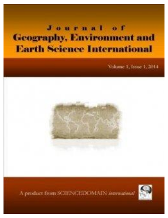

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The Use of Combined Geophysical Survey Methods for Groundwater Investigation in a Typical Basement Complex Terrain: Case Study of Erunmu, Ibadan, Southwest Nigeria

Abudulawal, Lukuman[1*]

[1] *Department of Geology, Faculty of Science, The Polytechnic, Ibadan, Oyo State, Nigeria.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

A combined Survey involving the very low frequency electromagnetic (VLF – EM) and Electrical resistivity surveys were carried out in order to appraise the groundwater potential, and locate appropriate positions for sighting boreholes in Erunmu Community, Egbeda local government area, Oyo State, Nigeria. VLF data were obtained along five traverses as the first step in order to locate suitable vertical electrical sounding (VES) stations. Vertical Electrical Soundings using Schlumberger array were thereafter carried out at twenty 20) locations. The integrated interpretation of both data confirms the presence of aquifers, which includes, weathered zone and basement transition/fractures beneath the area, which prior to this investigation have a history of failed boreholes and wells. The resistivity curve types obtained includes H and A which revealed the presence of 3 to 4 subsurface layers consisting of topsoil, the clay, the sandy clay, fractured zone and the highly resistive bedrock. The resulting geo-electric section from the interpretation revealed the Reflection coefficient which ranges from 0.45 – 0.98. The dominated curve type in the area investigated is the H which is typical of basement complex while the A-type is about 20% of the total curves. Hydrogeological, the topsoil is not important because the degree of water

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**Corresponding author: E-mail: abudulawall001@gmail.com;*

saturation in this layer is very low and cannot be utilized for groundwater. The fractured basement layer (which is present in less than 15% of the study area is very relevant in groundwater prospecting; when it is thick enough the layer could support borehole drilling. Areas identified as geological interfaces in the VLF anomaly charts were also confirmed by the interpreted VES data as poor and intermediate zones for groundwater potential in the study area. The significance of this study is such that it will serve as a useful reference for future research efforts in the aspect of basement complex groundwater studies.

Keywords: Vertical electrical sounding (VES); VLF-EM; reflection coefficient; basement layer.

1. INTRODUCTION

Groundwater occurrences in Precambrian basement terrain are hosted within zones of weathering and fracturing which often are not continuous in vertical and lateral extent. Electromagnetic (EM) profiling and VES are the two complementary and widely used geophysical methods in the delineation of basement regolith and location of fissured media and associated zones of deep weathering in crystalline terrains. In many instances, reconnaissance EM surveys are used to locate aquiferous zones such as fractures, faults and joints while Vertical Electrical Sounding, on the other hand, provides information on the vertical variation in electrical resistivity with depth. It is commonly used to assess the reliability of the fractures delineated from the EM survey [1,2]. Electrical resistivity (ER) and very-low-frequency electromagnetic induction (VLF) surveys are sensitive to groundwater quality medium [3,4,5,6,7,8,9]. The electromagnetic (EM) VLF methods have found a useful application in site investigation for groundwater development, most especially in basement complex areas [10,11,12]. Its relevance is claimed to be in overburden thickness (Depth to basement bedrock) estimation and basement fracture delineation [13].

The electrical resistivity method is a unique geophysical tool used in groundwater and landfill studies [14,15]. The resistivity method is used for electrical sounding and imaging. The electrical sounding provides information about vertical changes in subsurface electrical properties and thus, it is useful in the determination of hydrogeologic conditions such as the depth to the water table, depth to bedrock, and thickness of soil [14,16].

2. MATERIALS AND METHODS

2.1 The Study Area

The study area is located at Erunmu, Nigeria which is demarcated by the following coordinates latitude 7^0 25‘ N to 7^0 27’ N and longitude 4^0 3’ E to 4^0 4’ E, within the humid tropical region with two distinct seasons. The rainy season could be demarked from March to October and dry season from November to March. The basement complex is divided into two provinces. The Western Province and the Eastern province. The Western Province has comprised of NNE-SSW trending schist belts separated from one another by migmatites, gneisses and granites and the Eastern Province comprises mainly migmatites, gneisses and large masses of Pan-African granitoid (Older Granites) intruded in Jos plateau, by Jurassic peralkaline granites as shown in Figs. 1 and 2.

