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MAPPING OF GROUNDWATER POTENTIAL USING INTEGRATED GEOPHYSICAL TECHNIQUES AT FORESTRY RESEARCH INSTITUTE OF NIGERIA, IBADAN, SOUTH WESTERN NIGERIA

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ABSTRACT

Water is an essential commodity for life survival on Earth. Groundwater exists below the surface in the soil pores, fractures within rocks, fissures, and other weak geological features or zones. The aim of this research was to delineate groundwater potential within the Forest Research Institute of Nigeria (FRIN) and hence determining the possible areas suitable for siting borehole for sustainable potable water supply. Four electromagnetic traverses were carried out and ten vertical electrical sounding (VES) points were identified for detailed probing using the Schlumberger configuration. Wenner array survey was also carried out along two traverses. The VES data collected was processed using curve matching and Computer software called Winresist while Wenner array was processed using RES2DINV. The results from the interpretation of the four (4) EM profiles revealed low conductivity zone with a value ranging from 4.6 to 19.7 mS m.$^{-1}$ The results of VES give a maximum of four subsurface geo-electrical layers with five curve types, which are K, Q, AK, HK, and KH. The weathered basement has a resistivity value ranging from143.8 to 450 Ωm and depth to basement ranging between 13.9 m and 39.4 m. The interpretation of the ten VES points obtained suggested that three VES points (VES 2, 5, and 7) are suitable for borehole drilling. The results of the 2D resistivity value ranges from 17.5 to 747 Ωm with a varying depth between 3.25 and 15.9 m. The results of the integrated geophysical survey techniques have proven to be an effective method for groundwater delineation in the study area.

Keywords: Aquifer, Borehole, Electromagnetic, Geoelectric, and Groundwater

INTRODUCTION

Water plays a remarkable role in the survival of ecosystems. Scarcity of potable water is attributed to various factors such as climatic variations, global warming, deforestation, increase in population, improper management, and rapid increase in urbanization (Parry *et al*., 2007; Ridolfi, 2010 and Jamali *et al*., 2020). Water occurs in three forms: rain, surface flow, and subsurface flow. Rain and surface water are easily contaminated due to negligence of the regulatory bodies on water conservation and treatment for its sustainability (Adagunodo *et al.*, 2018; Joel *et al.*, 2019a, b; Joel *et al.*, 2020).

Groundwater is about one-third of the water that local and city water departments supply to households and businesses (Coker *et al.*, 2018). Groundwater is widely used in many ways and it is often considered clean and usually served with little or no treatment especially for deep boreholes.

Various geophysical methods have been employed in groundwater exploration globally such as electrical resistivity, magnetics, electromagnetic, seismic, radiometric techniques and so on (McNeill, 1991; Bernard and Legchenko, 2003; Goldman and Neubauer, 1994; Hewaidy *et al*., 2015; Shishaye and Abdi, 2016; Helaly, 2017; Muhammad and Khalid, 2017; Muthamilselvan *et al*., 2017; Poongothai and Sridhar, 2017; Umar *et al*., 2017; Gao *et al*., 2018; Joel *et al*., 2020).

Akinlalu and Afolabi (2018) carried out a study of the coastal environment of Lagos, southwestern Nigeria, to determine the depth to freshwater. Twenty geophysical log data, which were spread across Ikoyi, Victoria Island, and Lekki of Lagos metropolis were employed. The logging tool used was the natural gamma log and the resistivity log (64″). The results showed that the relative variation in the quality of water across the regions is due to the differences in the thickness of clay units, which serves as protective units separating the polluted zones from the unpolluted zones. The results suggested that water wells in Ikoyi, Victoria Island, and Lekki should be drilled to an approximate depth of 240 m and the last 18 m be screened.

Adagunodo *et al*. (2018) applied an electrical resistivity method using a Schlumberger electrode array to investigate groundwater potential at Aaba residential area of Akure, which falls within basement terrain of southwestern Nigeria. It was submitted that the eastern and the southwestern regions are associated with high groundwater yield. The groundwater potential of the northern, central, and southern parts of the study area was inferred to be of medium potential. However, the northeastern and the western zones are inferred to be characterized by low groundwater potential.

Forestry Research Institute of Nigeria being saddle with the responsibility of researching and providing the country and beyond with both indigenous and some exotics trees species through seeds and seedlings provision need to have the available of water supply at all time for plant growth (Nurseries maintenance), laboratory and human consumption to achieve its goal. Also, there is a prevailing need for groundwater in the study area due to the lack of surface water sources. The few existing boreholes in the study area are known to be of low yield. In view of these challenges, Electromagnetic, Vertical Electrical Sounding and 2D resistivity survey was employed in mapping the groundwater potential in FRIN.

Geology, Climate and Topography of the Study Area

Ibadan lies between latitudes 7^0 15″ to 7^0 30″N, and longitudes 3^0 42″ to 4^0 00″E within the basement complex terrain of southwestern Nigeria and covers about 300 km^2. The research was carried out at Forestry Research Institute of Nigeria (FRIN) Estate Ibadan, Oyo State, Nigeria. FRIN Estate is along Jericho G.R.A in Ibadan metropolis, Ibadan North West local government area and lies within latitudes 7°23′5″ to 7°24′00″N and longitudes 3°51′00″ to 3°52′15″E in Southwestern Nigeria. FRIN is bounded on the West by its College of Forestry, on the East by Alalubosa Estate, on the North by Jericho GRA estate, and South by Odo Ona. The study was carried out within Latitude

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7°23′20″ to 7°23′26″ and Longitude 3°51′32″ to 3°51′44″ (Figures 1 and 2).

