Application of the Geoelectric Characterization of the Aquifer in Kwakuti, North Central Nigeria

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Abstracts
Vertical Electrical Sounding (VES), using Schlumberger array was carried out to investigate the subsurface layer parameters used to delineate groundwater potential of a 500 x 500 m area of land defined by latitude 9.416622 N to 9.421171 N and longitude 6.618314 E to 6.622833 E located at Government Secondary School, Kwakuti, Niger State. A total of 36 VES points at 100 m interval were sounded with a 100 m maximum half inter current electrode spacing (AB/2). Result revealed that the study area is underlain by three (3) geoelectric layers which include: the top soil with 104.5 to 2260.5 Ωm, 0.6 to 3.8 m and 0.6 to 3.8 m as its range of resistivity, depth and thicknesses respectively; the weathered/fractured layer having resistivity of 44.9 to 606.0 Ωm, depth of 4.3 to 28.6 m and thickness of 4.2 to 26.2 m was considered aquifer layer. The fresh basement has 919.4 to 3816.9 Ωm as its range of resistivity value with undefined depth and thickness. The observed curve types were 100% H. Five (5) VES stations C3, C4, D2, D5, and E4 were delineated as aquifer potentials of the study area, having weathered/fractured resistivity, depths and thickness range from 135.2 to 227.7 Ωm, 20.6 to 28.6 m and 17.8 to 26.2 m respectively.

Key words: Aquifer, Schlumberger, Kwakuti, Resistivity

Introduction

Water is considered to be a basic component of life as all living things rely heavily on it for their existence. It is highly needed for domestic, agricultural and industrial use and its sources are mainly the surface and groundwater source. Presently, the use and sustainability of water is getting more complex due to population growth, urbanization and industrialization.

Groundwater is a tremendous major economic resource, particularly in most cities of Nigeria where potable water is scarce (Nwankwo *et al*., 2013) and is basically required for prosperous development of any habitation. Many homes, industries and institutions pump their required quantities of water from the ground because it is commonly less polluted and more economical to use than surface water (Plummer *et al.,* 1999). Groundwater has a natural protection against pollution by the covering layers of the ground and it requires less treatment for direct consumption and other domestic activities.

Groundwater refers to the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formation. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. Groundwater is found almost everywhere but to get this resource in some areas is very difficult and complex (Ejepu *et al.,* 2014).

Groundwater is available in different proportions, in various rock types and at various depths on the surface layer of the earth. The depth at which fractures or soil pore spaces in rock becomes fully saturated with water is called the water table (Alhassan et al., 2017).

It is considered to be a less contaminable source of water which makes it suitable for drinking and agricultural purpose; though fairly dispersed all over the world, it cannot be found in good quantity everywhere, hence the need for a careful investigation/survey beforehand (Alhassan *et al*., 2015).

Various geophysical methods have been employed successfully for ground water exploration in different parts of the world over the years. Some of these methods include magnetic, electrical, electromagnetic, gravity, seismic, remote sensing etc. Of all these methods, the electrical resistivity method has been the most widely used geophysical tool for groundwater investigation because of its advantage which include simplicity in field technique and data handling procedure and it is the most effective (Anomohanran, 2013; Alhassan *et al*., 2017).

The Vertical Electrical Sounding (VES) is an electrical resistivity method that is widely used for depth sounding due to its simplicity and it is used to estimate the electrical resistivity variation of the earth subsurface vertically downward since the electrical resistivity of most rocks is dependent on the amount of water in the pore spaces within the rocks, the dissemination of these pores and the salinity of the water in the pore spaces reliability (Olawuyi and Abolarin, 2013).

The aim of this study was to apply the electrical resistivity to characterized the Aquifer potentials of the study area.

