OnLine Journal of Earth Sciences 4 (1): 19-26, 2010
ISSN: 1991-7708

Estimation of Aquifer Hydraulic Characteristics of Low Permeability Formation from Geosounding Data: A Case Study of Oduma Town, Enugu State

A.C. Ekwe, I.N. Nnodu, K.I. Ugwumbah and O.S. Onwuka
Department of Geology, University of Nigeria, Nsukka

Abstract: Geo-electrical measurements using the Vertical Electrical Sounding (VES) method was utilized in determining aquifer characteristics of Oduma. Three geologic groups were delineated: Albian Asu River Group, Turonian Eze- Aku Group and Coniacian Awgu Group. Eight VES results using the Schlumberger configuration were acquired for the study area. A maximum half electrode spacing of 300 m was utilized for data acquisition. Eight soundings were processed using RESIST software. Geo-electric sections were generated from which the aquiferous layers were delineated and hydraulic parameters (hydraulic conductivity and transmissivity) were computed. The layer parameters obtained were used to calculate longitudinal conductance (S) and transverse resistance (R) variations in the study area. Data analysis was done based on Niwas and Singhal's established relationship between aquifer transmissivity (T) and Dar Zarrouk's parameters-R and S to calculate hydraulic conductivity and Transmissivity distribution in the study area. Knowledge of aquifer parameters from pumping test carried out on bore wells combined with existing litho-logs aided correlation of geo-electric sections to litho-logs. Results from geosounding interpretation show that transmissivity ranges between 14.17 m^2 day^{-1} at Obufia Ohofia and 174.89 m^2 day^{-1} at CSS Ohafia Oduma. Hydraulic conductivity ranges between 0.6243 m day^{-1} at Obufia Ohofia and 5.5091 m day^{-1} at Obodo Uhuanwuta. The depth to water table ranges between 6.7 m at Umuichite Obeagu to 32.7 m at CSS Ohofia while aquifer thickness ranges between 12.0 m at Umuichite Obeagu and 118.9 m at CSS Ohofia Oduma.

Key words: Hydraulic conductivity, transmissivity, porous media, oduma, south-eastern Nigeria

INTRODUCTION

The increasing population of Oduma area in south-eastern Nigeria has led to a subsequent increase in demand for potable water to satisfy the needs of the inhabitants. Therefore, quantitative description of aquifers has become vital in order to understand the hydrogeological problems in the area.

As a result, geo-electrical measurements using the Vertical Electrical Sounding method (VES) which are well suited for hydrologic investigation of geologic formations with large resistivity contrasts were utilized in determining aquifer hydraulic characteristics of Oduma.

The integration of aquifer parameters calculated from existing borehole locations and surface resistivity parameters extracted from surface electrical measurements was used effectively, not only for aquifer hydraulic conductivity estimation but also for a group of hydraulic parameters.

The electrical resistivity method is utilized in diverse ways for groundwater exploration (Zohdy, 1976; Choudhury *et al*., 2001; Sumanovac and Weisser, 2001; Kaya, 2001; Frohlich and Urish, 2002). Computer modelled direct interpretation techniques are used to resolve the true thicknesses and resistivities of the aquiferous zones from surface resistivity measurements (Johnson, 1977; Niwas and Singhal, 1981a, b; Onuoha and Ezeh, 1988; Onu, 1995; Ekwe *et al*., 2006).

When the thickness and resistivity of an aquifer is known, its transverse unit Resistance (R) and longitudinal conductance (S) can be calculated easily. Maillet (1947) was the first to give the concept of these parameters and subsequently called them the Da-zarrouk variable (R) and Dar-zarrouk function (S).

Da-zarrouk parameters have since been used in the estimation of the hydraulic characteristics of aquifers. Onuoha and Ezeh (1988) used the concept of Da-zarrouk parameters to estimate the transmissivity of Ajali sandstone aquifers in Southeastern Nigeria. Ekwe *et al*. (2006) applied the concept of Da-zarrouk parameters to estimate aquifer transmissivities within the middle Imo River basin.

In this study, we investigated the applicability of the Da-zarrouk parameters in estimating aquifer hydraulic characteristics in low permeability formations.

