Determination of Ground Water Resources in Elekuro and Environs, Abeokuta: Using the Geoelectric Method (Vertical Electrical Sounding)

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Abstract

Geophysical investigation of Elekuro and environs, Abeokuta, South western Nigeria was undertaken to explore the potential for further ground water development, considering the depth, thickness, resistivity and layer at which water can be obtained. The geo-electrical method used in the survey is Vertical Electrical Sounding. Six Vertical Electrical Soundings (VES) were conducted using the Schlumberger configuration covering the entire area. The VES data were subjected to an iteration software (WIN RESIST) which showed that the area is composed of top soil, weathered layer, fractured layer and basement. The result of a quantitative interpretation of the VES data obtained in a geophysical survey are represented by a geoelectric section which shows the sequence and relationship between the subsurface lithologies. The weathered layer and the fractured zone have been identified as the aquiferous in the area. The weathered layer is thicker in VES 1 and thinnest in VES 2, while the fracture basement is thickest in VES 1. Based on low resistivity values, overburden thickness and Reflection coefficient, VES1 has the highest and brightest potential for future groundwater exploration and development in addition to the existing ones.The study area falls within the basement complex of Southwestern Nigeria. The rocks are Precambrian in age as they lie between the pan African orogenic belts.

INTRODUCTION

Vertical electrical soundings, when combined with other geophysical methods, geologic mapping and available well data can greatly assist in the location and completion of water wells in bedrock areas of complex hydrogeology. The vertical electrical sounding (VES) method is usually considered more suitable for the subsurface investigation of geologic environments consisting of horizontal or nearly horizontal layers, such as occur in unconsolidated sedimentary sequences. Abrupt lateral changes in lithology and electrical properties brought about by steeply dipping beds, fracture and fault zones, or highly variable thicknesses of weathered bedrock materials can make interpretation of VES admittedly very difficult in this type of geologic setting.

However, with appropriate field techniques in completing the soundings combined with the application of appropriate geoelectrical and geological models, VES results can focus test drilling at locations and to target depths which will result in successful water wells, even at sites where "dry" or marginal wells were previously drilled. The case history presented herein illustrates one typical successful application.

In Nigeria, Crystalline rocks cover about fifty percent (50%) of the total rock exposure and about seventy percent (70%) of these crystalline rocks belongs to the basement complex (Oyawoye, 1964). The basement complex rocks of Nigeria are well represented on the south western part of the country. Elekuro and it environs a town in Abeokuta area south western Nigeria; it is underlain by some of the crystalline rocks described by Oyawoye (1964). These rocks belong to the youngest of the three major province of the West African craton; these rocks were rejuvenated during the pan African thermo-tectonic orogeny about 600ma Dada, (1993). Some of the outcrops are quite resistant to weathering while few of them show differential origin on surface. The various rocks units represented in the study area correspond to the generalized list of the basement complex rocks of Nigeria. The occurrence of the ground water in these areas is depended in the degree of fracturing and/or weathering of the basement complex rocks also the chemistry (quality) of the ground water is intimately to the geology and anthropogenic factors.

In this paper geophysical investigation was undertaken to explore the potential for further ground water development around Elekuro and environs, Abeokuta, South western Nigeria. Electrical resistivity vertical sounding is utilized. Field mapping was done and subsequent production and the geological map of the area was gotten. This exercise was done and directed towards carrying out geophysical investigation of groundwater in the study area. It is also aimed to identify different rock type and determine the mineral composition of the rocks, delineating the several geologic units beneath the surface of the area, ascertaining their hydro-geologic significance, determine the suitability of drilling a productive borehole at the points investigated and make appropriate recommendation to ensure the success of the borehole.

The vertical electrical sounding method was selected for this study because of its capability to distinguish between saturated and unsaturated layers, it has a greater penetration than the Wenner. In the resistivity method the Wenner discriminate resistivity of different geoelectric lateral layers while schlumberger configuration is used for depth sounding (Olowofela et al. 2005)

Geological setting of the study area. The study is located between longitude 3^0 18’-3^0 21’ and latitude $7^0$07’-$7^0$09’. It is a portion of south/Eastern part of Abeokuta South/Western Nigeria**.** The area fall within the basement complex. It covers a total of 21km^2 area. The study area include Aro, Apena, sogeke and Molekero as shown in Figure 1. The topography of the study area is generally undulating ranging from high to low relief. The drainage pattern exhibit by the stream and rivers can be described as being dendritic, which is the main river that divides the study area into half but most of the streams were dried up because of the dry season which made the area easily accessible.