Geology of the Study Area

The study area is underlain by rocks of the Nigerian basement complex comprising Magmatite-gneiss complex, Younger metasediments, older and Younger granites. It has an elevation of 304 m above sea level. It is bounded by latitudes 9^{o}25′N and 9^{o}27′N and longitudes 6^{o} 37′E and 6^{o} 39′E. Generally, the area mapped forms part of the Minna- granitic formation that consists of Metasediment and metavolcanics. The Metasediment include quartzites, gneisses and the metavolcanics are mainly granites. Among the main rock groups are granites which occur at the central and northern parts of the area, while on the south and east, cobbles of quartzite are found especially along the channels and valley. However, the other bodies like pegmatites and quartz veins also occur within the major rock types (Figure 1). The rocks are mainly biotite –granites with medium to coarse grained, light colored rocks with some variation in biotite content. The mineral constituents are leucocratic to mesocratic. However, the biotite minerals are thread like and are arranged rough parallel streak, although some are disoriented in the groundmass. The feldspar minerals occur as fine to medium grained, though grains are cloudy as a result of alteration mostly along the twin planes, while the quartz minerals are constituents of the granitic rocks which show strong fracturing in the granitic rocks of the area (Ajibade, 1980). The Paiko area is underlain by four geologic sections, namely; latterite, quartz, sandy clay as the first layer, weathered basement as the second layer, fractured basement as the third layer and fresh basement as the forth layer. It is also observed that a number of rock types which suffered weathering, fracturing and decompositions are granites and quartzites (Dangana, 2007; Asry *et al*., 2012). Groundwater occurrence in a Precambrian basement terrain is hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent (Jeff, 2006; Abubakar and Auwal, 2012). The aquifers of the basement complex rocks are the regolith and the fractures in the fresh bed rock which are known to be interconnected at depth (Abubakar and Auwal, 2012).

The raining period runs from April to October with the highest amount of rainfall recorded in August while the average annual rainfall is between 1200 mm- 1300 mm (Niger State water and sanitation board, 2001). The mean annual temperature is between 22^0C to 25^0C. The period

between November and February are marked with the NE trade wind called the harmattan, which often causes very poor visibility during its period.

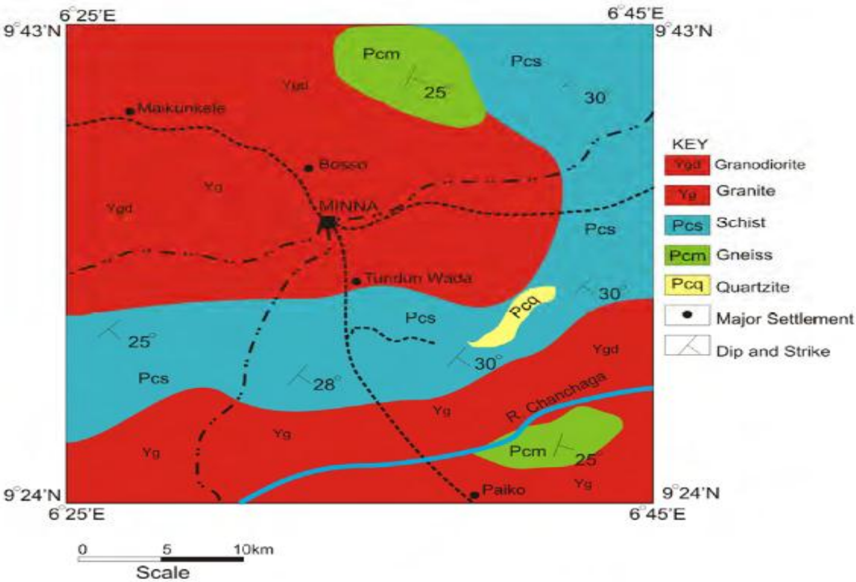

Figure 1: Geological Map of the Study Area Area (Alabi, 2011)

Methodology

Total of thirty six VES points were occupied in the study area, comprising of six traverses with 6 VES points each. The profile interval and inter VES point spacing were 100 meters respectively and the Schlumberger array pattern with half inter electrode spacing (AB/2) ranging from 1-100 meters was adopted. Through a pair of current electrodes A and B, direct current (DC) was injected into the ground and the potential difference was measured by means of another pair of electrodes M and N called the potential electrodes.

To increase the depth of investigation, the current electrode separation was increased while the potential separation remained constant. The sensitivity of the potential electrode measurement decreases as the current electrodes spacing increases, therefore, at some point, it was necessary to increase the potential electrode spacing.

