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Use of VLF–Electromagnetic and Electrical Resistivity Methods for Groundwater Investigation in Oke–Amu Area, Southwestern Nigeria

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Abstract: *Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity (ER) methods were integrated as a feasibility study for groundwater development in Oke-Amu, southwestern Nigeria. The aim of the study was to identify the conductive zones and aquifer units, determine the overburden thickness and recommend priority areas for possible groundwater development. The study area lies within the basement complex of southwestern Nigeria which is characterized by granite gneiss and migmatite gneiss complex. The VLF-Electromagnetic method was adopted as a fast reconnaissance tool to map possible linear fractures while the electrical resistivity method was used to investigate prominent electromagnetic anomalies and provide a geo-electric image of the subsurface sequence. Eleven VLF profiles running about 3.6 kilometres were established in the study area and measurements were taken at a station interval of 10 m along each profile line. Thirty three schlumberger vertical electrical soundings were conducted at locations identified as conductive zones from the VLF-EM method. The maximum current electrode spacing (AB/2) was 100 m. The filtered components for both real and imaginary parts of VLF-EM data were plotted against distance for each profile to identify the top of linear fractures. VES data were also plotted and subjected to iteration using WIN RESIST. The results of the VLF anomaly curves indicated that apparent conductivities for the area are generally lower than 25 S/m, and VES curves interpretation showed how resistivity varies in the study area. These were later presented as geo electric sections. The geo electric sections identified three to four subsurface sequence. This sequence included the topsoil, lateritic clay (in case of four subsurface), weathered basement (clay/sandy clay/clayey sand) and fractured/fresh basement. The results revealed that the study area has a shallow depth to basement ranging from 2.3 m to 26.0 m with a mean of 9.9 m. The weathered basement in the study area has resistivity range within 33 ohm-m and 645 ohm-m, with a mean of 156 ohm-m, and also the thickness of this layer ranges from 1.4 m to 24m. This study showed a good correlation with the groundwater potential of the three boreholes drilled in the area prior to this investigation.*

Keywords: *Electrical Resistivity, Conductive Zones, Geoelectric Section, Overburden.*

1. Introduction

The basement complex rocks are naturally poor aquifers as they are characterized by crystalline igneous and metamorphic rocks with low porosity and negligible permeability. However, fracturing and weathering activities of basement complex rocks may lead to appreciable secondary porosity and permeability of the rocks thereby making them good aquifers [1]. Over the years, people of this community have really suffered enormous problems of water supply either surface or groundwater. These problems have been noticed to be much more severe at the peak of the dry season when ironically demand for water is greatest and most of the surface sources dry up completely. Before now, the greater majority in the community relied on such sources as streams and ponds especially during the dry seasons when hand-dug wells would have dried up. This situation definitely led to the outbreak of water borne diseases like cholera, diarrhoea, guinea worm that seriously threatened lives in the community in the 80’s running through early 90’s. Also valuable time could be wasted in water fetching and trekking long distances to and fro from water points. Although, efforts have been made in recent times to enhance the groundwater potential of this area. In this sense, three boreholes have been drilled in different parts of the study area but observation has shown that only one out of the boreholes is functioning perfectly well with appreciable volume of water production through-out the year. The major problem associated with the unproductive wells has been identified to be inadequate geological and geophysical surveys, which reveal the proper understanding of the hydrogeological characteristics prior the drilling of boreholes in the area [2][3].

1.1. Site Description

Oke-Amu is located in Itesiwaju Local Government Area of Oyo-State in the southwestern part of Nigeria. It lies between latitudes $08^{0}07^{1}10^{11}$N and $08^{0}07^{1}40^{11}$N and longitudes $03^{0}31^{1}00^{11}$E and $03^{0}31^{1}45^{11}$E. The study location covers an area of about 1.215 square kilometre. The area is moderately accessible because of the availability of road networks system both tarred and untarred linking the town to other towns and as well as the footpaths within, linking one another.

The drainage pattern of the study area can be described as dendritic in nature. The topography of the area can be described as undulating with several high and low altitudes which have elevations ranging from 334m to 370m above sea level across the entire town and its environs. The ruggedness of the topography is characterized by slopes, valleys and some plains at the suburb of the area, used for agricultural purpose. The topography map showing the study area is shown in figure 1.