Corresponding Author: A.C. Ekwe, Department of Geology, University of Nigeria, Nsukka

MATERIALS AND METHODS

The study area: The study area lies between latitudes 06°02'N and 06°09'N and longitudes 07°36'E and 07°40'E (Fig. 1) and covers an area of about 1451.52 km^2. It is bordered by the villages Nomeh to the North, Ndeaboh and Umunaga to the South, Awgu to the West and Ohofia to the East. The area is drained by River Asu and other tributaries. Oduma is mainly dominated by rural dwellers whose occupation is majorly farming (they cultivate mostly rice and maize); hence their main use of water is for agricultural and domestic purposes.

Geology of the study area: Several geoscientists have worked in the Lower Benue Trough where the study area is located. The study area is majorly underlain by Asu River, Eze-Aku and Awgu Shales with a small fraction underlain by Agbani Sandstone. Asu river group consists of alternating shales and silt stones with occurrences of sandstone having its maximum thickness as 1500 m (Nwajide, 1979). Cratchley and Jones described the Eze-Aku as consisting of flaggy calcerous shale thin sandy or shaley limestone and calcerous siltstone indicating the renewal of marine deposition in the Benue Trough. Eze-Aku Formation varies in thickness up to 1200 m (Burke *et al.*, 1970) and it is overlain by about 900 m of bluish grey, bedded shale with some fine-grained carbonaceous limestone beds (Awgu Shale), locally replaced with sandstone (Agbani Sandstone).

Aneke (2007) carried out an assessment of the water resources of the Awgu shale Group using hydrological data. He found out that proper planning and development could assist water resource developers in the area to design better exploration strategies for exploiting water from the fractured shaley units. Fractured shales are the main aquifer units within the study area.

Vertical Electrical Sounding (VES): Vertical electrical sounding furnishes information concerning the vertical succession of different conducting zones and their individual thicknesses and resistivities. For this reason, the method is practically valuable for investigations on horizontally or near horizontal stratified earth. In the electrical sounding with the Schlumberger array, the

