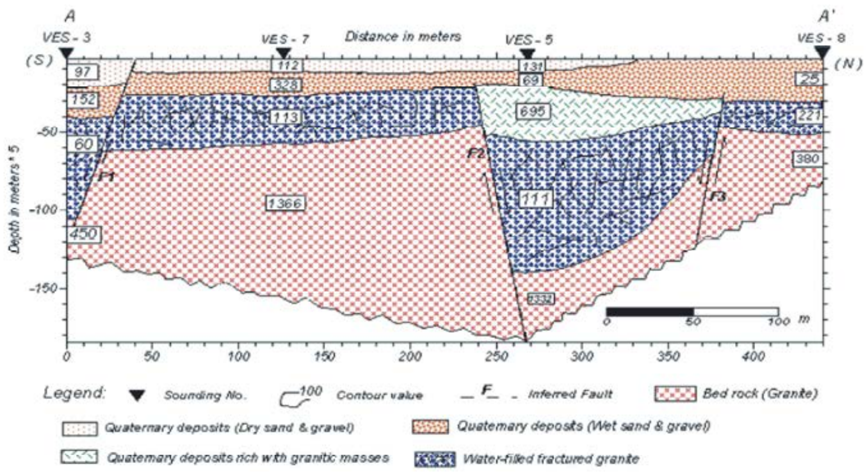

Fig. 7: Geoelectric section (B-B') passing through VES's 3, 7, 5 and 8

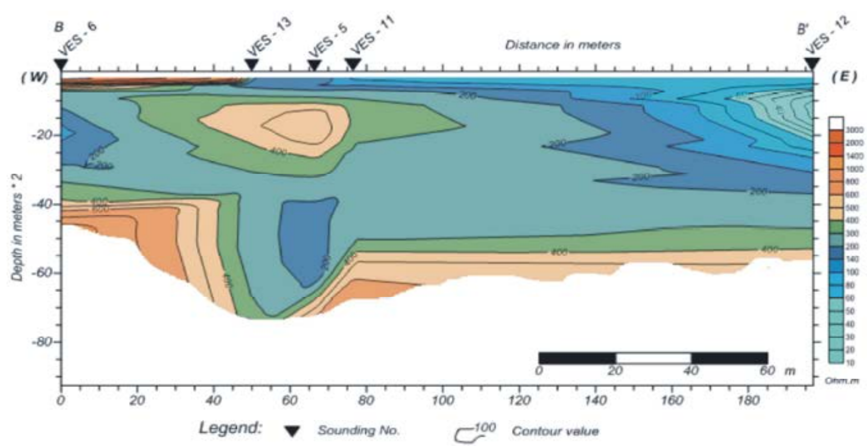

Fig. 8: Subsurface true resistivity contour section (B-B') through VES's 6, 13, 5, 11 and 12

The measured apparent resistivities are then presented in a contoured pseudosection, which reflects qualitatively the spatial variation in resistivity in the vertical cross-section [9]. Therefore, the interpretation of VES data is carried out using the subsurface true resistivity contour and geoelectric sections (Figs. 6, 7, 8 and 9) as well as the individual soundings. The careful examination of the subsurface sections can provide useful information about the subsurface lithology, structures and groundwater occurrences. It can also give additional information about the lateral discontinuities in the subsurface lithology [10].