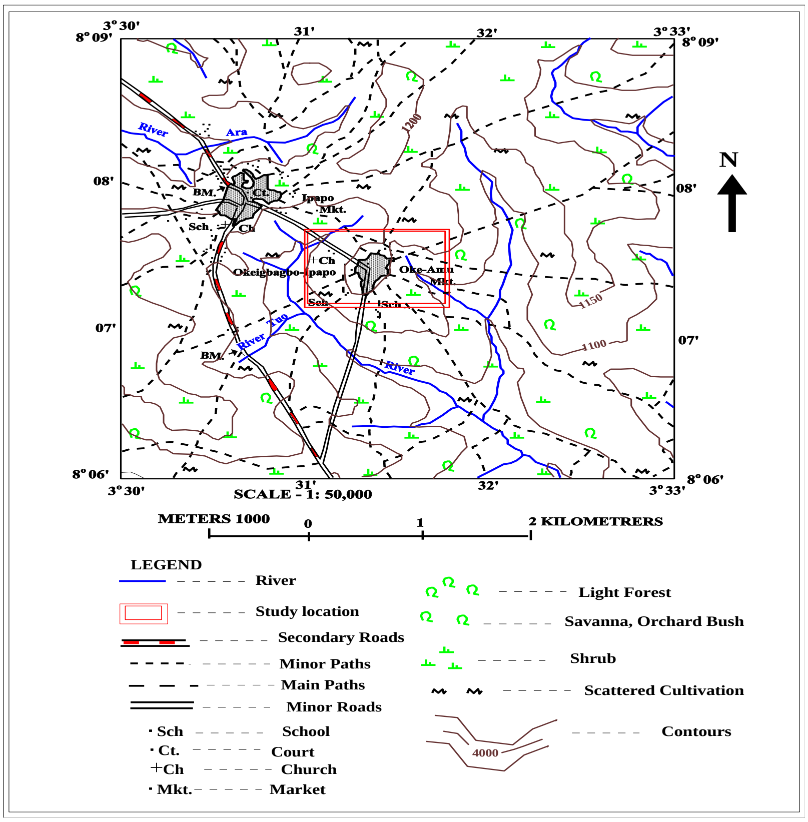


Figure1. *The topography map showing the study area.*

1.2. Geological Setting of the Study Area

Oke–Amu, which is the study area, occurs within the Precambrian basement complex of southwestern Nigeria as shown in figure 2, and therefore should be expected to have groundwater problem unless there is/are evidence(s) of fracturing and weathering activities on the rocks constituting this area. Also, the degree or extent of these activities would determine the quality of aquifers. Highly productive water wells are obtained by drilling in rock that is broken along joints and small fractures [3][4][5]. The local geological mapping of the study area revealed that the area is underlain mainly by a rock unit, granite gneiss. The rocks are concealed in most areas and only six outcrops are exposed and visited within the study area. It is therefore suspected that the overburden is relatively thin within the study area. The rocks are generally trending in northwest-southeast direction and dipping to the west. All the exposed outcrops observed have low fractures, indicating minor evidence of deformation. The megascopic minerals observed in this rock type include quartz, feldspar and biotite. Plate 1 below shows granite gneiss rock with quartz vein intrusion in one of the locations within the study area.

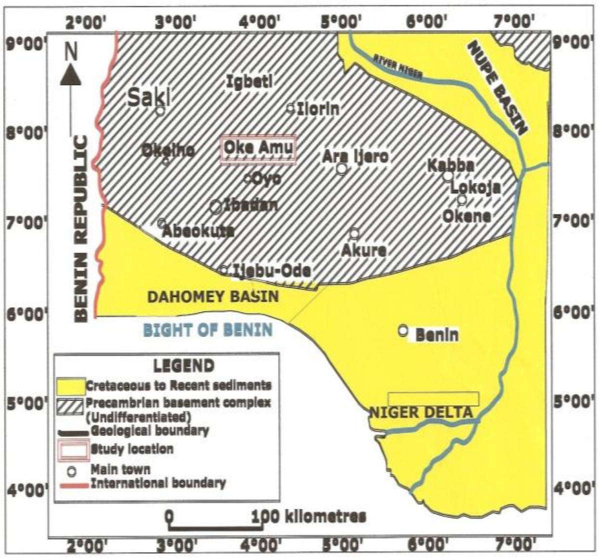


Figure2. *Modified Geological map of South-western Nigeria showing the study area [6].*

Plate1. *Granite gneiss (with quartz vein)*

2. Data Acquisition and Processing

2.1. Static Water Level

A total of thirty-three hand-dug wells were studied and some parameters were measured. These parameters included geographic coordinates, elevation, depth to water level and total depth of well. Also, three boreholes have been drilled in the area and only one of the drilled boreholes is productive while others are not productive. Figure 3 shows the location of the boreholes and the sampled hand-dug wells across the study area and figure 4 shows a typical static water level measurement.