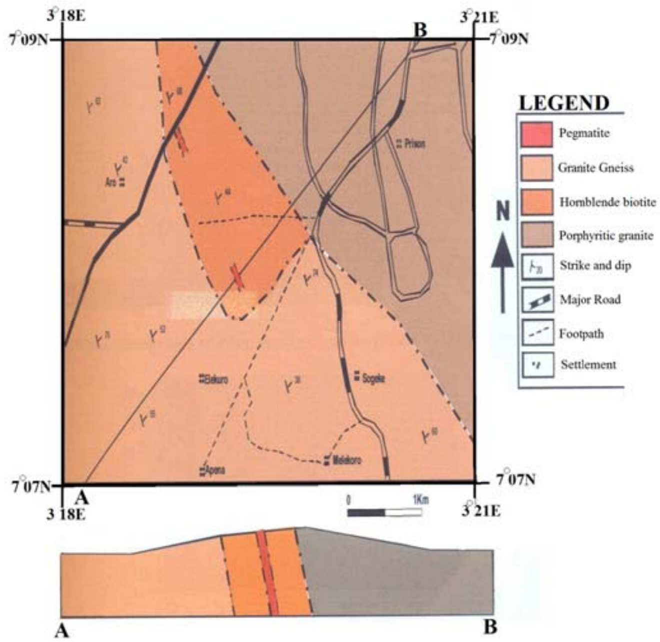

Figure 1. Geologic map showing the study area.

METHODOLOGY

Survey method and electrode configuration. Vertical Electrical Sounding was carried out using the Syscal R2 unit terrameter for the survey. The Schlumberger electrode configuration was selected for this study due to its logistic man power, ability to distinguish between saturated and unsaturated layers and its characteristic deep penetration into the subsurface.

The Schlumberger array is characterized with a more complex configuration with the spacing between the current electrodes not equal to the spacing between the potential electrodes. The schlumberger array requires that four steel electrodes are arranged and pinned collinearly into the earth with the current electrode spacing much greater than the potential electrode and ensuring that AB/2≥5MN/2, where "AB" is current electrodes separation and "MN" is the potential electrode separation (Figure 2).

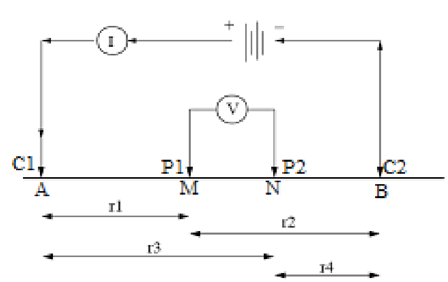

Figure 2. Schlumberger configuration ($AB/2 \geq 5MN/2$).

Procedure. Six points were investigated in the area as shown in Figure 3. These points were selected based on the grids on the map for Vertical Electrical Sounding (VES) using the Schlumberger Array.

The Schlumberger array was used for the VES operation. This array is capable of isolating successive hydrogeologic layers beneath the surface using their resistivity contrast. The method has been recognized to be more suitable for hydro geological survey of sedimentary basin (Kelly and Stanislav 1993).

A maximum of 100 m was attained for the current electrode spacing ($AB/2$) at the two locations. In VES, with schlumberger, the potential electrodes are moved only occasionally, and current electrode are systematically moved outwards in steps $AB \geq 5MN$. The field data obtained are resistance values for the points investigated; the apparent resistivity was calculated for all the sample points using their corresponding geometric factors.

The values obtained were then plotted on a log-log paper as points with the resistivity values being on the vertical axis and the electrode spacing ($AB/2$) on the horizontal axis. The points were joined and curve matched manually using pre-calculated master curves and their auxiliaries. The results obtained from the exercise were used as the input-model for the eventual computer aided iteration (Vanda Velpen, 1988) WINRESIST program.