The geometric factor, (K) was first calculated for all the electrode spacing using the formula:

$$K = \pi\left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right) \qquad (1)$$

Then the apparent resistivity (ρa) values were obtained by multiplying K with the resistance (R) values

$$\rho_a = KR \qquad (2)$$

Also, the apparent resistivity values obtained were plotted against AB/2 using winResist software and from the plots; the resistivity, depth and thickness of each subsurface layer were deduced.

Results and Discussion

Geoelectric Section

The Geoelectric section (VES curve) as shown in Figure 2a and 2b, provides information about the subsurface layer resistivity, depth and thickness that were interpreted from VES curves and then summarized in table 1.

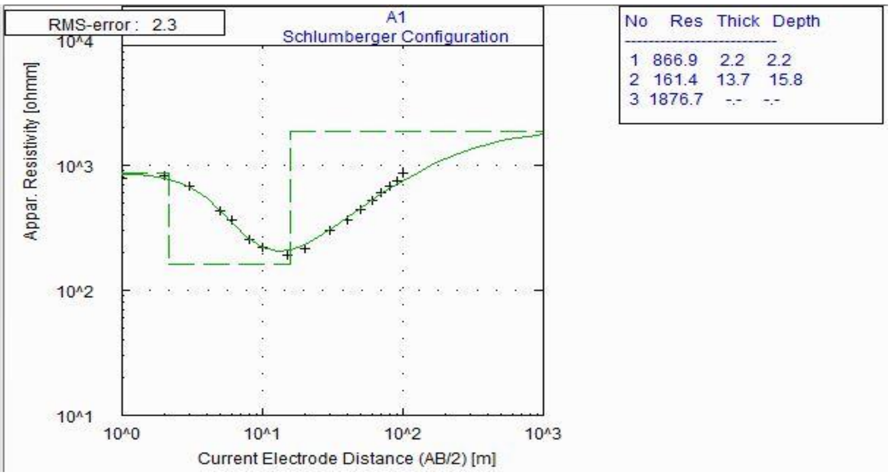

Figure 2a: Geoelectric section of VES point A_1

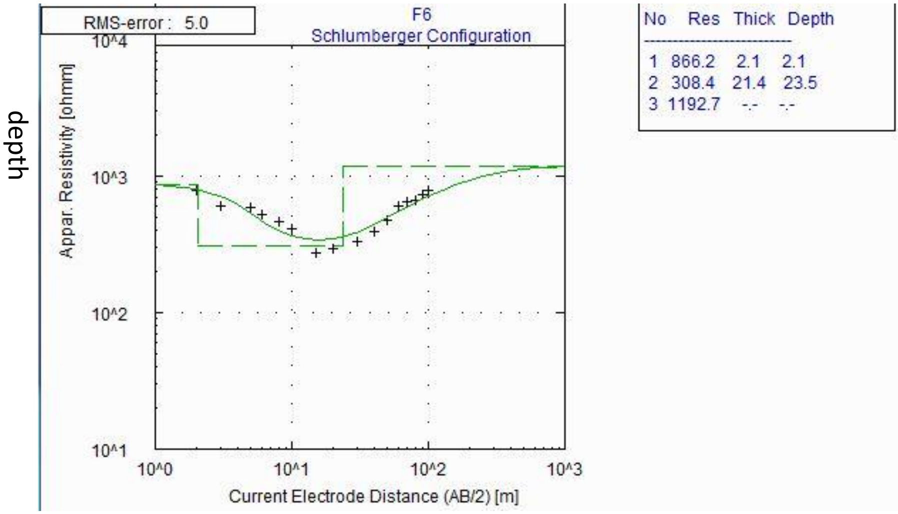

Figure 2b: Geoelectric section of VES point F_6

Table 1 shows the summary of interpreted VES curves generated from geoelectric sections across profile A to F which reveals that the study area is underlain by three (3) geoelectric subsurface layers. The first layer which is the top layer has resistivity value ranging from 104.5 – 2260.5 Ωm, its depth and thickness vary between 0.6 and 3.8 m and 0.6 and 3.8 m respectively which correspond to the geoelectrical parameters of loose soil and fresh laterite. The second layer has resistivity value of 44.9 – 606 Ωm, depth of 4.3 – 28.6 m and thickness of 3.4 – 26.2 m; this layer refers to the weathered/fractured basement. The resistivity of the third layer ranged from 919.4 – 3816.9 Ωm, its depth and thickness are undefined.