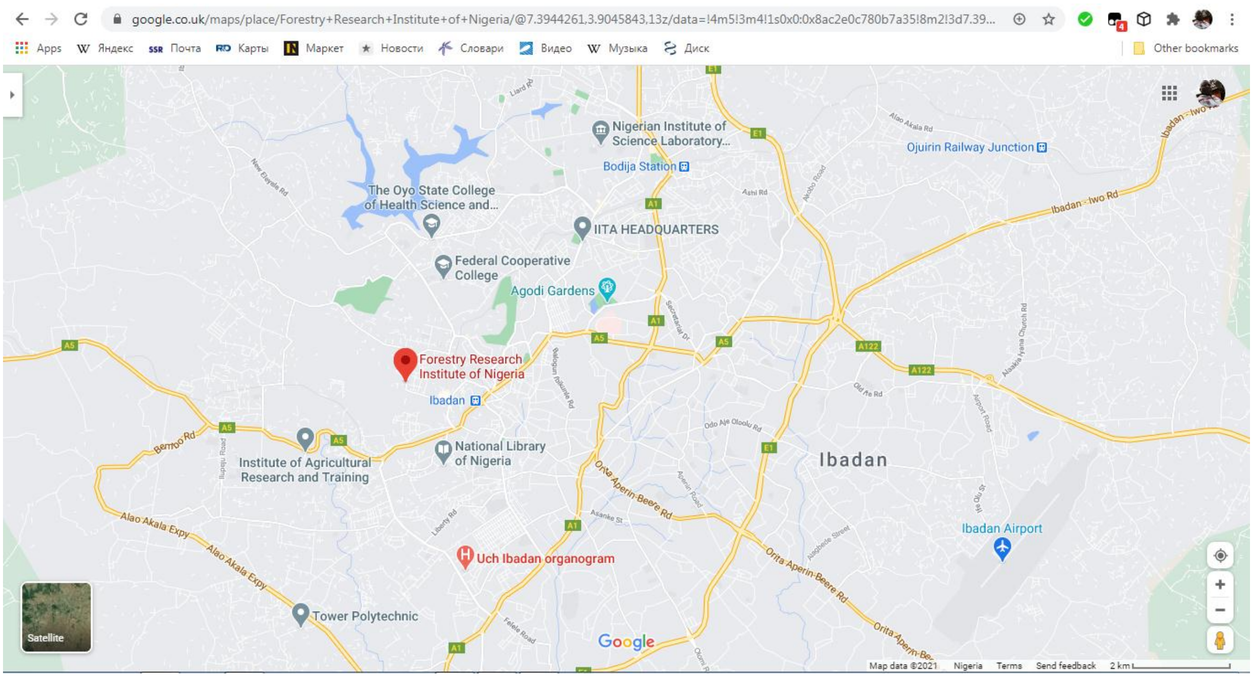

Figure 1: Map of Forestry Research Institute of Nigeria (Source: Google map, 2021)

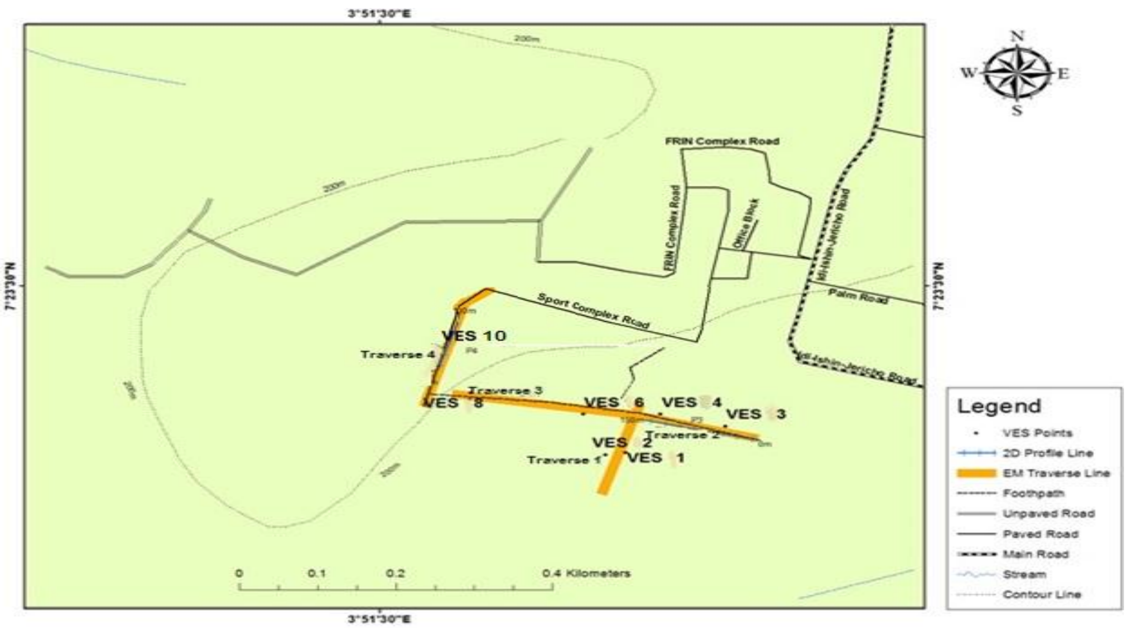

Figure 2: Map of FRIN showing the study area.

The study area is underlain by banded and augen gneisses, schistose quartzite (quartz-schist), and amphibolite (Figure 3) (Amanambu, 2015). The weathered rock and soil cover indicate that the area are being derived from the weathering of the basement rock which underlain the area, the rock is highly weathered and fractured with well-developed foliation planes and strikes between 34^0 and 35^0 and dipping between 27^0 and 37^0E. Soil type varies from clay, sand to laterite in most parts of the study area (Durotoye, 1976). The basement is covered by the superficial overburden derived from the weathering of the basement rocks. Pediment gravels described as thin secondary or detrital laterites overlie weathered rock and are believed to have been deposited during the climatic dry phase of the quaternary. The rocks are sedimentary in origin (Durotoye, 1976).

The study area falls within the humid and sub-humid tropical climate of Southwestern Nigeria. Ibadan has a tropical wet and dry climate with a lengthy wet season and relatively constant temperatures throughout the course of the year (Omokhagbo, 2008). During the rainy season, the area is under the influence of maritime southwest monsoon wind which blows inland from the Atlantic Ocean (Omokhagbo, 2008).