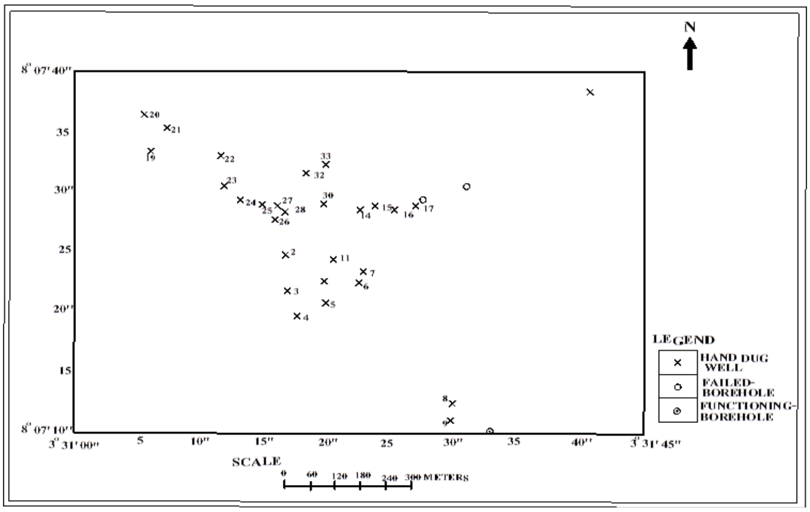


Figure3. *Location of the boreholes and the sampled hand-dug wells across the study area.*

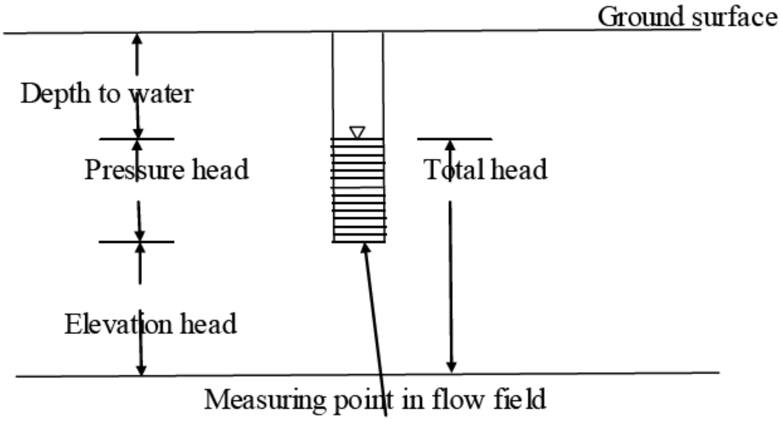


Figure4. *Static water level measurement.*

From the illustration in figure 4 above,

Altitude (Elevation) = Depth to water + Pressure head + Elevation head

But, Pressure head + Elevation head = Total head

Altitude = Depth to water + Total head

Total head = Altitude – Depth to water

Groundwater moves in the direction of decreasing total head, which may or may not be in the direction of decreasing pressure head or water column [7].

2.2. Very Low Frequency-Electromagnetic

The VLF–EM survey utilizes the electromagnetic radiation (primary field) generated in the low frequency band of 15-30 KHz by the powerful radio transmitters used in long-range communication and navigation systems [8]. This method of geophysical survey was carried out with ABEM-WADI SYSTEM and measurements were taken at station interval of 10 m along each profile line. Eleven profile lines were established over the study area which run about 3.6 kilometres as shown in figure 5 below. The filtered components for both real and imaginary parts of the EM data were plotted against distance for each profile [3]. This double plot of filtered real and filtered imaginary anomaly curves enable qualitative identification of the top of linear fractures with positive peak filtered real component [3].

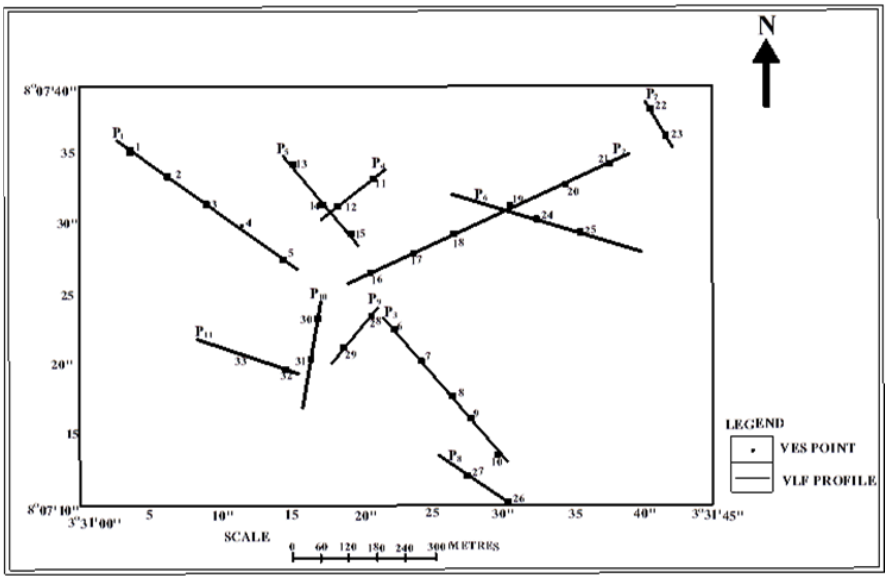


Figure5. *The field survey layout for VLF and VES investigations across the study area.*

2.3. Vertical Electrical Sounding

Areas noted to be conductive from VLF results were therefore selected for vertical electrical soundings. A total of thirty-three vertical electrical soundings (VES) were carried out, using schlumberger electrode array, with maximum current electrode spacing (AB/2) of 100 m. The separation between adjacent sounding points was between 80 m and 130 m but mostly 100 m. These soundings were made mostly on high conductivity anomalies over the already-established VLF-EM profiles. Figure 5 above shows the field survey layout for VLF and VES investigations across the study area.