Table 1: Layer resistivity, depth, thickness and curv

VES Stations	Latitude (°)	Longitude (°)	No. of Layers	Layer Resistivity, *ρ* (Ωm)			Layer Depth, *d* (m)			Layer Thickness, *h* (m)			Curve Type
				ρ1	*ρ2*	*ρ3*	*d1*	*d2*	*d3*	*h1*	*h2*	*h3*	
A1	9.416622	6.618314	3	866.9	161.4	1876.7	2.2	15.8	∞	2.2	13.7	∞	H
A2	9.416628	6.619224	3	1081.8	239.7	2204.5	1.5	16.7	∞	1.5	15.3	∞	H
A3	9.416634	6.620134	3	1463.1	189.6	2030.3	1.9	16.7	∞	1.9	14.8	∞	H
A4	9.416640	6.621044	3	1003.7	155.5	2305.5	2.3	13.8	∞	2.3	11.5	∞	H
A5	9.416646	6.621954	3	1035.6	168.9	3528.0	1.6	12.2	∞	1.6	10.6	∞	H
A6	9.416652	6.622864	3	1073.4	281.3	3816.9	2.0	14.0	∞	2.0	12.1	∞	H
B1	9.417525	6.618308	3	1274.9	164.2	2093.7	2.3	17.2	∞	2.3	14.9	∞	H
B2	9.417531	6.619218	3	1340.7	179.2	2286.9	2.7	17.3	∞	2.7	14.6	∞	H
B3	9.417538	6.620128	3	774.2	174.4	3696.2	3.1	18.2	∞	3.1	15.2	∞	H
B4	9.417544	6.621038	3	651.0	189.4	2088.6	2.0	15.5	∞	2.0	13.5	∞	H
B5	9.417550	6.621948	3	848.8	252.5	2667.1	1.9	17.6	∞	1.9	15.7	∞	H
B6	9.417556	6.622858	3	450.6	254.6	2029.9	1.4	23.0	∞	1.4	21.6	∞	H
C1	9.418429	6.618302	3	1103.5	197.4	1906.2	2.7	21.7	∞	2.7	19.0	∞	H
C2	9.418435	6.619212	3	1114.1	186.2	3233.8	1.5	14.1	∞	1.5	12.6	∞	H
C3	9.418441	6.620122	3	1190.8	135.2	1991.3	2.2	23.0	∞	2.2	20.8	∞	H
C4	9.418447	6.621032	3	657.4	135.3	982.4	2.4	28.6	∞	2.4	26.2	∞	H
C5	9.418454	6.621942	3	104.5	44.9	3131.8	0.8	4.3	∞	0.8	3.4	∞	H
C6	9.418460	6.622852	3	1070.3	163.9	1834.9	0.6	4.8	∞	0.6	4.2	∞	H
D1	9.419333	6.618295	3	666.8	606.0	2746.8	1.0	7.2	∞	1.0	6.1	∞	H
D2	9.419339	6.619205	3	1019.7	159.7	1172.5	2.8	20.6	∞	2.8	17.8	∞	H
D3	9.419345	6.620115	3	1859.6	135.8	1252.2	1.8	18.7	∞	1.8	16.9	∞	H
D4	9.419351	6.621026	3	1443.1	200.2	1024.0	1.5	20.1	∞	1.5	18.5	∞	H
D5	9.419357	6.621936	3	1480.7	227.7	1468.5	1.6	25.7	∞	1.6	24.1	∞	H
D6	9.419363	6.622846	3	537.3	192.4	1452.3	2.1	20.5	∞	2.1	18.4	∞	H
E1	9.420236	6.618289	3	1656.5	85.9	946.1	1.5	24.0	∞	1.5	22.4	∞	H
E2	9.420242	6.619199	3	2260.5	102.8	919.4	1.5	16.7	∞	1.5	15.2	∞	H
E3	9.420249	6.620109	3	1076.3	136.5	1612.5	3.3	20.2	∞	3.3	16.9	∞	H
E4	9.420255	6.621019	3	889.3	186.6	1369.5	2.5	26.0	∞	2.5	23.5	∞	H
E5	9.420261	6.621929	3	834.2	230.7	1604.5	1.3	25.4	∞	1.3	24.1	∞	H
E6	9.420267	6.622840	3	532.4	231.4	1432.2	1.1	23.2	∞	1.1	22.1	∞	H
F1	9.421140	6.618283	3	1426.9	97.3	1299.4	1.4	9.4	∞	1.4	8.0	∞	H
F2	9.421146	6.619193	3	888.7	112.4	1457.2	3.8	19.9	∞	3.8	16.2	∞	H
F3	9.421152	6.620103	3	2203.2	130.2	1504.9	3.3	21.1	∞	3.3	17.8	∞	H
F4	9.421158	6.621013	3	1048.4	172.4	1492.5	3.3	21.2	∞	3.3	17.9	∞	H
F5	9.421165	6.621923	3	1455.5	193.4	1799.5	2.8	20.2	∞	2.8	17.4	∞	H
F6	9.421171	6.622833	3	866.2	308.4	1192.7	2.1	23.5	∞	2.1	21.4	∞	H