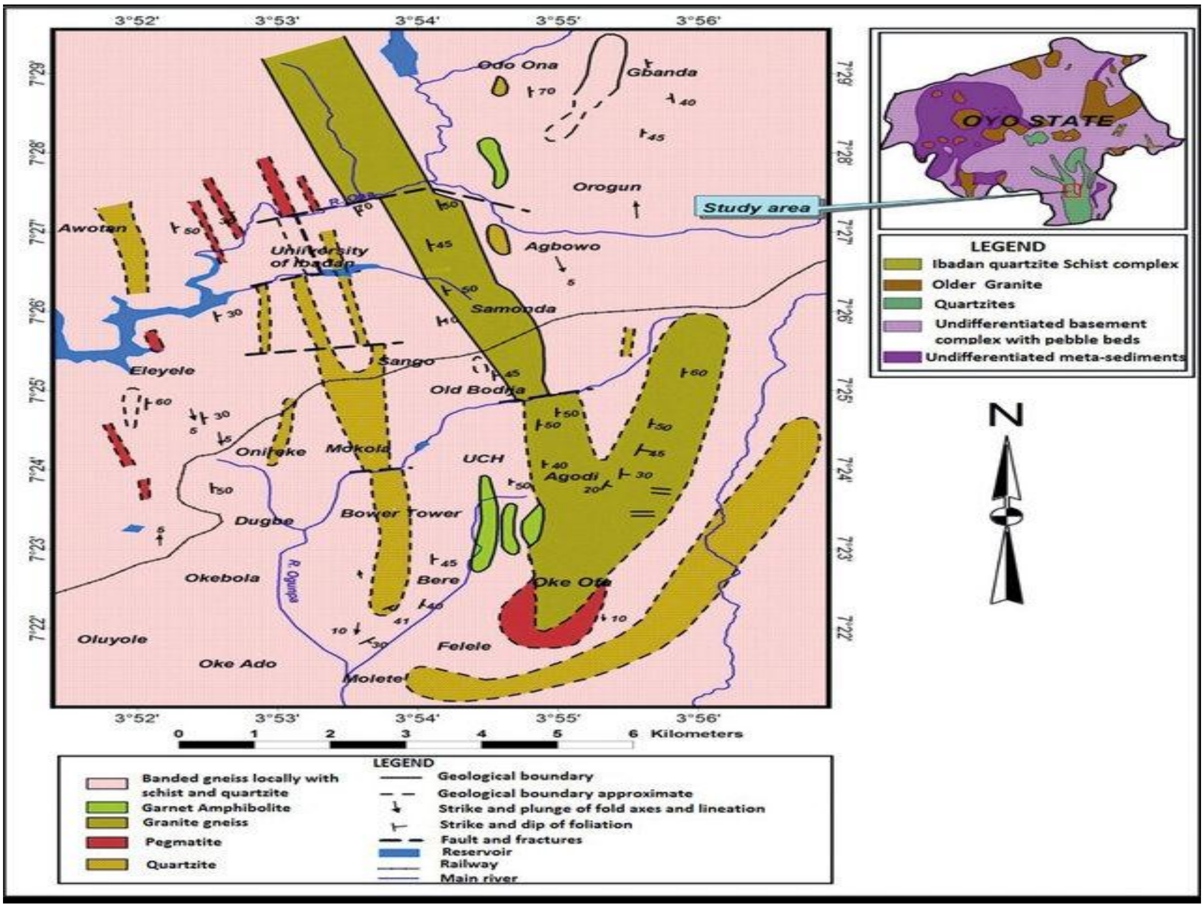

Figure 3: Geological map of Ibadan (Amanambu, 2015).

Ibadan's wet season runs from March through October, though August sees somewhat of a lull in precipitation. This lull nearly divides the wet season into two different wet seasons. November to February forms the city's dry season, during which the typical West African harmattan

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and dry dust-laden winds from the Sahara Desert are experienced. There are two peaks for rainfall, July and September with mean annual rainfall of 1420.106 mm (Ayandokun *et al.*, 2015). The mean relative humidity was 82% between June and September and 60% between December and February (Ugwu and Ojo, 2015, Ayandokun *et al.*, 2015). The mean minimum temperature is between 21.7 ^{o}C and 24.4 ^{o}C and mean maximum temperature between 27.4 ^{o}C and 34.6 ^{o}C (climate-data.org, 2021)

The natural vegetation in Ibadan is of a typical rainforest, mostly consisting of tall grasses, herbs, and small trees. The vegetation has an effect on the nature of the topsoil in the area because the denser the vegetation at a location, the thicker and darker will be the topsoil at that same location (Otelaja, 2007).

Ibadan is described as scenery dominated by three major landform units, namely the hills, plains, and river valleys. The hills are the most striking features. Although they constitute less than 20% of the total surface area, two main types can be recognized, namely quartzite ridges and gneissic inselbergs, of which the former are by the most extensive landform system in the area with elevation ranging between 180 m and 210 m above sea level. They cover, essentially the areas between the hills bases and the usually entrenched valley bottoms (Olayinka, 2001).

Generally, the plains are smooth with a convex-concave slope, the surfaces are usually marked by various kinds of dissection and undulation and regoliths. The river valleys are the narrowest landform in the environment and are characterized by the conspicuous incision of the river into the flood plain or river bed, the relief can be described as undulating (figure 4).

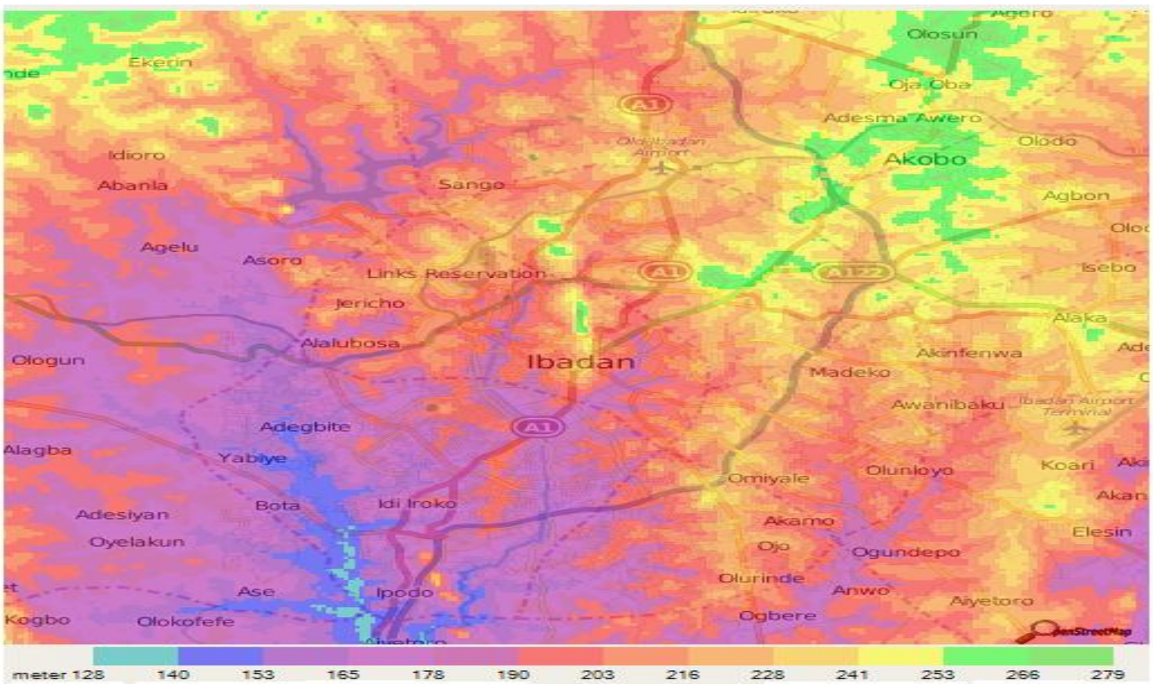

Figure 4: Topographical map of Ibadan (Source: Floodmap, 2021).