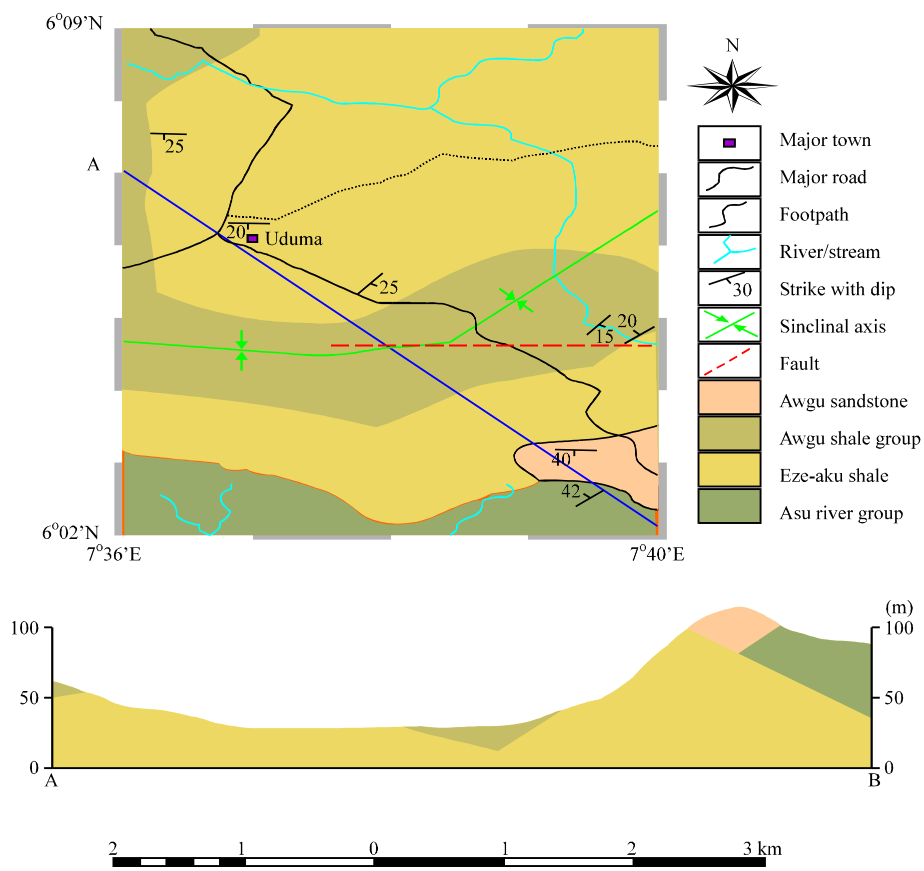

Fig. 1: Geologic map of study area with a cross-section along AB

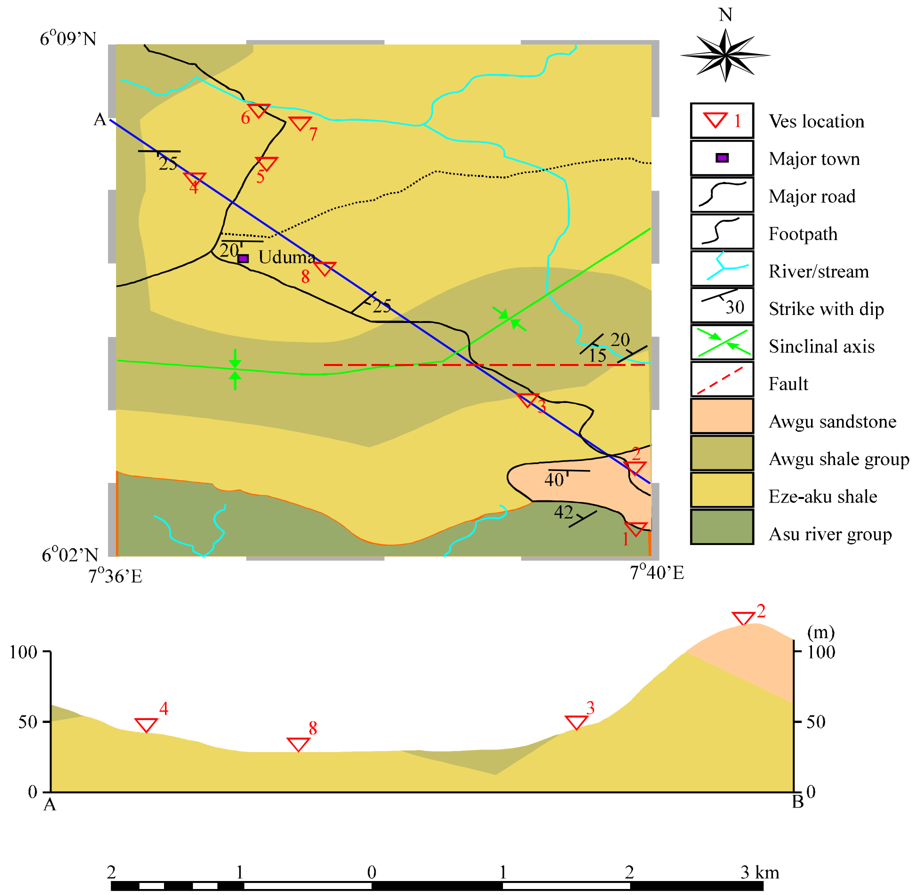

Fig. 2: Map of the study area showing sounding locations

midpoint of the electrode array remains fixed but the spacing between the electrodes is generally increased to obtain more information about the deeper sections of the subsurface. For Schlumberger configuration, apparent resistivity is given by (Keller and Frischknecht, 1966):

$$\rho a = \pi R (a^2/b - b/4)$$

Where:

a = Half current electrode separation
b = Potential electrode spacing

The Schlumberger array was adopted because field data acquisition is faster and less manpower is required.

Data acquisition: The sounding locations are shown in Fig. 2. Eight Schlumberger soundings were acquired in the study area with a maximum current electrode separation (AB) of 600 m.The instrument used was the ABEM 300B terrameter, a digital averaging instrument for direct current resistivity work.