Geologic sections of the study area

Figure 3a - 3f reveals the vertical geologic section through profile A – F showing the layers of the subsurface structure, their depth and thickness.

Geologic Section of Profile A

The geologic section through profile A (Figure 3a) reveals that the profile is characterised by three layers. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 866.9 – 1463.1 Ωm, 1.5 – 2.3 m and 1.5 – 2.3 m respectively.

The second layer is a weathered/fractured layer, its resistivity, depth and thickness varies between 155.5 and 281.3 Ωm, 12.2 and 16.7 m and 10.6 and 15.3 m respectively; it spreads across the entire profile. The third layer underlies the second layer, it is the fractured/fresh basement, it has a resistivity range of 1876.7 – 3816.9 Ωm and undefined depth and thickness.

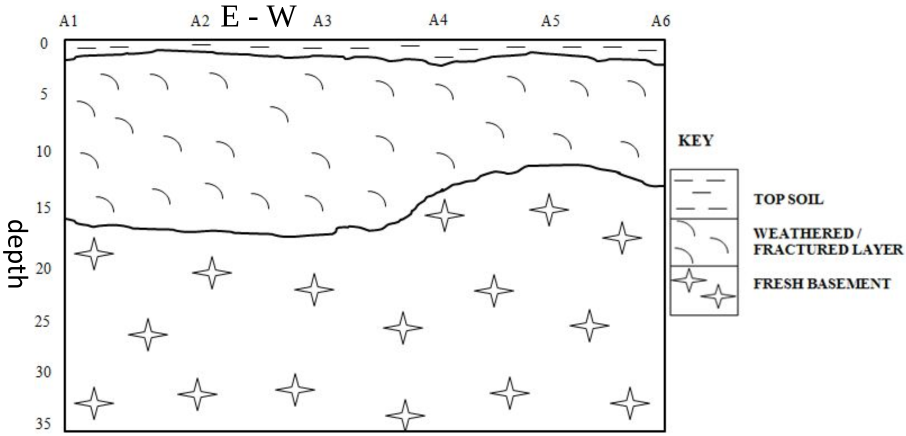

Figure 3a: Vertical geologic section through profile A

Geologic Section of Profile B

Figure 3b represents the geologic section through profile B, it reveals that the profile is characterised by three geoelectric layers.

The first layer which is the top soil spreads through the entire profile; its resistivity, depth and thickness range from 450.6 – 1340.7 Ωm, 1.4 – 3.1 m and 1.4 – 3.1 m respectively. The second layer refers to the weathered/fractured layer, its resistivity, depth and thickness varies between 164.2 – 254.6 Ωm, 15.5 – 23.0 m and 13.5 – 21.6 m respectively; it spreads across the entire profile. The second layer is underlain by the third layer which is the fresh basement, it has a resistivity value of 2029.9 – 3696.2 Ωm and undefined depth and thickness.