RESULTS AND DISCUSSIONS

The locations of the soundings are shown on Figure 3, the sounding curves and interpreted geoelectric models are shown in Figure 4a-4f and 6 respectively. The soundings were made using a Syscal R2 unit Schlumberger Array. Current electrode spacing (AB/2) varied from 1-100m

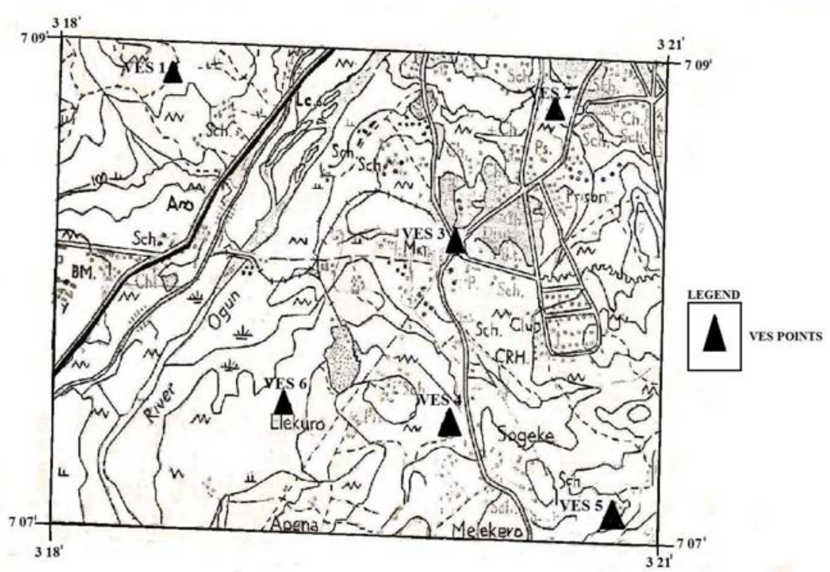

Figure 3. Showing the VES points and Water samples location.

Results and interpretation. The field data obtained from the surveyed locations is presented in Table 1, The interpretation of the sounding curves were done both qualitatively and quantitatively. The qualitative interpretation entails the observation of the sounding curves as plotted on the bi-logarithm graph paper.

Data interpretation. An iteration software (WIN RESIST) is used to iterate curves of VES 1-6 and it is represented in Figure 4a-4f. The smooth curves taken through the set of data points were interpreted quantitatively by the method of partial curve matching. Layer resistivity and thickness were gotten from Figure 4a-4f.

Table 1. Resistivity values with their corresponding electrode spacing.

SN	AB/2(m)	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6
1	1	354.8	100	526.3	170.6	120.8	121.8
2	2	126.8	182	392.4	162.9	97.1	60
3	3	74	212.2	340	173.6	78.9	46.4
4	4	50.2	206.4	300	180.4	80.6	46.4
5	5	45	166.7	200	158.6	100	48
6	6	62.2	135	130	135.5	124.9	61.8
7	12	100	95	120	117	143.3	75
15	15	115.1	78.8	120	100	150.5	90
8	20	130	78.6	140	101	141.1	118.7
9	25	135	85	160	120	144.1	144.7
10	32	139.6	100.7	190	86.7	136	170
11	40	160	136.6	240	248	130	230
12	65	195.6	158.6	253.7	298.9	120.7	286.5
13	80	210	210	290	374.1	119.5	356.1
14	100	309	250	335.3	467	125	423.9

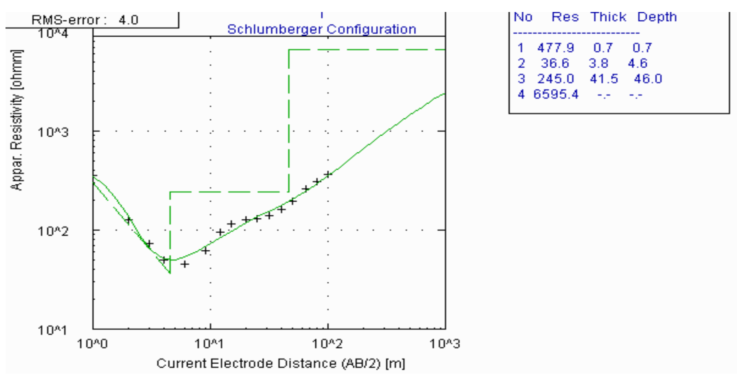

Figure 4a. Field sounding curve for point VES 1 in Elekuro and environs.