Actual data acquisition begins with the selection of a sounding point. Once the sounding location was determined, the terrameter was deployed to the position. The spatial location (latitude and longitude) and elevation of the chosen station was read from a GPS and written in a field notebook.

The measuring tapes were used tomark out the current and potential electrode spacings while the electrodes are coupled into the ground with the hammer. In very hard grounds, where coupling is very difficult, water mixed with common salt is poured in such grounds to enhance coupling and conductivity.

Transmitters send out well defined and regulated signal current. Receivers discriminates noise and measures voltage correlated with transmitted signal current (resistivity surveying mode) and also measures uncorrelated D.C potentials with the source discrimination and noise rejection. The micro processor and monitor, controls operations and calculates result.

Data processing: After the field survey, the measured field Resistance (R) in ohms was converted to apparent resistivity (ρa) in ohm-meters using the formula:

$$\rho a = \top\top L^2/2L\ (\Delta V/I)$$

Where:

L	=	AB/2 (m)
I	=	MN/2 (m)
$\Delta V/I$	=	Resistance in (Ω)
$\top\top L^2/2I$	=	Geometric factor (K)
AB	=	Current electrode spacing (m)
MN	=	Potential electrode spacing (m)

The sounding curve for each point was obtained by plotting the apparent resistivity on the ordinate against half electrode spacing on a bilogarithmic transparent paper. Parameters such as apparent resistivity and thickness obtained from both partial curve matching and the method of asymptotes were used as input data for computer iterative modelling (Zohdy, 1976; Koefoed, 1979). The Vertical Electrical Sounding (VES) were processed using RESIST, a computer iteration resistivity software and the layers. Detailed quantitative interpretation was done with the RESIST Software.

RESULTS AND DISCUSSON

Analysis of VES curves: The form of curves obtained by sounding over a horizontally stratified medium is a function of the resistivities and thicknesses of the layers as well as the electrode configuration (Zohdy, 1976). The geo-electric sections were described in terms of the relationship between the resistivity of the layers and the letters Q, A, K and H are used in combination, to indicate the variation of resistivity with depth. The resistivity type curve associated with the study area from VES 1-8 include: AK, KH, HA, QH, QH, QH, HK and QH type curves, respectively (Table 1). The most prominent type curve is H making up the type curve combinations for the eight different sounding curves of the study area. The H type curve is a true representative of what is obtainable in Oduma because hard shale behaves as basement rocks storing water in fractures. In addition, H type curves indicate fractured shale layers sandwiched between more resistive non-fractured shales. These fractures are usually targets for water exploration in low permeability formations.

Generation of geo-electric sections: A geo-electric layer is described by two fundamental parameters: its resistivity (ρ_i), its thickness (h_i) where the subscript I indicates the position of the layer in the section. The geo-electric sections for the eight vertical electrical sounding are shown in Fig. 3-5:

Variation of aquifer thickness and depth to water table: The thickness of the aquifer (Fig. 6) in the area was found to vary between 12.0 and 118.9 m while the depth to water table ranges from 7-33 m (Fig. 7).

The resistivity and thickness of aquifer media are directly related to transmissivity and hydraulic conductivity of the aquifer. Therefore, integration of these two data can give the groundwater potential of an area (Table 2).

Aquifer parameters within the study area: The relationships established by Niwas and Singhal (1981a) between the aquifer hydraulic parameters and the electrical resistivity sounding data was used in computing aquifer hydraulic parameters in this study (Fig. 2) and it is shown:

$$S = H/\rho$$

$$R = H\rho$$

Where H and ρ are the thickness and resistivity of the layers. The parameters R and S are commonly called the Dar Zarrouk parameters. It has been shown (Niwas and Singhal, 1981b) that in areas of similar geologic setting and water quality, the product $K\sigma$ (hydraulic conductivity) remains fairly constant.