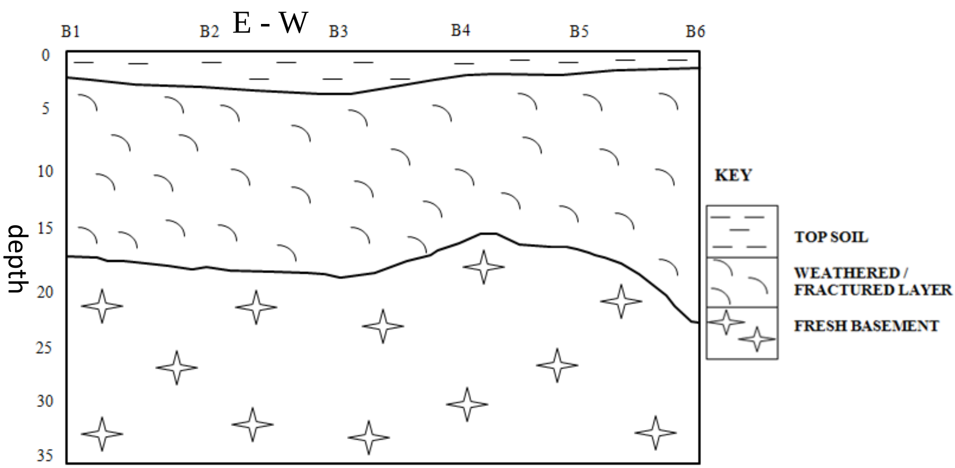

Figure 3b: Vertical geologic section through profile B

Geologic Section of Profile C

The geologic section through profile C (Figure 3c) reveals that three distinct layers exist therein. The first layer is the top soil spreading through the entire profile; its resistivity, depth and thickness ranges from 104.5 – 1190.8 Ωm, 0.6 – 2.7 m and 0.6 – 2.7 m respectively. The second layer is a weathered/fractured layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 44.9 – 197.4 Ωm, 4.3 – 28.6 m and 3.4 – 26.2 m respectively. The third layer which is the fresh basement underlies the second layer; it has a resistivity range of 982.4 – 3233.8 Ωm and undefined depth and thickness. There is a reservoir effect spreading from VES C_3 to C_4 which makes these points favourable for groundwater development.

Geologic Section of Profile D

Three geoelectric layers exist within profile D as clearly revealed by its geologic section (Figure 3d). The first layer which is the top soil spreads through the entire profile; its resistivity, depth and thickness range from 537.3 – 1859.6 Ωm, 1.0 – 2.8 m and 1.0 – 2.8 m respectively. The second layer which is the weathered/fractured layer has resistivity, depth and thickness of 135.8 – 606.0 Ωm, 7.2 – 25.7 m and 6.1– 24.1 m respectively; it spreads across the entire profile. The fresh basement which is the third layer underlies the second layer, it has a resistivity range of 1024.0 – 2746.8 Ωm with depth and thickness undefined. VES point D_2 and D_5 are good points for groundwater exploitation.