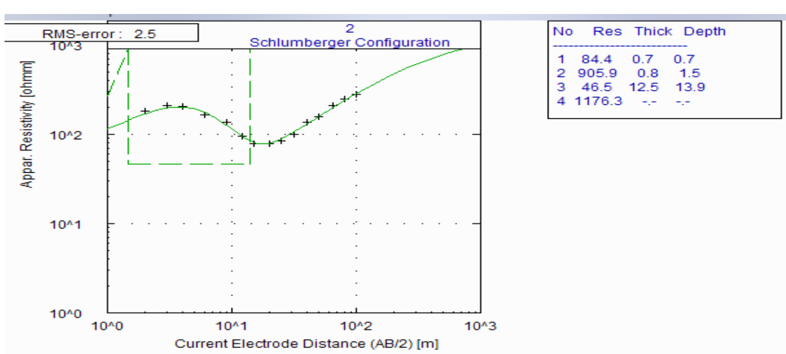

Figure 4b. Field sounding curve for VES 2 in Elekuro and environs.

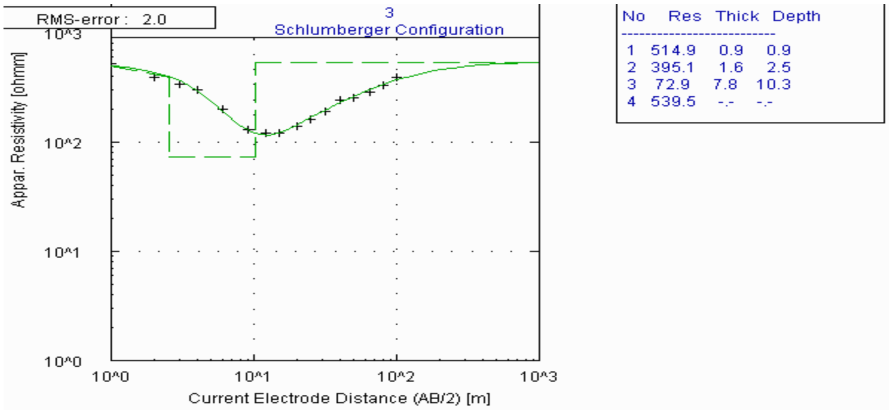

Figure 4c. Field sounding curve for point VES 3 in Elekuro and environs.

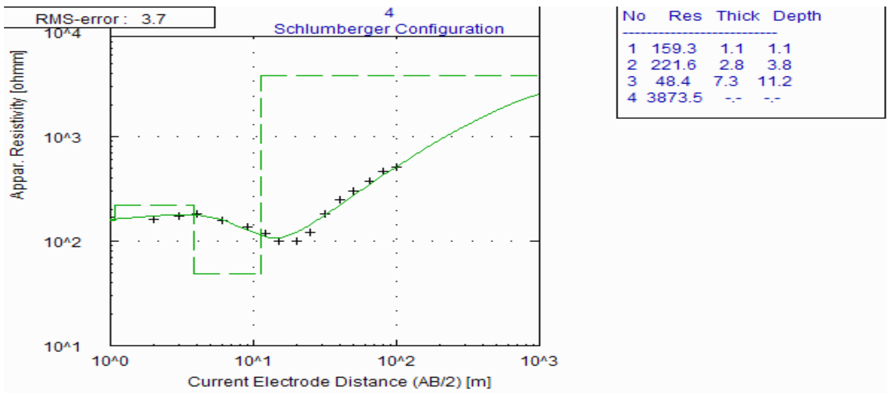

Figure 4d. Field sounding curve for point VES 4 in Elekuro and environs.