Thus knowing K values for existing boreholes and σ values extracted from the sounding interpretation for the aquifer at borehole locations, it has been possible to determine transmissivity and its variation from place to place including those areas where no boreholes are available. The earlier assertion was made possible by using the relation:

Table 1: Model theoretical resistivity type curves and the geoelectrical parameters from the study area

VES no.	Type curve	Model geoelectrical parameters deph m)//resistivity(Om)
1	AK	101/5.5/13.7/32.7/151.6/220.7//18.0177.5/278.3/247.0/3820.4/1412.8/872.4
2	KH	1.6/4.4/11.9/54.9/107.9//97.1/707.9/79.4/3901.4/795.3/164.3
3	HA	1.1/5.7/10.6/18.4/41.1/160.5//201.8/35.5/132.2/426.0/1621.6/3418.51325.2
4	QK	2.7/20.0/40.0/67.0/130.8//80.0/48.0/29.0/263.0/185.0/735.0/806.0
5	QH	2.7/20.0/53.0/133.0/267.0//305.0/84.0/42.0/185.0/735.0/800.0
6	QH	1.0/1.9/4.2/6.7/18.6/43.8//1181.8/347.3/120.3/313.4/23.7/578.0/2380.7
7	HK	1.5/4.0/12.0/67.0/133.0//700.0/413.0/44.0/38.0/52.0/70.0
8	QH	2.9/7.6/53.6/144.9/323.7//3840.6/1000.0/46.0/74.8/23.2/12.2

Kσ = constant (Niwas and Singhal, 1981a, b)

$$K = \frac{a - \text{value}}{\sigma}$$

$$T = Kb$$

Where:

b = Aquifer thickness designated by σR

K = Hydraulic conductivity

Geo-electric log-lithologic log correlation: Resistivity measurements separate the sub-surface into different layers based on their resistivity values. Litho-log data was obtained from borehole data from the study area. These litho-logs were compared with the geo-electric sections for areas close to borehole points. The correlation was based on the fact that a lithologic log differs from a geo-electric log when the boundaries of a litho-log do not coincide with the boundaries of different resistivity.