MATERIALS AND METHODS

Data Acquisition and Processing

The land base Electromagnetic method was used for reconnaissance survey (Figure 5). The Oasis Montaj, Version 8.3.1 software was employed to plot the data acquired from each of the profiles. Graphs of station intervals (in meters) against the apparent conductivities (in mmhos m^{-1}) were obtained. Also, the graph of conductivity versus distance was plotted for horizontal dipole (HD) and vertical dipole (VD) to compliment the modeling from the Oasis Montaj software. Points, where the VD conductivities exceeded the HD conductivities, were noted for VES investigation. Other points were also selected for the Wenner survey investigation.

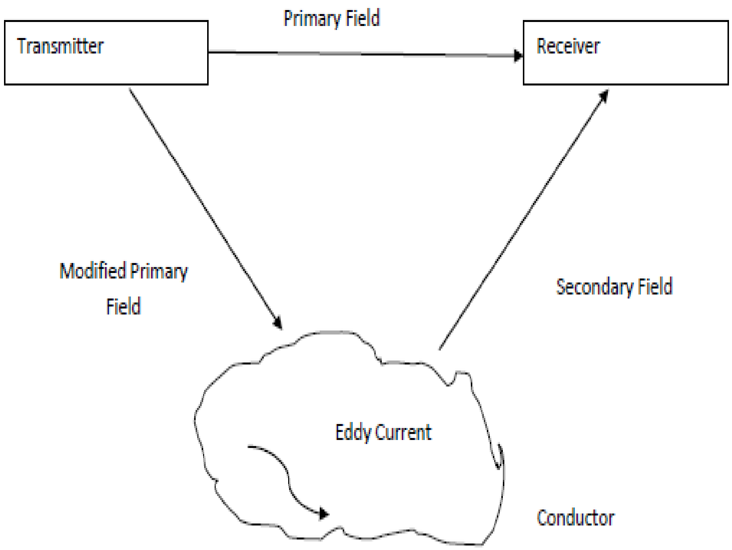

Figure 5: Generalized Schematic Diagram of the Electromagnetic Survey Method. (Source: Kearey and Brooks, 2002)

Ten Vertical Electrical Soundings were conducted using the symmetrical-Schlumberger electrode spread technique (Figure 6) at each of the selected points. The resistivity values of each of the VES sites were read directly from the Terrameter. These values were multiplied by the geometric factor of the array to give apparent resistivity values.

The obtained data from the instrument were fed into the software for further calculations. The preliminary interpretation of the VES curves was carried out by the curve matching technique in which the field curves are matched with the theoretical master curve. A software package, WINRESIST was used for the resistivity data processing. The inverted data were printed and saved in word file format. The output is the plot of apparent resistivity against electrode separation which is referred to as the sounding curve. Additional information on the number of layers, the resistivity of the layers as well as their thicknesses was generated from the software to make interpretation less ambiguous.

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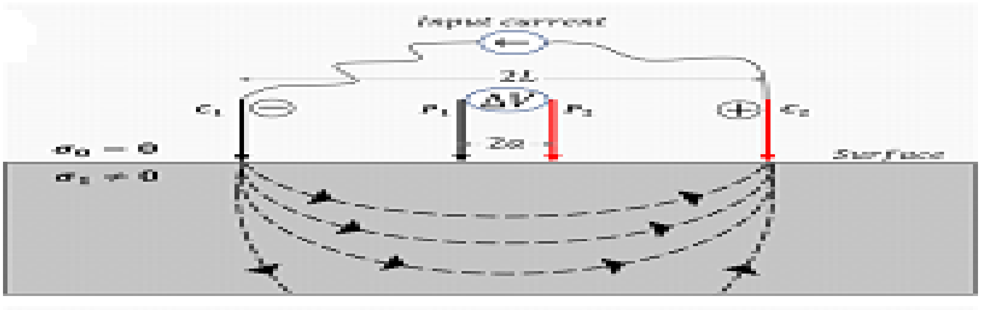

Figure 6: Schematic Diagram of the Vertical Electrical Sounding Survey Method. (Source: Kearey and Brooks. 2002)

The Wenner array survey was carried out after the Vertical electrical sounding using the same equipment as in the case of Schlumberger data acquisition (Figure 7). In all, two Wenner array were carried out at the location. A third party software package, Surfer 12 and RES2DINV were used for the resistivity data processing. The data was converted into CSV -file extension with Surfer 12 software, before processing with the RES2DINV software. This conversion was done to enable the RES2DINV software to read the Wenner data. In the RES2DINV software platform, each of the apparent resistivity data files was read and inverted with the user model. The inverted data was printed and saved in word file format. The result is an inverse model resistivity section which is referred to as pseudo section.

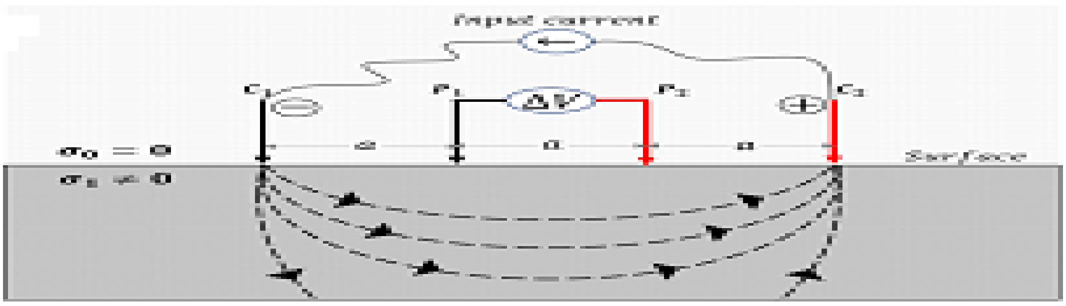

Figure 7: Schematic diagram of the 2-D Resistivity Survey Method. (Source: Kearey and Brooks, 2002)

RESULTS AND DISCUSSION

Electromagnetic method

Profile one covers a distance of 150 m, Profile two and three each covers a distance of 200 m, and Profile four covers a distance of 180 m (Fig. 8 (a-d)). The pseudo section of profile one revealed well-defined zones. There is a low conductivity zone ranging in value from 14.80 to 15.94 mS m^{-1} in the North-West, South, and South-East region from a lateral distance of 0 m to 40 m, 40 m to 85 m, and 121 m to 150 m along the profile. There exists a high conductivity zone with the value ranging from 19.83 to 23.27 mS m^{-1}.