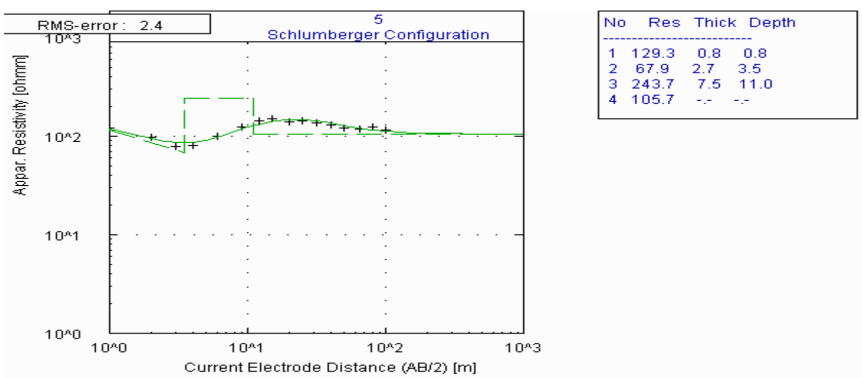

Figure 4e. Field sounding curve for point VES 5 in Elekuro and environs.

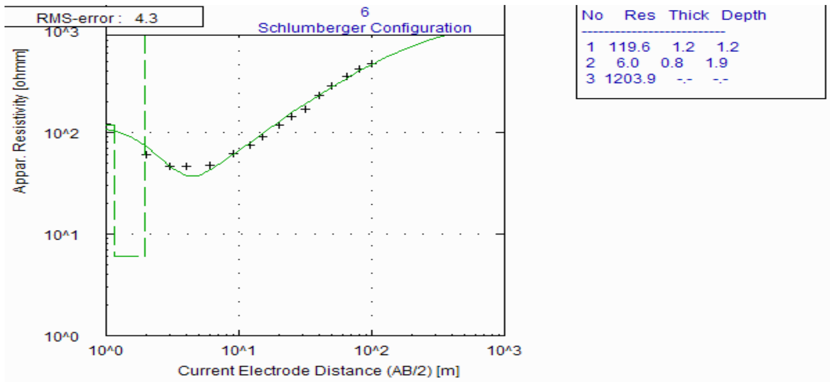

Figure 4f. Field sounding curve for point VES 6 in Elekuro and environs.

Table 2. Result of vertical electrical sounding showing the layers, thickness, depth, resistivity and inferred lithology.

VES	Layer	Resistivity Ωm	Thickness (m)	Depth (m)	Inferred Lithology
1	1	477.9	0.7	0.7	Top soil
	2	36.6	3.8	4.6	Weathered layer
	3	245.0	41	46.0	Fractured layer
	4	6595.4	-.-	-.-	Fresh basement
2	1	84.4	0.7	0.7	Top soil
	2	905.9	0.8	1.5	Weathered layer
	3	46.5	12.5	13.9	Fractured layer
	4	1176.3	-.-		Fresh basement
3	1	514.9	0.9	0.9	Top soil
	2	395.1	1.6	2.5	Weathered layer
	3	72.9	7.8	10.3	Fractured layer
	4	539.5	-.-	-.-	Fresh basement
4	1	159.3	1.1	1.1	Top soil
	2	221.6	2.8	3.8	Weathered layer
	3	48.4	7.3	11.2	Fractured layer
	4	3873.5	-.-	-.-	Basement
5	1	129.3	0.8	0.8	Top soil
	2	67.9	2.7	3.5	Weathered layer
	3	243.7	7.5	11	Fractured layer
	4	105.7	-.-	-.-	Fresh basement
6	1	119.6	1.2	1.2	Top soil
	2	6.0	0.8	1.9	Weathered layer
	3	1203.9	-.-	-.-	Fresh basement

Reflection co-efficient. The reflection coefficients (r) of the study area were calculated using the method of Olayinka (1996), Bhattacharya and Patra, (1968) and Loke, (1999). Increase in the Reflection co-efficient and overburden thickness enhances the productivity of boreholes in some parts of the basement complex of southwestern Nigeria (Olorunfemi and Oloruniwo, 1985). Reflection co-efficient can be calculated using equation 1.The reflection coefficient, curve type and characteristics and their respective number of layers are shown in Table 3.

$$\text{Reflection Coefficient (r)} = \frac{R_n - R_{n-1}}{R_n + R_{n-1}} \quad (1)$$

where R is the resistivity value and "n" is the amount of layers. Based on low resistivity values, overburden thickness and Reflection coefficient, VES1 has the highest and brightest potential for future groundwater exploration and development in addition to the existing ones.