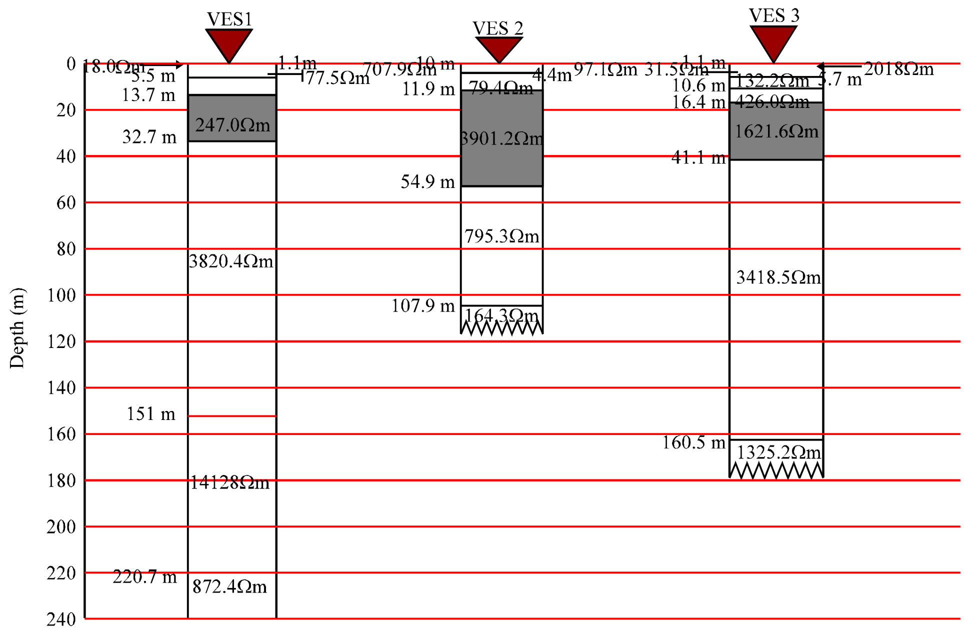

Fig. 3: Geo-electric sections generated from VES 1, 2 and 3

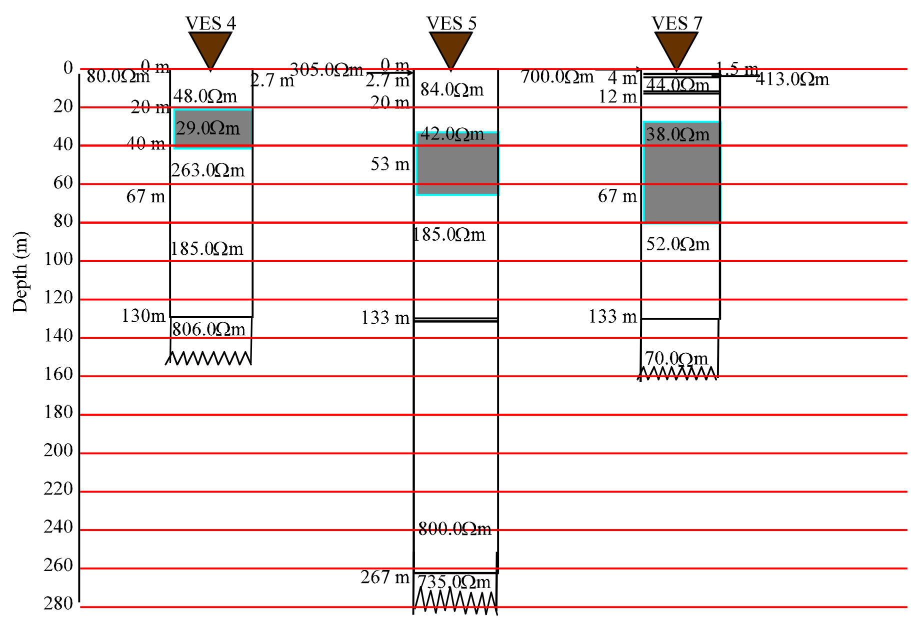

Fig. 4: Geo-electric sections generated from VES 4, 5 and 7

Table 2: Aquifer parameters of the sounding locations

Bulk resist. (ohm.m) ρh	Aqufer resist. (ohm.m) ρa	Aquifer thick (m)	Trans. resist-R_t	Long cond-S	Cond-σ	km day^{-1}	k*σ	Aver. value	km day^{-1}	tm^2 day^{-1}
6579.400	3820.4	118.9	45245.60	0.031122	0.000262	-	-	-	1.47090	174.89
5745.239	3901.2	43.0	167751.60	0.011022	0.000256	0.88128	0.000226	0.00040	1.50190	64.58
7156.500	1621.6	22.7	36810.32	0.013999	0.000617	0.88128	0.005430	0.00040	0.62530	14.17
1411.000	29.0	20.0	580.00	0.689655	0.034483	-	-	-	5.50910	110.18
2151.000	42.0	33.0	1386.00	0.785714	0.023810	2.01312	0.047932	0.08490	2.59980	85.79
4945.200	23.7	12.0	284.40	0.506329	0.042194	2.01312	0.084842	0.08490	1.46703	17.60
1317.000	38.0	55.0	2090.00	1.447368	0.026316	2.01312	0.052977	0.03300	2.35220	129.37
4996.200	46.0	45.9	2111.40	1.997826	0.021739	0.88128	0.191581	0.88128	0.88320	40.54