The apparent resistivity values obtained from the field were plotted against the electrode spacing on bilogarithm coordinates and a preliminary interpretation was carried out using partial curve matching involving two-layer master curve and the appropriate auxiliary charts [8][9]. The layered earth model obtained later served as input for an inversion algorithm using WIN RESIST.

3. Results and Discussions

3.1. Static Water Level

The total head of the hand-dug wells were calculated and this indicator was used to determine the groundwater flow direction (groundwater moves in the direction of decreasing total head). Figure 6 shows the groundwater flow direction for the study area superimposed on the field survey layout.

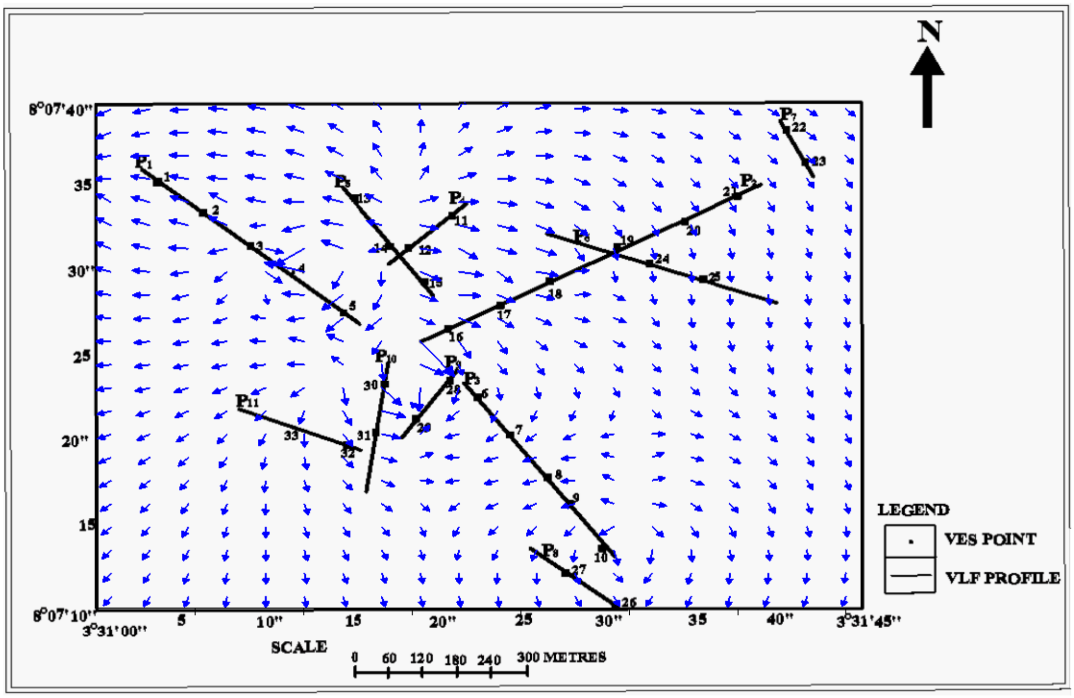


Figure6. *Superimposition of groundwater flow direction on the field survey layout.*

3.2. Very Low Frequency Electromagnetic

The representative VLF-EM anomaly curves shown in figures 7a and 7b below reveal that the study area generally has low apparent conductivities that indicate a highly resistive area. The apparent conductivities widely varied on each profile line and over the study area. Table 1 shows the highest apparent conductivity values obtained by the filtered real part of the anomaly curve as against its corresponding distance for each profile line.