The pseudo section of the second profile shows a laterally well-defined layer of both low and high conductivity zone. The low conductivity zone has a value ranging from

4.6 to 8.2 mS m^{-1} with a lateral distance range of 5 to 190 m. A high conductivity zone with a value ranging from 15.0 to 19.6 mS m^{-1} is also revealed at the South-East region of the profile at a depth of about 18 m to 60 m.

Profile three shows two regions for both high and low conductivity occurrence. The low conductivity value which ranges from 9.9 to 12.5 mS m^{-1} was observed between 0 to 68 m and 87 to 200m at the North-East and North-West region of the traverse while the high conductivity zone exists at the South-East and South-West region ranging in value between 15.2 to 17.2 mS m^{-1} at a depth of 25 to 60 m in the South-West and 30 to 60 m in the South-East region of the profile.

The pseudo section of profile four revealed a low conductivity zone with a value ranging from 14.8 to 19.7 mS m^{-1} at a distance between 0 to 45 m in the North-West region of the profile. A high conductivity zone is also presented laterally from the central part of the West to East across the profile with conductivity values ranging from 77.9 to 116.1 mS m^{-1}. These are the prospective point where drilling can yield positive results.

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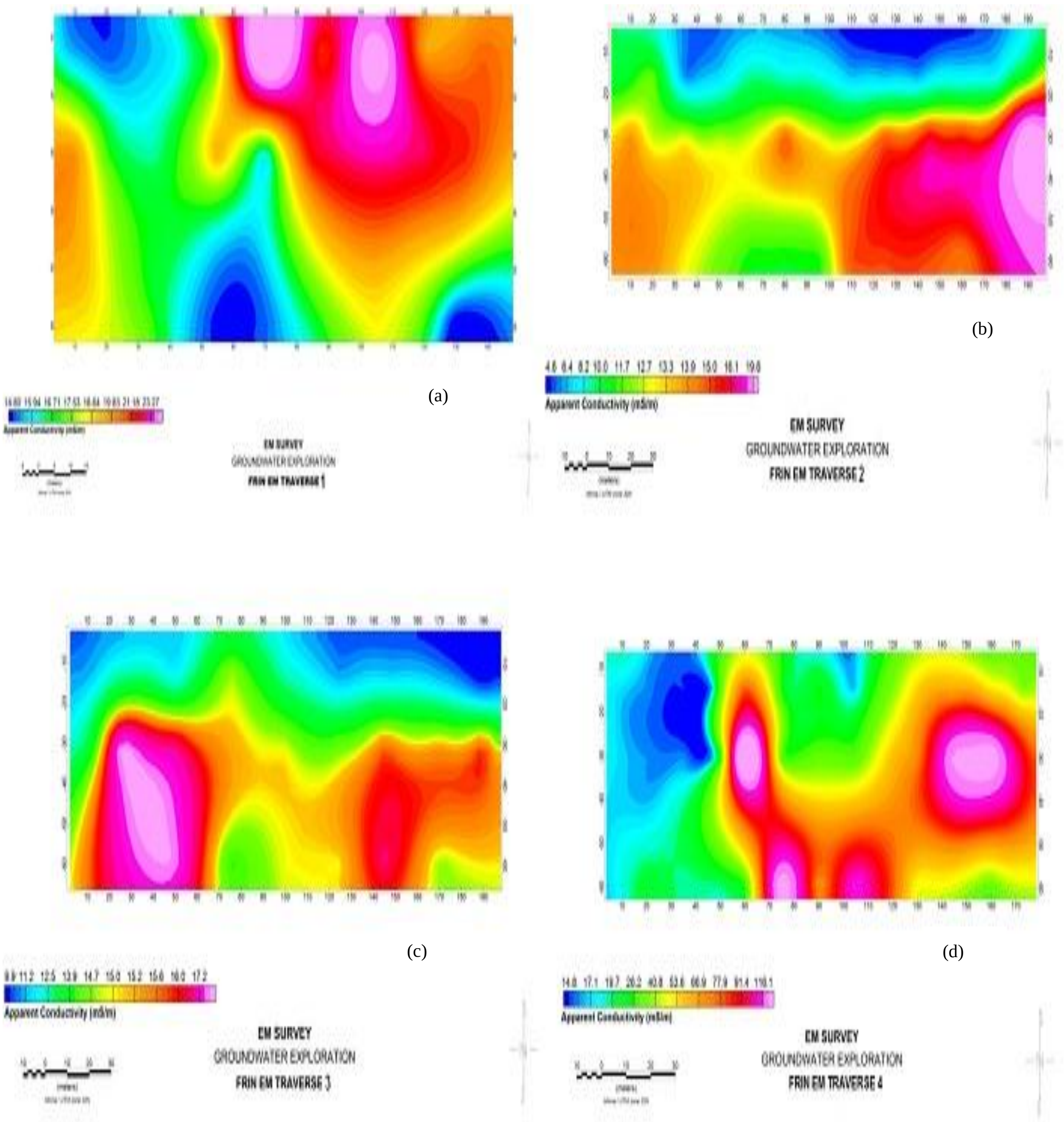

Figure 8: Pseudosection presentation of profile 1 – 4 of EM results

Vertical Electrical Sounding Method

VES points 1 to 10 were investigated at profiles 1, 2, 3, and 4 (Figure 9). The results and important features of the subsurface parameters are given in Table 1. The types of three-layer VES curves obtained in this location are K and Q-type (VES 4, 6, 7, 8) while HK, KH, AK-type are the four-layered VES curves seen at VES 1, 2, 3, 5, 9, and 10 (Table 1). The VES curve analyses, revealed that the subsurface structure of 4 out of the 10 VES points was underlain by three lithological layers while the remaining 6 are of four-layer types of varying resistivities. The results indicated slight to moderate fracture development in the bedrock.