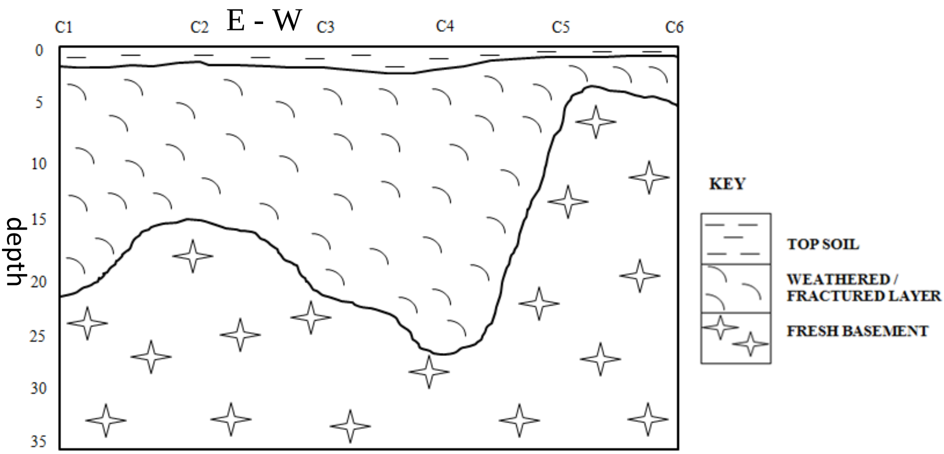

Figure 3c: Vertical geologic section through profile C

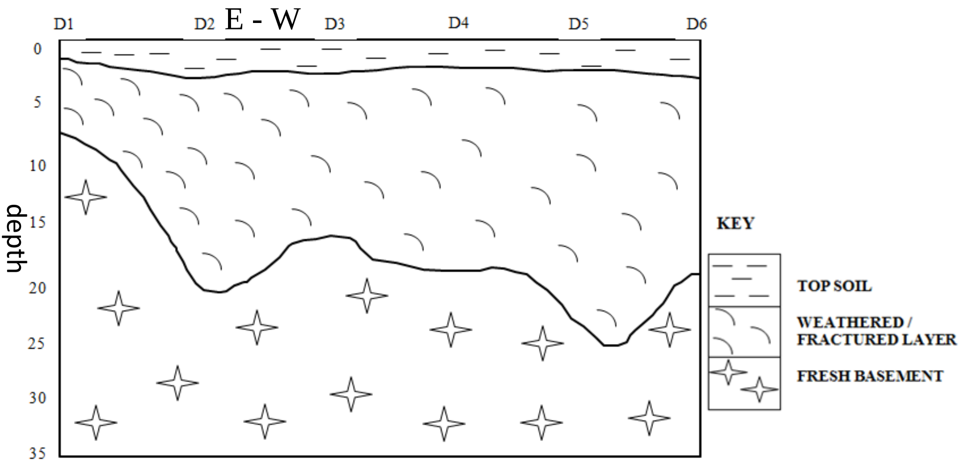

Figure 3d: Vertical geologic section through profile D

Geologic Section of Profile E

Figure 3e shows the geologic section through profile E, it reveals that three distinct layers exist therein. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 532.4 – 2260.5 Ωm, 1.1 – 3.3 m and 1.1 – 3.3 m respectively. The second layer is a weathered/fractured layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 85.9 – 231.4 Ωm, 16.7 – 26.0 m and 15.2 – 24.1 m respectively. The third layer which is the fresh basement has a resistivity range of 919.4 – 1612.5 Ωm with an undefined depth and thickness. VES point E_4 will be suitable for groundwater development.