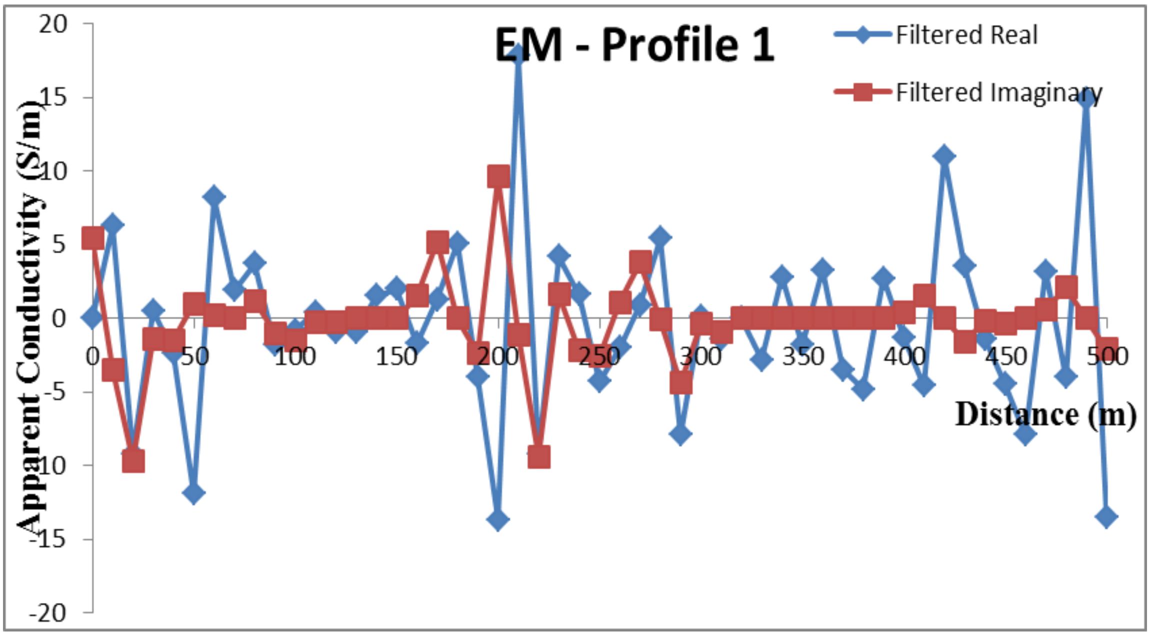


Figure7a. *Representative VLF-EM anomaly curves*

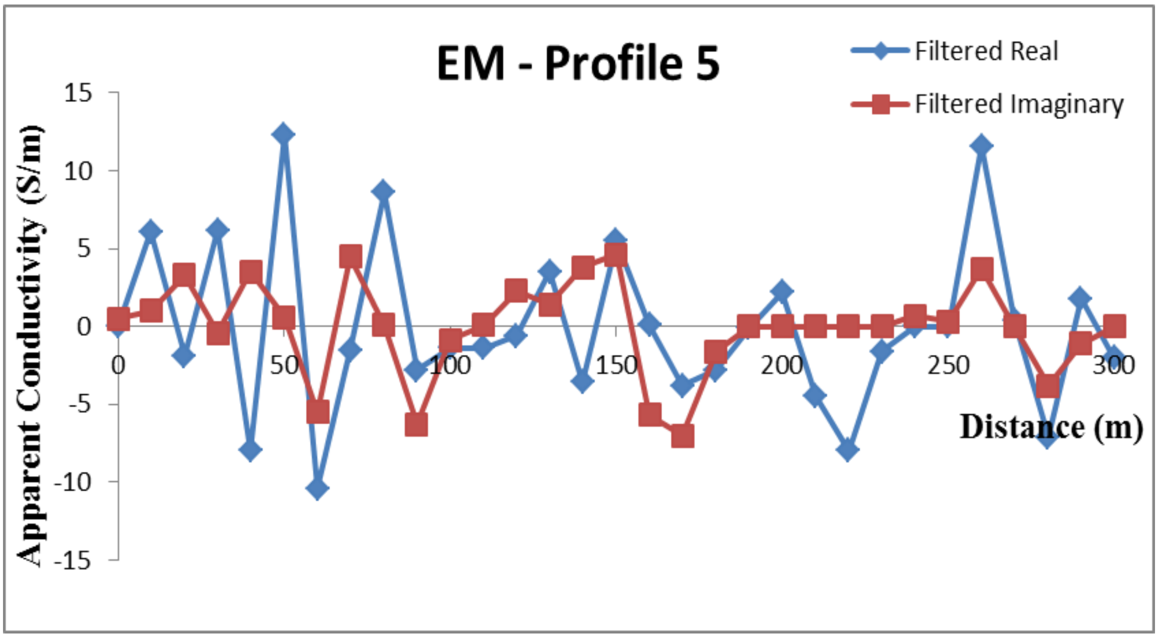


Figure7b. *Representative VLF-EM anomaly curves*

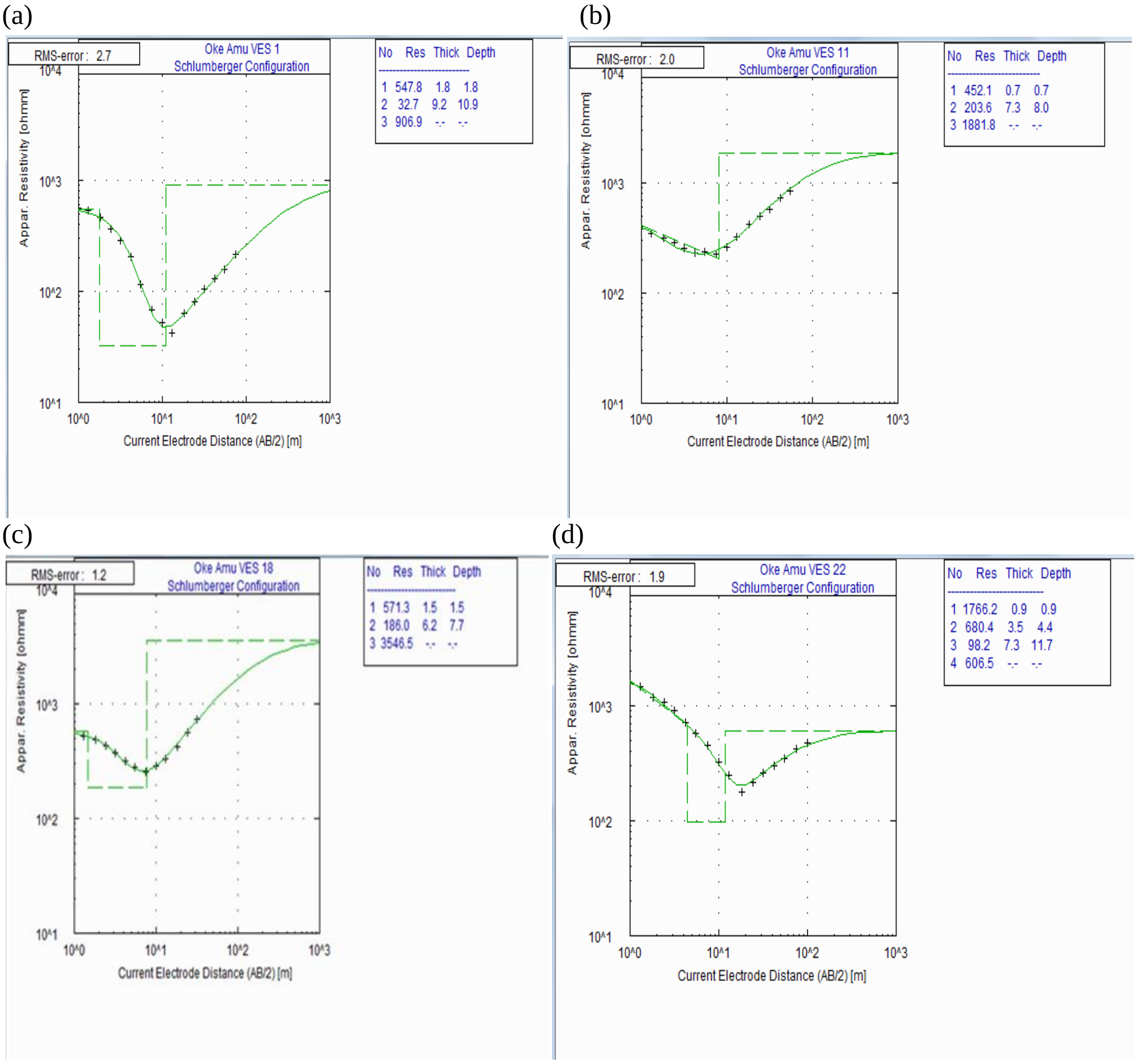
Table1. *Table showing highest apparent conductivities across VLF-EM profile line*

VLF-EM PROFILE LINE	HIGHEST APPARENT CONDUCTIVITIES AT FILTERED REAL (S/m)	CORRESPONDING PROFILE DISTANCE (m)
1	18.0	210
2	20.0	390
3	24.0	220
4	12.5	60
5	12.5	50
6	10.0	120
7	20.0	140
8	6.0	10
9	12.0	10
10	15.0	310
11	2.5	100

The table above indicates that apparent conductivities for the area are generally lower than about 24 S/m. Large positive anomalies in the filtered real part curve have been the suitable zones to explore for groundwater as they are characterized by good conductors. VLF Profile 1 shows how apparent conductivities over this part of the study area are highly varied. High apparent conductivities are noticed at point-distance 60m, 210m, 420m and 490m with 8S/m, 18S/m, 12S/m and 15S/m respectively, compared to other points.

3.3 Vertical Electrical Sounding

The results of the VES interpretation were presented as curves, charts, tables and geoelectric sections. The representative VES curves shown in figures 8(a)-(d) below reveal that the study area is underlain by three distinct layers in some parts while other part is underlain by four layers. Table 2 shows the representative summary of the geoelectric parameters and the geologic interpretation.