The interpretation of the 10 VES suggested that 3 points were suitable for borehole drilling. Since the evaluation of groundwater potential is based on the appreciable thickness of overburden, low resistivity of the subsurface layer recorded as well as the fracture of the basement. On this note, VES 2, 5, and 7 are considered to be potential areas for drilling boreholes.

Low resistivity reflects the presence of water, appreciable overburden and a fractured basement that is productive. Both layers will be the sources of water by which the borehole is being recharged at all time. The results of other VES points (VES 1, 3, 4, 6, 8, 9, and 10) have low resistivity values less than 9.2 Ωm and low yield point for borehole siting.

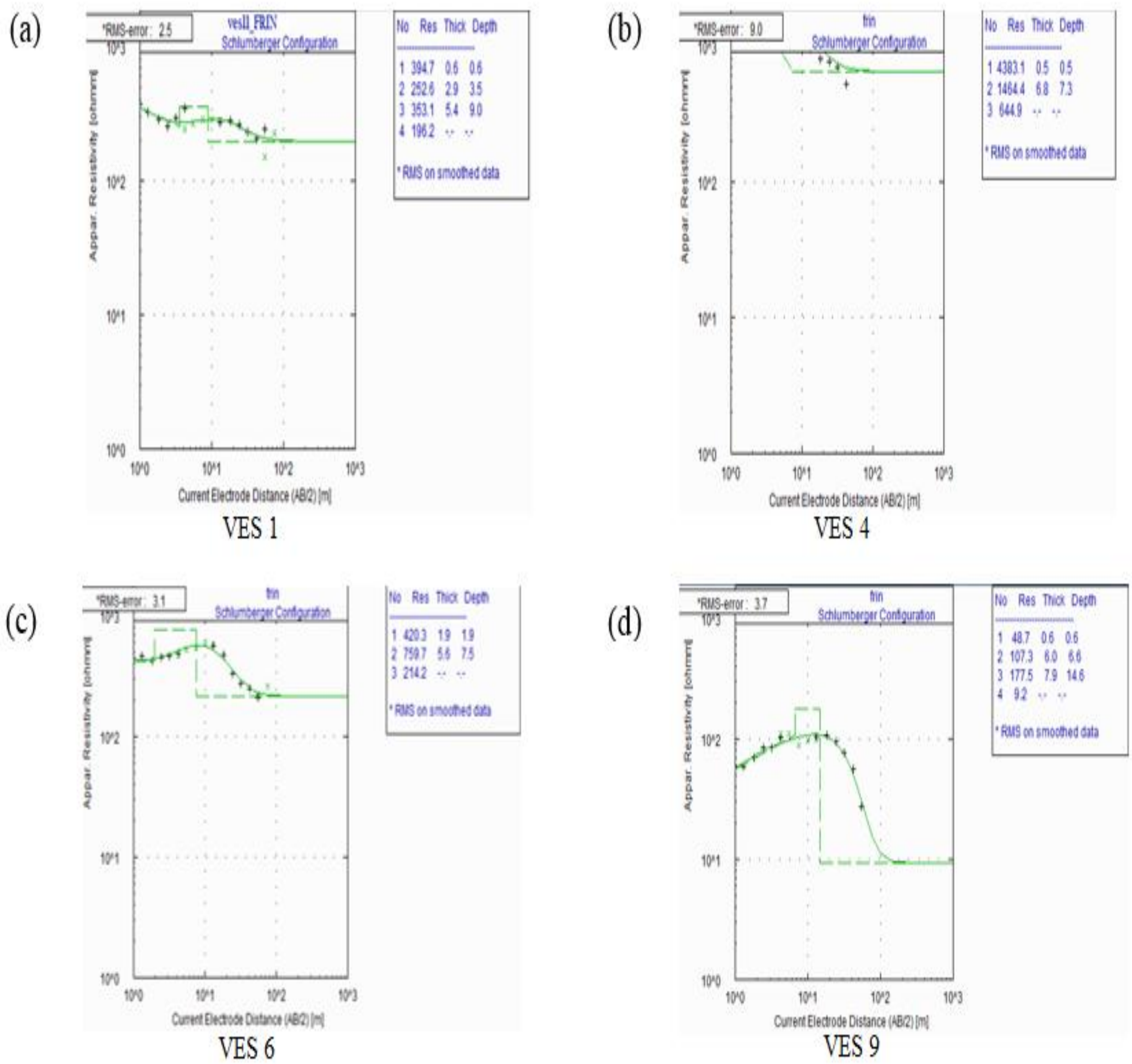

Figure 9: Schlumberger Array Curve for VES 1, 4, 6, 9, Representing Profile 1- 4

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Table 1: VES interpretation of the study area

Profile No	Layer Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Layer	Curve Type
	394.7	0.6	0.6	Top Soil	
1	252.6	2.9	3.5	Sandy Clay	
	353.1	5.4	9	Weathered Basement	HK
	196.2			Fractured Basement	
2	391.6	0.8	0.8	Top Soil	KH
	465.5	10.8	11.6	Clayey Sand	
	143.8	27.2	39.4	Weathered Basement	
	323.6			Fractured Basement	
3	858	0.6	0.6	Top Soil	HK
	233.3	1.3	1.9	Sandy Clay	
	1076.1	12.2	14.1	Dry Sand	
	201.7			Fractured Basement	
4	4383.1	0.5	0.5	Top Soil	
	1464.4	6.8	7.3	Dry Sand	
	644.9			Fractured Basement	Q
5	641.8	0.7	0.7	Top Soil	
	144.3	1	1.7	Sandy Clay	
	450	12.3	13.9	Weathered Basement	HK
	230.4			Fractured Basement	
6					
	420.3	1.9	1.9	Top Soil	
	759.7	5.6	7.5	Clayey Sand	K
	214.2			Fractured Basement	
7	361.8	2.8	2.8	Top Soil	
	554.8	10.8	13.6	Clayey Sand	
	70.5			Fractured Basement	K
8	143.4	1	1	Top Soil	
	507.2	17	18	Clayey Sand	
	264.6			Fractured Basement	K
9	48.7	0.6	0.6	Top Soil	
	107.3	6	6.6	Sandy Clay	
	177.5	7.9	14.6	Weathered Basement	AK
	9.2			Fractured Basement	
10	297.5	1.6	1.6	Top Soil	
	485.2	5.9	7.5	Clayey Sand	
	145	13.9	21.4	Weathered Basement	KH
	3772.4			Fresh Bedrock	