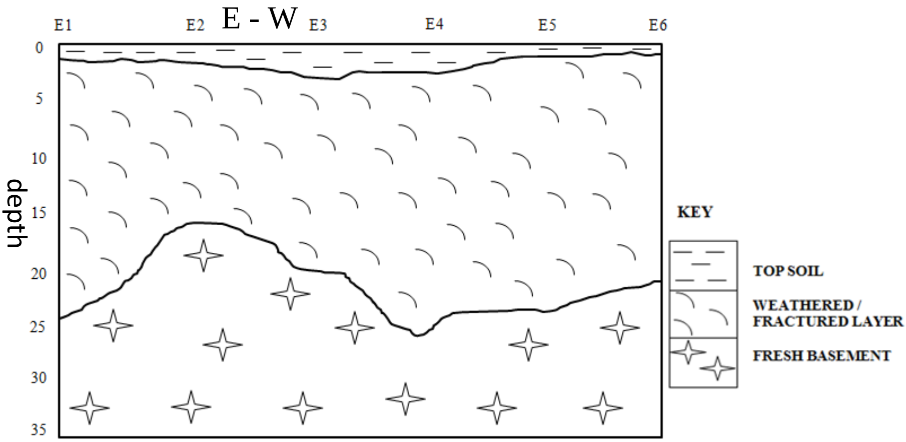

Figure 3e: Vertical geologic section through profile E

Geologic Section of Profile F

The geologic section through profile F (Figure 3f) reveals that the subsurface is made up of three geoelectric layers. The first layer is the top soil which spreads through the entire profile; its resistivity, depth and thickness range from 866.2 – 2203.2 Ωm, 1.4 – 3.8 m and 1.4 – 3.8 m respectively. The second layer is a weathered/fractured layer which also spreads across the entire profile, its resistivity, depth and thickness varies between 97.3 – 308.4 Ωm, 9.4 – 23.5 m and 8.0 – 21.4 m respectively. The third layer which is the fresh basement has a resistivity range of 1192.7 – 1799.5 Ωm with an undefined depth and thickness.

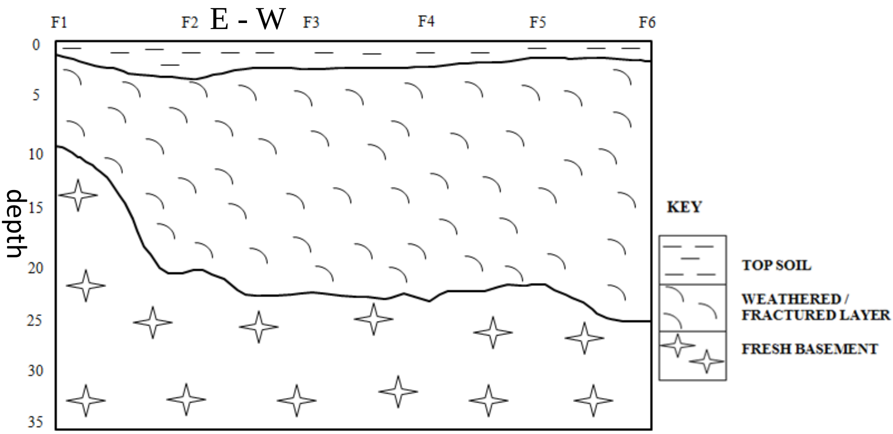

Figure 3f: Vertical geologic section through profile F

Table 2 contains the VES points delineated as aquifer potential of the study area, having range of resistivity, depth and thickness of weathered/fractured layers from 135.2 to 227.7 Ωm, 20.6 to 28.6 m and 17.8 to 26.2 m respectively and with consideration to the geologic cross sections along the profiles.

Table 2: Delineated aquifer potentials of the study area

VES Stations	Latitude (°)	Longitude (°)	No. of Layers	Layer Resistivity ρ (Ωm)			Layer Depth (m)			Layer Thickness (m)			Curve Type
				ρ1	ρ2	ρ3	d1	d2	d3	h1	h2	h3	
C_3	9.418441	6.620122	3	1190.8	135.2	1991.3	2.2	23.0	∞	2.2	20.8	∞	H
C_4	9.418447	6.621032	3	657.4	135.3	982.4	2.4	28.6	∞	2.4	26.2	∞	H
D_2	9.419339	6.619205	3	1019.7	159.7	1172.5	2.8	20.6	∞	2.8	17.8	∞	H
D_5	9.419357	6.621936	3	1480.7	227.7	1468.5	1.6	25.7	∞	1.6	24.1	∞	H
E_4	9.420255	6.621019	3	889.3	186.6	1369.5	2.5	26.0	∞	2.5	23.5	∞	H

Conclusion

Electrical resistivity method has been shown to be a suitable and very efficient tool in investigating groundwater potential by the results obtained from the analysis of the data acquired in field of survey. The resistivity of the top layer, weathered/fractured layer and fresh basement layer vary from 104.5 to 2260.5 Ωm, 44.9 to 606.0 Ωm and 919.4 to 3816.9 Ωm respectively across the entire study area; the depth of the top layer ranges from 0.6 to 3.8 m, that of the weathered/fractured layer vary between 4.3 and 28.6 m while that of the fresh basement layer is undefined across the six (6) profiles investigated; also, the study area has 0.6 to 3.8 m and 4.2 to 26.2 m as the thickness of its the top layer and weathered/fractured layer respectively, the fresh basement layer has an undefined thickness.

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