Figures 8(a)-(d). *Representative VES curves.*

Table2. *The representative summary of the geoelectric parameters*

VES Station	Layers	Resistivity (Ohm-m)	Thickness (m)	Depth to Bedrock (m)	Curve type	Probable Lithology
1	1	548	1.8			Topsoil
	2	33	9.2			Weathered Basement
	3	907	-	11.0	H	Fresh Basement
11	1	452	0.7			Topsoil
	2	204	7.3			Weathered Basement
	3	1882	-	8.0	H	Fresh Basement
18	1	571	1.5			Topsoil
	2	186	6.2			Weathered Basement
	3	3547	-	7.7	H	Fresh Basement
22	1	1766	0.9			Topsoil
	2	680	3.5			Lateritic clay
	3	98	7.3			Weathered Basement
	4	607	-	11.7	QH	Fractured Basement

Generally, the mean values for the thickness of these units are 1.3 m for topsoil, 2.6 m for lateritic clay and 8.1 m for weathered basement. Likewise, the mean values for the resistivity of these units are 648 Ohm-m for topsoil, 797 Ohm-m for lateritic clay, 156 Ohm-m for weathered basement and 1988 Ohm-m for fractured/fresh basement. The depth to basement or overburden thickness across the study area ranges between 2.3 m and 26.0 m at VES 17 and VES 26 respectively with a mean value of 9.9 m thereby indicating a shallow basement.

The results of the interpreted VES curves were transformed into geoelectric sections which gave a clearer picture of the subsurface in terms of lateral variation in resistivity of subsurface layers with respect to depth. Eleven geoelectric sections were drawn across the study area. Figure 9 shows a representative of the section. From the VES curves interpretation, it is obvious that H-type curve is the predominant type while other curves obtained are A-type, QH-type and KH-type.

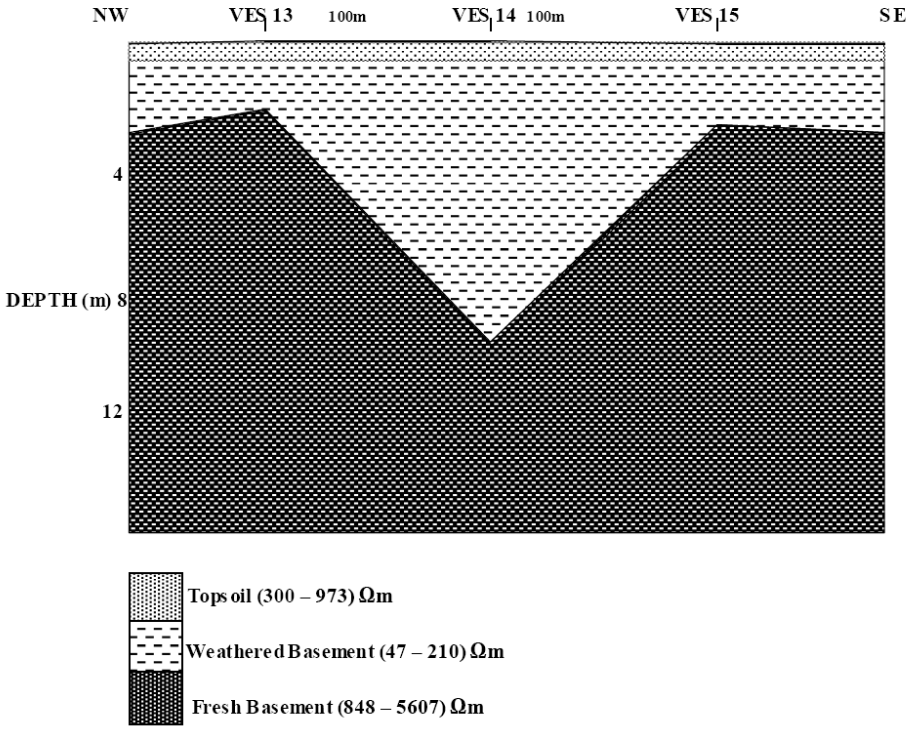
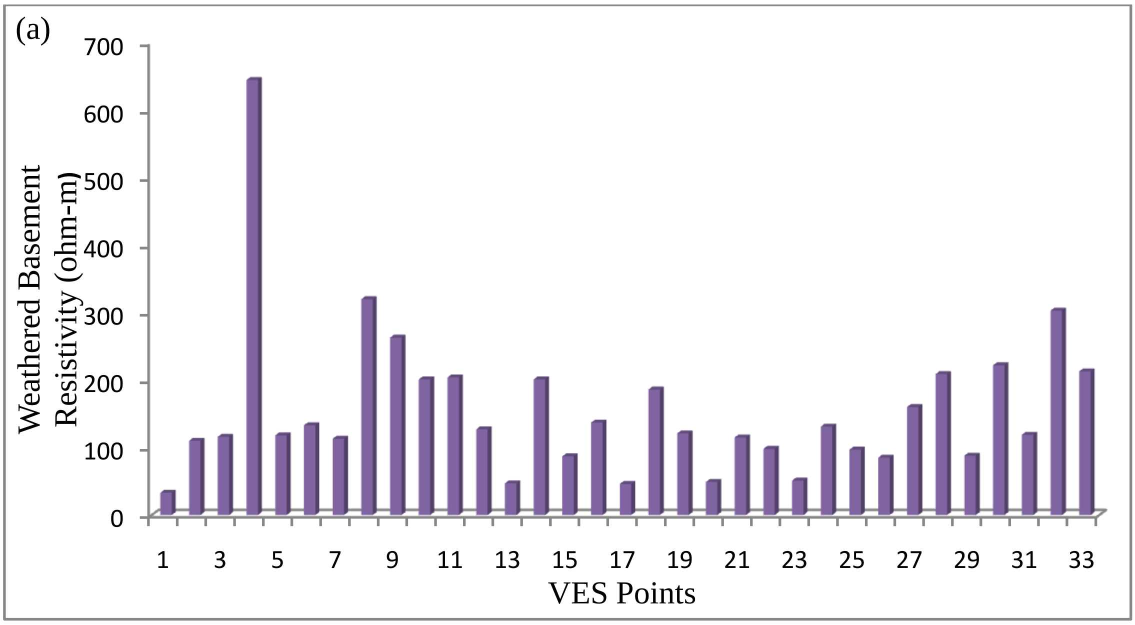