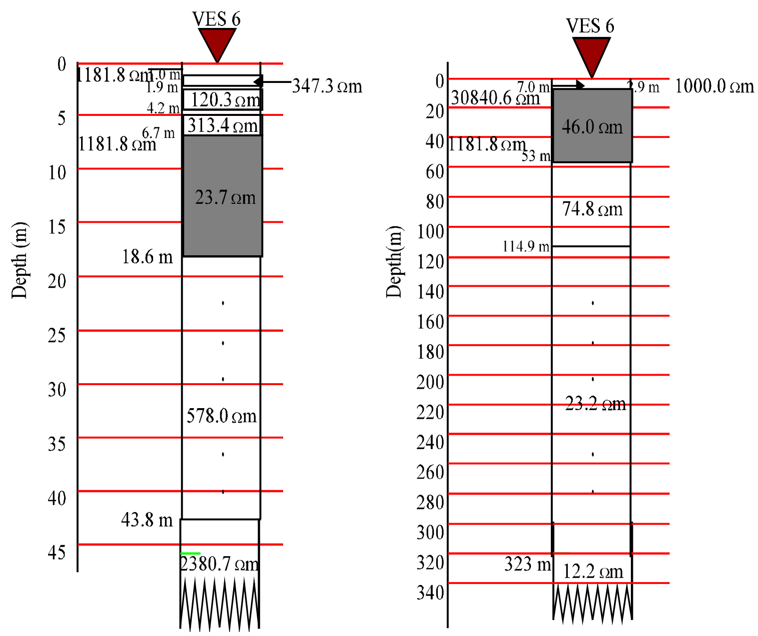

Fig. 5: Geo-electric sections generated from VES 6 and 8

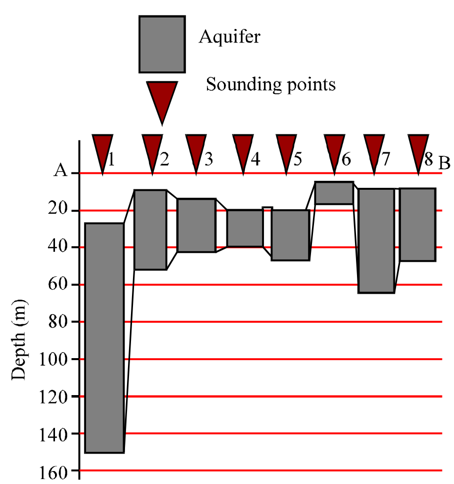

Fig. 6: Cross-section along AB showing aquifer thickness and depth across the study area

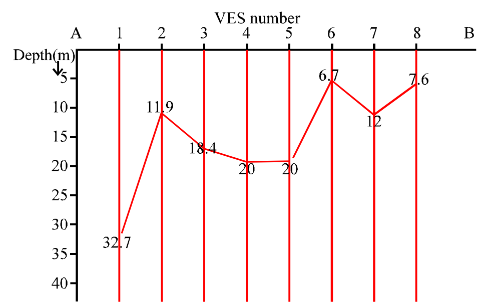

Fig. 7: Interpretative Cross – Sections AB showing water table

Figure 8 and 9 shows the correlation and subsequent interpretation of geoelectric logs and lithology logs at Ohofia and Amankanu in the study area. Figure 9 shows that the first geo-electric layer has an apparent resistivity value of 201.8 Ωm and corresponds to the first and second litho-layers that consist of top soil and laterite. The second and third geo-electric layers with apparent resistivity values of 31.5 and 132.2 Ωm, respectively corresponds to the third litho-layer (clay). The fourth geo-electric layer with apparent resistivity

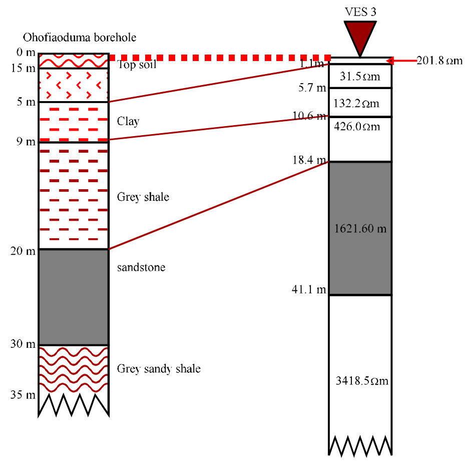

Fig. 8: Comparism of drill hole log of Ohofia Oduma borehole and the computer interpretation of VES 3