The geo-electric section revealed four subsurface geo-electrical layers in VES 1, 2, 3, 5, 9, and 10 and three subsurface geo-electrical layers in VES 4, 6, 7, and 8. The first, uppermost, geo-electrical layer is relatively thin. The topsoil contributes to the development of groundwater because it is the passage for the flow of surface water to the fractured layer. It is known as the aeration area and water in this layer is called sub-surface water. The top geo-electric layer has a resistivity value ranges from 48.7 to 4383.1 Ωm with mean resistivity of 794.09 Ωm reflecting the effect of surface conditions. Its highest value was observed at VES 4 and the lowest at VES 9 (Table 1). The top layer thickness ranges from 0.5 (VES 4) to 2.8 m (VES 7) with a mean thickness of 1.11 m.

For VES 1, 2, 3, 5, 9, and 10 which have four layers. The second layer shows Clayey Sand at VES 2 and 10, and Sandy Clay at VES 1, 3, 5, and 9. It has a resistivity value ranging from 107.3 (VES 9) to 485.2 Ωm (VES 10) with mean resistivity of 281.37 Ωm, while the thickness ranges from 1 (VES 5) to 10.8 m (VES 2.) with a mean thickness of 4.65 m.

The second layer of VES 4, 6, 7, and 8 shows two varieties of soil types (Clayey Sand and Dry Sand), and the third layer of VES 1, 2, 3, 5, 9, and 10 shows two zones (Weathered basement and Fractured basement) has resistivity ranging from 507.2 to 1464.4 Ωm and 143.8 to 1076.1 Ωm with mean resistivity of 821.525 Ωm and 390.9167 Ωm respectively. The lowest resistivity value was at VES 2 and the highest resistivity value at VES 4 respectively.

The third layer of VES 4, 6, 7, and 8, and the fourth layer of VES 1, 2, 3, 5, 9, and 10 constitute the Fractured basement and Fresh bedrock which has a resistivity that ranges from 70.5 to 644.9 Ωm and 9.2 to 3772.4 Ωm with mean resistivity of 298.55 Ωm and 788.9167 Ωm respectively. The lowest resistivity value was at VES 9 and the highest at VES 10. The fourth layer in VES 10 can be considered as Fresh bedrock due to its higher resistivity value of 3772.4 Ωm.

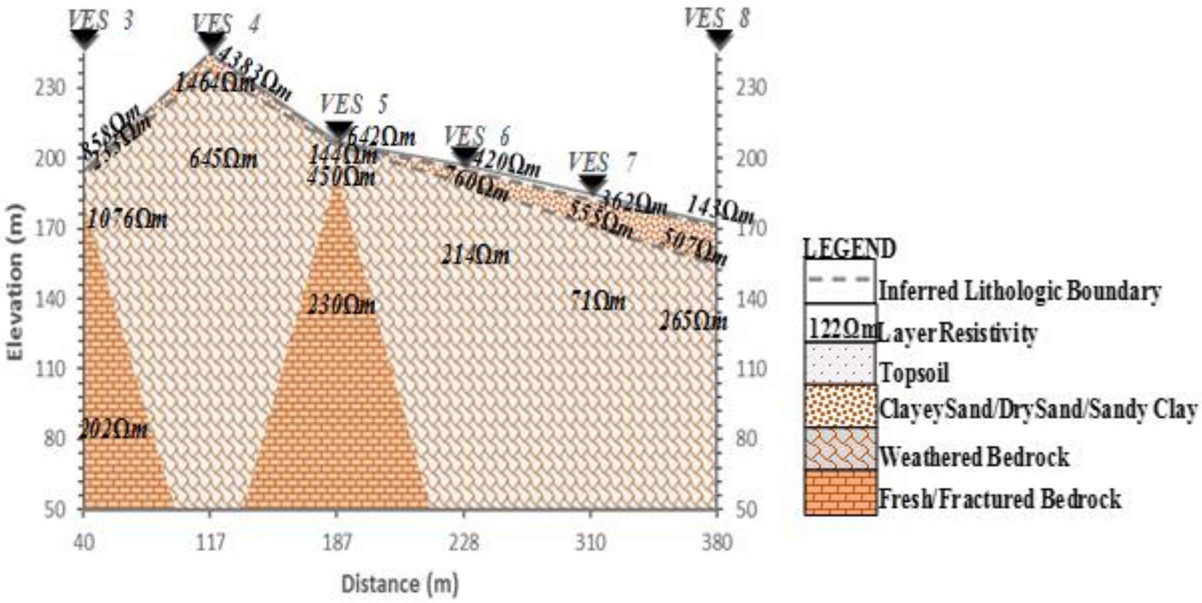

Figure 10: Geo-electric section at VES 3, 4, 5, 6, 7 and 8

The geo-electric section (Figure 10) shows three and four subsurface geo-electrical layers and the summary of the results are presented in Table 1. The first uppermost layer is the topsoil with resistivity value ranging from 143 to 4383 Ωm. Its highest value was observed at VES 4 and the lowest at VES 8. The top layer thickness ranges

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from 0.5 to 2.8 m. The second layers revealed Clayey Sand at VES 6, 7, 8, Dry Sand at VES 4, and Sandy Clay at VES 3 and 5 respectively. The second layer resistivity value ranges from 144 to 1464 Ωm. Its lowest value was observed at VES 5 and the highest at VES 4. Its thickness ranges from 1(VES 5) to 17 m (VES 8).

The third layers of VES 4, 6, 7, and 8 revealed zones of the fractured basement. These VES points constitute three-layered geo-electric subsurface layers. The layer resistivity value ranges from 71 to 645 Ωm. Its lowest value was observed at VES 7 and the highest at VES 4. The third layer of VES 3 revealed zones of Dry Sand while that of VES 5 revealed a weathered basement. These two VES points have four geo-electric subsurface layers with resistivity values of 1076 and 450 Ωm respectively. The fourth layer constitutes the Fractured Basement with resistivity values ranging from 202 (VES 3) to 230 Ωm, (VES 5).