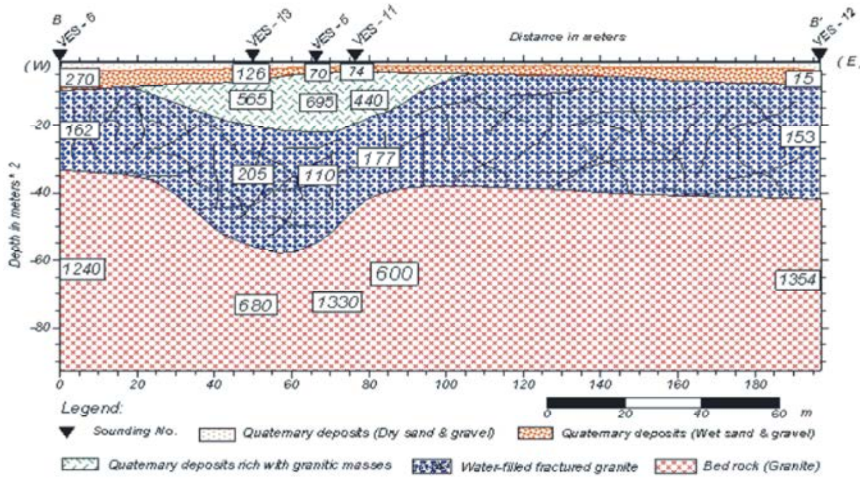

Fig. 9: Geoelectric section (B-B') passing through VES's 6, 13, 5, 11 and 12

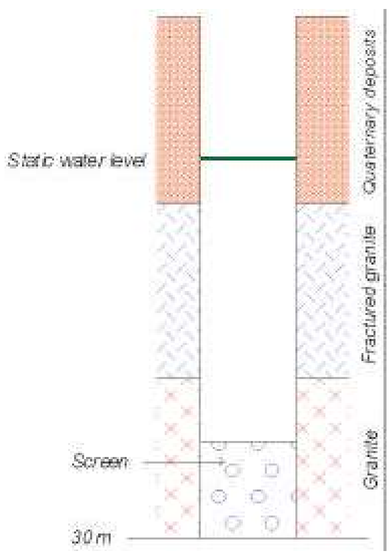

Fig. 10: Borehole description

Discussion and Interpretation: According to the behavior of the field curves and number of the subsurface geoelectric layers for each sounding, the study area could be subdivided into three zones differing in their resistivity characters; the northern, central and southern zones. The first zone (to the north of the area) is widely occupied by huge outcropping granitic masses. The layering models of soundings 1, 8 and 9 reflect the presence of three geoelectric layers. The first and second layers attain average thickness about 5 m and 7 m respectively. The third layer represents the bed rock at an average depth of 12 m.

The second zone is located approximately at the center of the fenced area in the front of its entrance gate. This part involves the VES'es 5, 11 and 13 which are close to each other in a trial to verify the acquired resistivity data. The models of these three soundings are formed of five geoelectric layers. The great similarity of the field curves, geoelectric models and number of layers, in addition to the resistivity values proves that this zone has similar geoelectric characteristics. The fourth geoelectric layer which has an average depth about 10.5 m and an average resistivity value of 105 Ohm.m, represents the promising layer for groundwater accumulation in this zone. The average depth to the massive bedrock is about 28 m, proving that this zone is the deepest one among the three zones.

The third zone involves the remainder seven soundings Nos. 2, 3, 4, 6, 7, 10 and 12. It covers the majority of the study area and occupies mainly its southern parts. The models of this zone consist of four geoelectric layers; the third one is the promising water-bearing layer. The top of this third layer attains 7 m as an average depth and 95 Ohm.m as an average resistivity value. The maximum thickness of this layer is recorded as 18 m beneath VES 3, while the average thickness for the same layer in the third zone is 10.5 m. The depth to the basement rocks in this zone was estimated as 20 m, whereas these rocks could be reached at 26.5 m in the site of sounding 3.

The subsurface true resistivity contour section, A-A\ (Fig. 6) and its equivalent geoelectric section (Fig. 7) of soundings 3, 7, 5 and 8 cut through the three interpreted zones nearly from south to north. The close examination of these sections reflects clearly the interpreted subsurface geoelectric modeling of the area. In spite of the evidences which refer to water occurrences in the fractured zone of the granitic rocks in the area, there are also good evidences that the water-bearing horizons are structurally controlled. The causes of irregularities in DC resistivity data could be due to several factors such as; faults or abrupt lateral changes in properties. Accordingly, three normal faults denoted F1, F2 and F3 could be recognized in the two sections trending more or less in the E-W direction. This structural setting led to the formation of subsided and uplifted blocks. The deepest block (subsided) under VES 5 has five geoelectric layers; while these layers diminish to three only at the site of VES 8 in the northern zone of the area. As noticed from the geoelectric section (Fig. 7), the variation in the resistivity values for a layer might be due to the presence of granitic masses and weathering products which increase the resistivities in a place relative to the rest of the layer.

The second subsurface true resistivity contour section, B-B\ (Fig. 8) passes through VES's 6, 13, 5, 11 and 12 from west to east. It intersects the first section at the location of VES 5. The equivalent geoelectric section (Fig. 9) reflects also the geoelectric mode of the study area. The area of intersection of the two sections includes VEs's 13, 5 and 11. It shows subsiding area since it is highly affected with two inferred faults denoted F2 and F3. The promising layer along section A-A\ attains 127 Ohm.m as an average resistivity value which varies from 60 to 221 Ohm.m, whereas it records 162 Ohm.m as average value in section B-B\.