Table 3. A table showing the co-ordinates and reflection co-efficient with their corresponding curve types.

Reflection Coefficient	Name/Location	Curve Type	Curve Characteristics	No of layer
0.93	VES 1	H	$\rho_1>\rho_2<\rho_3$	3
0.92	VES 2	KH	$\rho_1<\rho_2>\rho_3>\rho_4$	4
0.76	VES 3	H	$\rho_1>\rho_2<\rho_3$	3
0.97	VES 4	KH	$\rho_1<\rho_2>\rho_3>\rho_4$	4
-0.39	VES 5	HA	$\rho_1>\rho_2<\rho_3<\rho_4$	4
0.99	VES 6	H	$\rho_1>\rho_2<\rho_3$	3

The interpretation of field resistivity data are in terms of resistivities and depth to the bedrock and interfaces across which a strong electrical exists. The analysis and interpretation of the surveyed data shows 3-4 geoelectric layers as shown in Table 2. These layers are lateritic top soil which consists of the various rock types from clayey sand to sandy clay to compact sand. The second is the fresh/highly resistive basement. The fresh basement is characterized by high and infinite resistivity value and could not be contended on for groundwater, but the weathered zone and fractured basement which have lower resistivity value constitute good water zone.

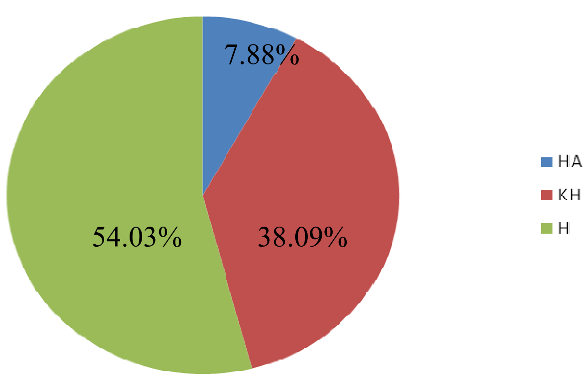

Figure 5. Pie Chart Presentation of Resistivity Curve Types.

The pie chart shown in Figure 5 is a statistical representation of the resistivity curves. The H type is dominant accounting for about 54.03%, with KH and HA type having 38.09% and 7.88% respectively, The H curve has an intermediate layer of low resistivity value that is recognized as the aquifer unit at these VES 1,3 and 6 location. The first layer is the topsoil, followed by a sandy formation and the weathered layer in that order. The weathered layer in these sequences is very favorable for underground water abstraction.

The KH type curve is a four layer model of the subsurface and was obtained at VES 2 and 4. The HA curves in VES 5 is typified a typical basement complex environment which contains a low resistivity layer underlined and overlain by a more resistive materials. (Olayinka and Mbachi, 1992).

Geoelectric Section. The VES results of the data delineates 3-4 layers (H, HA, and KH) types of curve with the H type of curve predominating. The geo-electric section of the study area was produced, revealing 3 main geo-electrical layers; the top soil, the weathered layer (made up of clayey, sandy clay and clayey sand) units and the infinite basement rock as illustrated in Figure 6.

The quantitative interpretation of the VES data resulted in the production of numbers of geoelectric section. The section provides composite information along lithologic depth, the geoelectric section revealed four subsurface geoelectric layers. The top layer which consists of (clayey sand and sandy clay) has resistivity value ranging from 84 ohm-m to 514.9 ohm-m, the maximum layer thickness is 1.1m..

The resistivity of the second layer (Weathered zone) ranges from 6 ohm-m to 905.9 ohm-m while the thickness varies between 0.7m to 12.5m. The third layer is the fractured basement which has layer thickness varying from 7.3m-41.5m with resistivity value ranging between 46.5 ohms-m to 1203.9 ohms-m, The layer will be good for groundwater accommodation if the fractures are interconnected and permeable. The fresh basement which is the fourth layer is characterized by high resistivity value up to 6595 ohm-m. The fresh basement is made up of infinitely resistivity rock in all the stations which form the bedrock.