Wenner Configuration

Profile 1(figure 11), reveals patches of low resistivity zones ranging from 92.6Ω m to 279Ωm at a distance of 30 to 45m and depth of 15.9m respectively, and also, between 50.0 m and 95.0 m along with the profile and to a depth of about 15.9 m. These low resistivity zones are as a result of water. A high resistivity zone also exists at a depth of about 3.75 m to 12.4 with lateral distance of about 7 m to 25 m with resistivity range of 1460 Ωm to 4398 Ωm. The best point for potential groundwater drilling consideration is between the distances of 80m to 90m along the profile to a depth 15.9m.

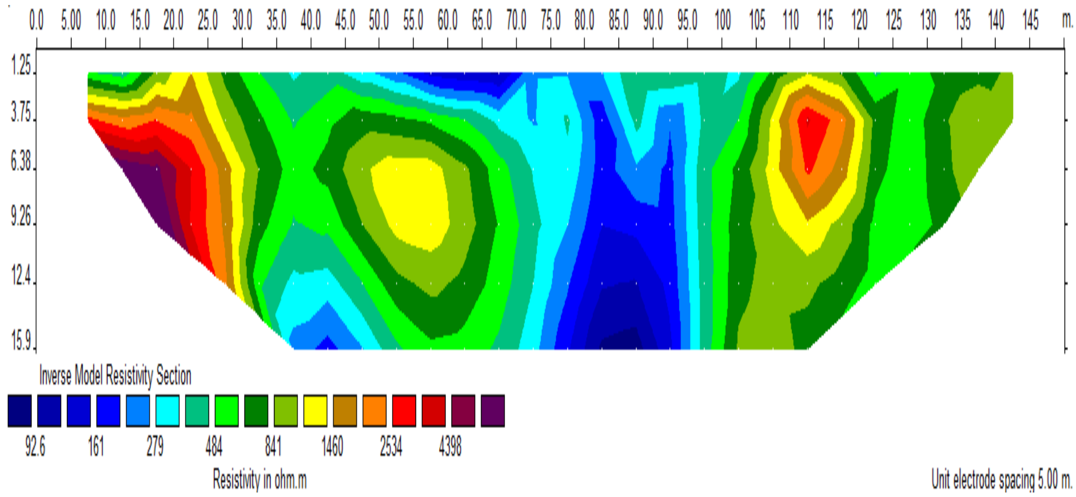

Figure 11: Result of 2D Inversion of the Wenner Array data along with profile 1

The inverse resistivity model of Profile 2 (Figure 12) shows portions of low resistivity zones along the profile at a distance from 45 m to 80 m with resistivity values ranging from 17.5 Ωm to 51.2 Ωm. The low resistivity zones are overlain by highly resistive material with a resistivity value of 256 Ωm to 747 Ωm at a depth range of about 1.25 to 12.4 m along the profile at a distance of 7.0 m to 45.0 m and 60.0 m to 110 m respectively. This low resistivity value indicates the presence of an aquifer. The best point for drilling is between 42 m to 65 m distance along the profile to a depth of 15.9 m.

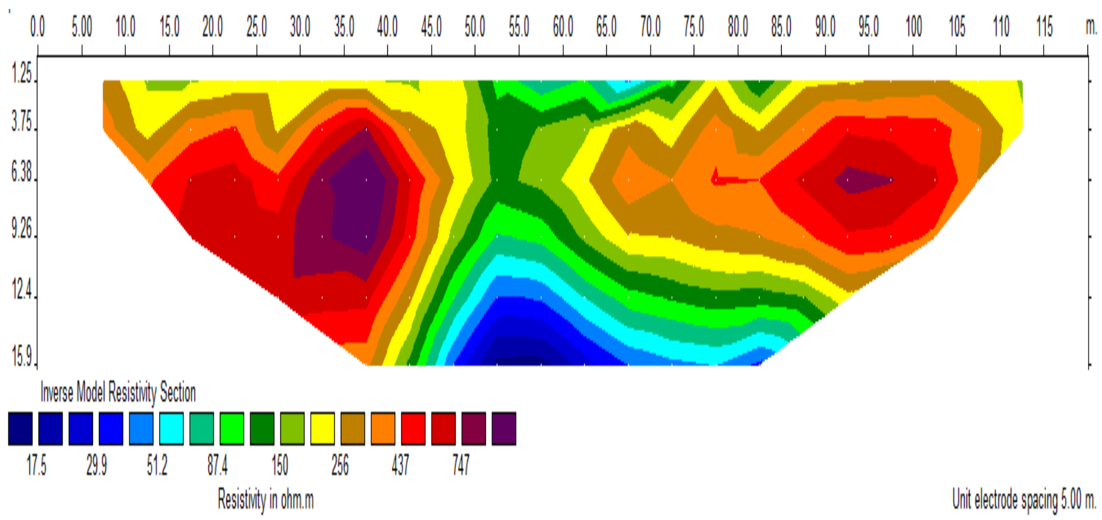

Figure 12: Result of 2D Inversion of the Wenner Array data along with profile 2.

Correlation of EM, VES and WENNER Results

The geological sections of three techniques succeeded in delineating the boundaries between layers. The EM survey provides faster and easier data acquisition and is mostly used as a reconnaissance tool. The inverse models of the 2D imaging technique are better in delineating the aquifers and in determining the vertical and horizontal changes in resistivity within layers and aquifers. The VES result complimented the EM and Wenner by the generation of different curve types and geo-electric parameters to further give the accuracy of the layer resistivity, thickness, and the materials that constitute the profiles thereby provide the evaluation of the groundwater potential of the study area.

CONCLUSION

This study has demonstrated the usefulness of the integrated geophysical method in the exploration of groundwater potential at FRIN – Ibadan, South-Western Nigeria. A total of four electromagnetic traverses were carried out as a reconnaissance survey. The VES curves obtained exhibited a three and four-layer characteristic displaying different curve types. The results of geological sections and inverse models showed the presence of aquifers.

The interpretation of the 10 VES points obtained suggested that three (3) VES points were suitable for borehole drilling. From the VES curve analyses, it was also revealed that the subsurface structure of 4 out of the 10 VES points was underlain by three lithological layers while the remaining 6 are of four-layer types of varying resistivities. Since groundwater potential evaluation is based on the appreciable thickness of overburden, low resistivity of the subsurface material recorded as well as the fracture of the basement, VES 2, 5, and 7 are considered to be a good potential area for the drilling of boreholes. The 2D results reveal a resistivity value of 17.5 Ωm which implies that the study area has low resistivity. The results of the EM, VES, and 2D obtained have proven to be an effective integrated geophysical survey method for groundwater delineation.

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