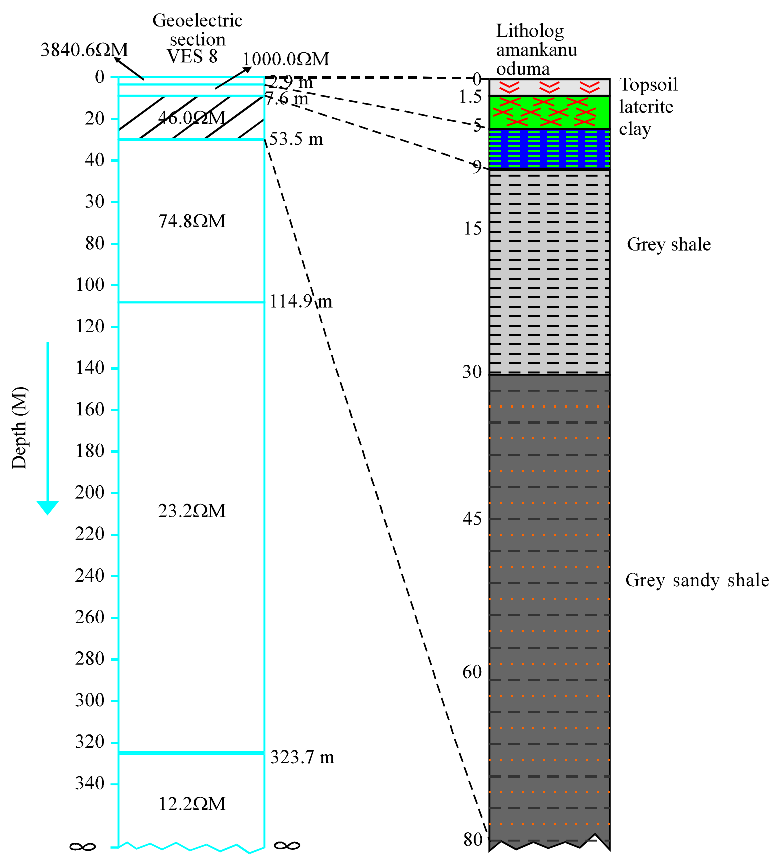

Fig. 9: Comparism of drill hole log of Amankanu Oduma borehole and the computer interpretation of VES 8

value of 426.0 Ωm corresponds to the fourth litho-layer (grey shale). The fifth geo-electric layer with a resistivity of 1621.6 Ωm corresponds to the fifth and sixth litho-layers which are sandstone and grey sandy shale, respectively. The fifth layers both in the geo-electric section and litho-log is the aquiferous layer as shown by the high resistivity value andthe lithology. No further correlation was done on this log section because of the limited depth of the litho-section.

In Fig. 10, the first geoelectric layer with apparent resistivity of 3840.6 Ωm is entirely laterite overlain with a thin layer of top soil. The second layer is clay. This layer is underlain by an aquiferous layer of grey shale and grey sandy shale with apparent resistivity value of 46.0 m.

CONCLUSION

The use of surface geo-electric measurements provides a less expensive method to study groundwater conditions of an area. It is a good alternative for well drilling to enhance hydraulic parameters calculation. The results show a close resemblance to values obtained from pumping test. Computer modelled interpretation technique (which aided in the generation of geo-electric sections) revealed the thicknesses of aquiferous layers throughout the study area and also depths at which they are encountered. These areas are underlain by Eze-Aku Shale and Agbani Sandstone. Results from geosounding interpretation show that transmissivity ranges between 14.17 m^2 day^{-1} at Obuofia Ohofia and 174.89 m^2 day^{-1} at CSS Ohafia Oduma. Hydraulic conductivity ranges between 0.6243 m day^{-1} at Obufia Ohofia and 5.5091 m day^{-1} at Obodo Uhuanwuta. The depth to water table ranges between 6.7 m at Umuichite Obeagu to 32.7 m at CSS Ohofia while aquifer thickness ranges between 12.0 m at Umuichite Obeagu and 118.9 m at CSS Ohofia Oduma. The closeness of hydraulic conductivity values obtained from pumping test and those calculated from sounding interpretations is a good indication of the reliability of this study. Calculated transmissivity values indicate that majority of the aquifers in Oduma are of low yield which is as a result of the dominance of shales. The calculated hydraulic parameters of the aquiferous units are very useful for further studies of the groundwater regime in the area. It is however recommended that a more sophisticated electrical sounding equipment like SAS 4000 (Lund imaging system) should be used to get a better image of the fractures within the shales. This would help to map areas with high density of fractures, these are suitable areas for borehole drilling and development.

ACKNOWLEDGEMENTS

The researchers are grateful to Messers Ejike Ugboaja and Oliver Agbo of the Geology Department, University of Nigeria, Nsukka for their invaluable assistance during data acquisition.

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