Overburden Layer. The thickness of the overburden is an important hydrogeologic consideration in groundwater development in the basement terrain (Ajayi & Hassan 1990, Olorunfemi & Idonigie, 1992). Because water gets into the saturated zone through the overburden, the thickness of the overburden ranges from 1.5m to 4.6m in the study area (Figure 6).

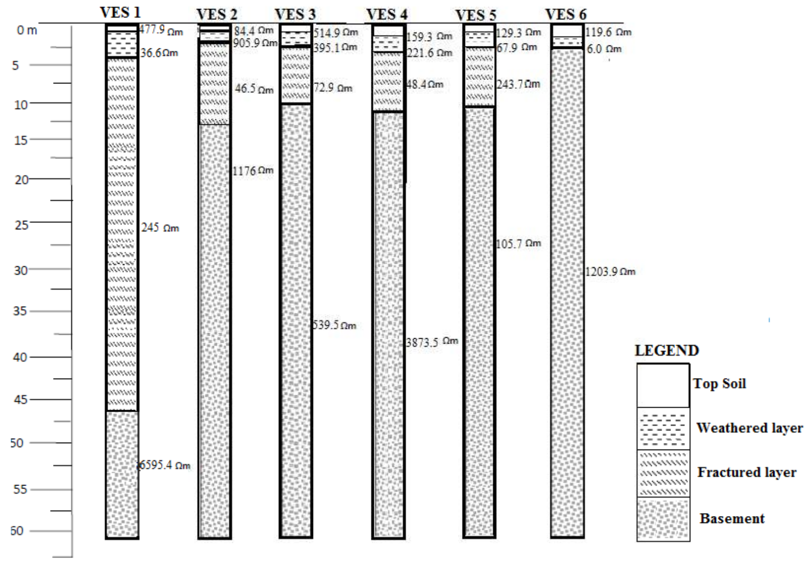

Figure 6. Geo-electric section of profile 2.

The geo-electric section also helped out in relating resistivity with geology by delineating the varying thickness (es) of each layer. It also aids comparison between the different layers from one point to the other in the study area

CONCLUSION

This geophysical investigation of groundwater project benefited from the application of hydrogeology and geophysical surveys, with particular emphasis on the role of VES to characterize favorable subsurface environments for groundwater production. In the complex bedrock geologic environment of the Elekuro and environs, the need for costly random drilling, resulting in dry holes or marginal production from wells can largely be eliminated by the judicious application of these kinds of geological and geophysical studies. The result of a quantitative interpretation of the VES data obtained in a geophysical survey over part of Abeokuta, on a location Elekuro and Environs South Western Nigeria are represented by a geoelectric section which shows the sequence and relationship between the subsurface lithologies. The weathered layer and the fractured zone have been identified as the aquiferous in the area. The weathered layer is thicker in VES 1 and thinnest in VES 2, while the fracture basement is thickest in VES 1. The H curve type is dominant, accounting for about 54.03%, with HA and H curve types having 38.09% and 7.88% respectively, The H curve has an intermediate layer of low resistivity value that is recognized as the aquifer unit at these VES 1 location. The first layer is the topsoil, followed by a weathered layer and The KH type curve is a four layer model of the subsurface and was obtained at VES 2 and 4. The HA curves in VES 5 is typified a typical basement complex environment which contains a low resistivity layer underlined and overlain by a more resistive materials. (Olayinka and Mbachi, 1992). The H curve has an intermediate layer of low resistivity value that is recognized as the aquifer unit at these VES 3 location. The first layer is the topsoil, followed by a weathered and the fractured layer in that order. The weathered layer in these sequences is very favorable for underground water abstraction. Based on low resistivity values, overburden thickness and Reflection coefficient, VES1 has the highest and brightest potential for future groundwater exploration and development in addition to the existing ones. In conclusion, the study area falls within the Basement Complex of Southwestern Nigeria. The rocks are Precambrian in age as they lie between the pan African orogenic belts.

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