The resistivity value of the saturated layer in the area ranges between 37.5 and 177.5 Ohm.m with an average value about 81 Ohm.m. According to Bernard [11]: in order to identify the presence of groundwater from resistivity measurements, one can look to the absolute value of the ground resistivity: for a practical range of fresh water resistivity of 10 to 100 Ohm.m, a usual target for aquifer resistivity can be between 50 and 2000 ohm.m. A porous or fractured rock bearing free water has a resistivity which depends on the resistivity of the water and on the porosity of the rock (see below): several tens to several thousands Ohm.m.

The groundwater aquifer in the study area is mainly composed of two different layers with different characteristic features, taking into consideration the groundwater movement and the different factors affecting this movement. The surficial layer consists of sand with graded sizes and gravel. The lower one consists of the eroded and fractured uppermost part of the granitic rocks, which were affected by either fluvial erosion or tectonic movements leading to disturb faults, cracks and lineation in this part. The fore-mentioned conditions are suitable for groundwater accumulation either in porous medium in the uppermost part or in cracks and faults in the lower one.

Resistivity data interpretation is confirmed by a test borehole drilled at the site of VES 3 in the third southern zone. The diameter of the borehole is 25 cm with total depth 30 m. The cased length in the borehole is 24 m and the screen length is 6 m (Fig. 10).

It was found that the static water table is detected at 7.8 m in the drillhole whereas; it was estimated at 8 m from the geoelectric survey. The total saturated thickness of the unconfined aquifer is 22.2 m. The interpreted resistivity data refer that the depth to the bed rock is 26.5 m hence, the saturated thickness is 18.5 m, while, it goes up to 22.2 m as shown from the measurements of the drilling which reaches 30 m depth.

CONCLUSION

The application of geoelectric study showed that the granitic rocks in the area are highly fractured and filled with water at depth of 6 to 8 m. The area is highly affected with structural elements which led to the formation of down-faulted and uplifted blocks. The area could be subdivided into three zones differing in their resistivity characters and depths. It also proved that, the deepest subsided block which involves VES 5 occupies the middle of the area. The depth to the bed rock in the area reaches 12 m in the northern zone, 20 m in the southern zone and 28 m in the middle deepest zone. The geoelectric interpretation results were confirmed with the drilling results of a drillhole chosen at the site of VES 3.

ACKNOWLEDGEMENT

The author is deeply indebted to Dr. Homoud M. Al Thobaity and all members of Al Thobaity Offices for water studies, Jeddah, KSA for the great assistance through the field work and data acquisition.

REFERENCES

1. Genetti, A.J., 1999. Manual of Engineering and design groundwater hydrology. U. S. Army Corporations of Engineers. CECW-EH, Washington DC, 20314-1000 No.
2. Dawson, C.B., L.W. Lane, E.A. White and M. Belaval, 2002. Integrated geophysical characterization of the Winthrop Landfill Southwestern flow path, Winthrop, Maine. Proceeding of Environmental and Engineering Geophysical Society, Denver, Colorado, pp: 22.
3. Loke, M.H., 2002. Tutorial 2-D and 3-D Electrical Imaging Surveys, pp: 124.

4. Mack, T.J. and J.R. Degnan, 2004. Geophysical Characterization of Fractured Bedrock at Site 8, Former Pease Air Force Base, Newington, New Hampshire. Open-File Report 02-279, USGS.
5. Zohdy, A.A.R., G.P. Eaton and D.R. Mabey, 1974. Application of surface geophysics to ground-water investigations: U.S. Geological Survey Water-resources Investigations, Book 2, Chap. D1, pp: 86.
6. Sabet, M.A., 1975. Vertical Electrical resistivity soundings to locate ground water resources: A feasibility study. Department of Geophysical Sciences, Old Dominion University Norfolk, Virginia 23508.
7. Zohdy, A.A.R. and R. Bisdorf, 1989. A program for automatic processing and interpretation of Schlumberger sounding curves in Quick Basic 4.0. U. S. Geological Survey Open - File Report, 67: 89-137.
8. Velpen, B.P.A., 1988. Resist program, V. 1.0. MSc Research project, ITC, Holland.
9. Griffiths, D. and J. Turnbull, 1985. A multi-electrode array for resistivity surveying. First Break, 3(7): 16-20.
10. Sadek, H.S., S.A. Soliman and H.M. Abdulhadi, 1989. A correlation between the different models of resistivity sounding data to discover new fresh water fields in El Sadat City, Western Desert of Egypt. Proc. of the 7th International Mathematical Geophysics Seminar, Free University of Berlin, pp: 329-346.
11. Bernard, J., 2003. Short note on the principles of geophysical methods for groundwater investigations. www.Terraplus.com (info@terraplus.com).