Figure9. *Representative of Geoelectric section on VLF Profile 5*

The weathered basement which has been observed to be the second layer in 81.82 % of the VES points investigated and the third layer in the remaining VES points has resistivity values ranging from 33 to 645 Ohm-m at VES 1 and VES 4 with a mean of 156 Ohm-m. The thickness of this layer also ranges from 1.4 to 24.7 m with a mean of 8.1 m. A chart for the weathered basement resistivity in the study area is presented in figure 10 (a) while figure 10 (b) shows the chart for weathered basement thickness. The thickness is relatively thin in the central part of the study area and becomes thicker while moving outward from the central part. The weathered basement thickness has been observed to be thickest in the south-southeastern (SSE) part of the study area.



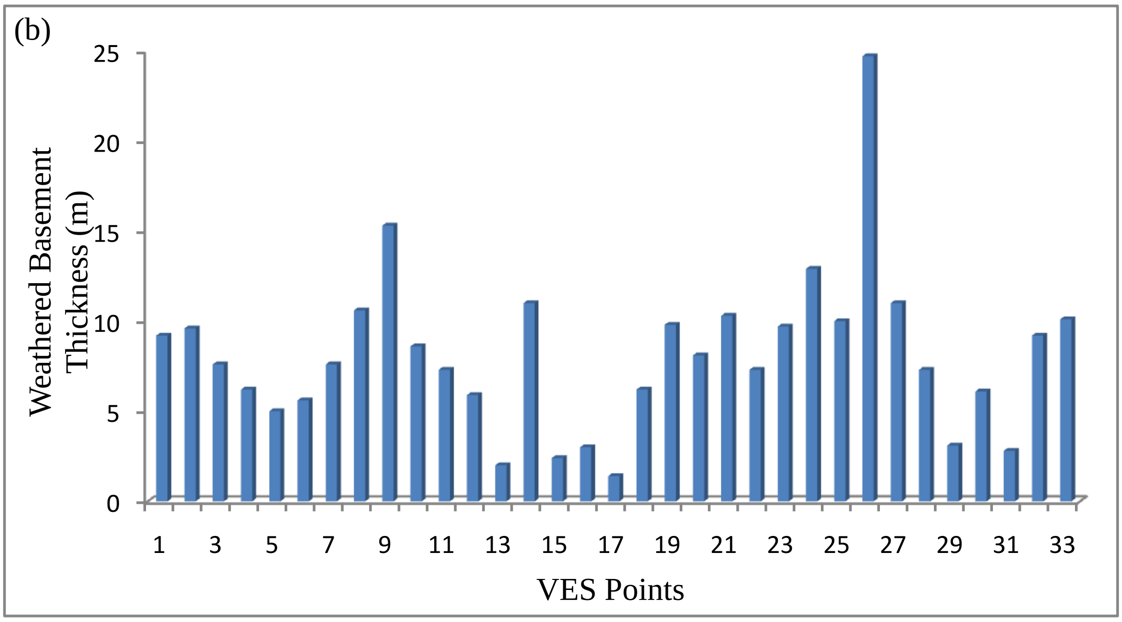


Figure10. *(a) Weathered Basement Resistivity Chart. (b) Weathered Basement Thickness Char*

4. Conclusions

Very Low Frequency Electromagnetic survey has been very relevant in the delineation of near surface fractures while Vertical Electrical Sounding of Electrical Resistivity survey has been more relevant and useful in the estimation of overburden thickness and presentation of geoelectric section. Areas with some thick weathered basement, low resistivity, thick overburden, fracture basement and basement depression are priority areas for possible groundwater development. The research study has shown a good correlation with the groundwater potential of the boreholes drilled prior to this investigation and also provided adequate information for a good understanding of the hydrogeology potential of the subsurface.

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