2.2 Method of Data Acquisition

The geophysical investigation involved the Very Low Frequency (VLF) Electromagnetic and Electrical Resistivity methods. These two methods are both responsive to water-bearing fractures columns due to their relatively high-bulk electrical conductivities. The Electrical Resistivity method involved the vertical electrical sounding (VES) with the use of the Schlumberger array. The soundings (twenty in all) were carried out at locations of prominent VLF anomalies, which are presumably typical of basement fractures. The VLF-EM measurements were made at 5.0m interval along with five (5) approximately North-South Traverses (Fig. 2). The VLF Traverses range in length from 150- 600m. The ABEM WADI VLF-EM meter was used for the data collection. The equipment measured the real (in-phase) and quadrature (out of phase) components of the vertical to horizontal magnetic field ratio.

Characteristic pattern and nature of the anomalies presented by various rock and soil types and how they vary with the conditions of the pattern (depth, dip, presence of a conductive intrusive bodies and lateral variations of the resistivities at depths, etc.) are displayed in the profiles and iso-values maps of the real (the in-phase). The data collected along the existing routes were filtered using both Fraser and Karous-Hjelt filters, thereby providing a means of removing geologic and noise originating from the transmitter. Karous and Hjelt [17] filter computes approximate current density of the subsurface giving rise to relative data across the resulting profiles [18]. In a similar way, the Fraser filter transforms the VLF anomalies to contours in such a way that proper crossovers are transformed to positive peak readings, while reverse crossovers become negative values [8]. The VLF survey was carried out by collecting data along five (5) trasverses and modeling this using computer software (KHFIT), from which twenty (20) VES stations were delineated in the study area. The data collected from the twenty (20) stations were interpreted manually using partial curve matching to obtain the initial model parameters, while these parameters were fed into the computer using a specialized software (RESIST 1.0) in order to obtain the final model parameters, which were then analyzed qualitatively using type curves and geo-electric section to evaluate the sub-surface hydrogeological conditions.

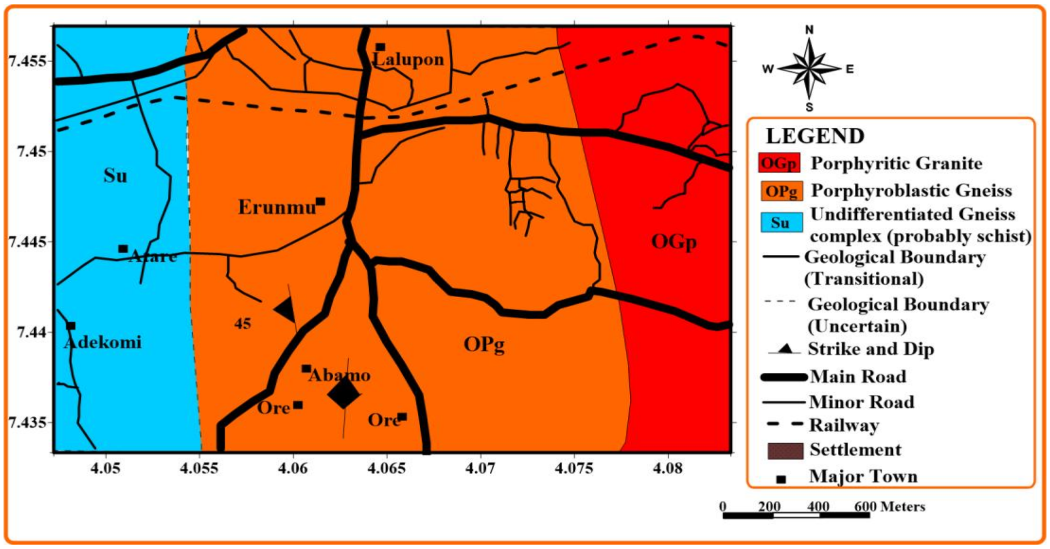


Fig. 1. Map of the study area

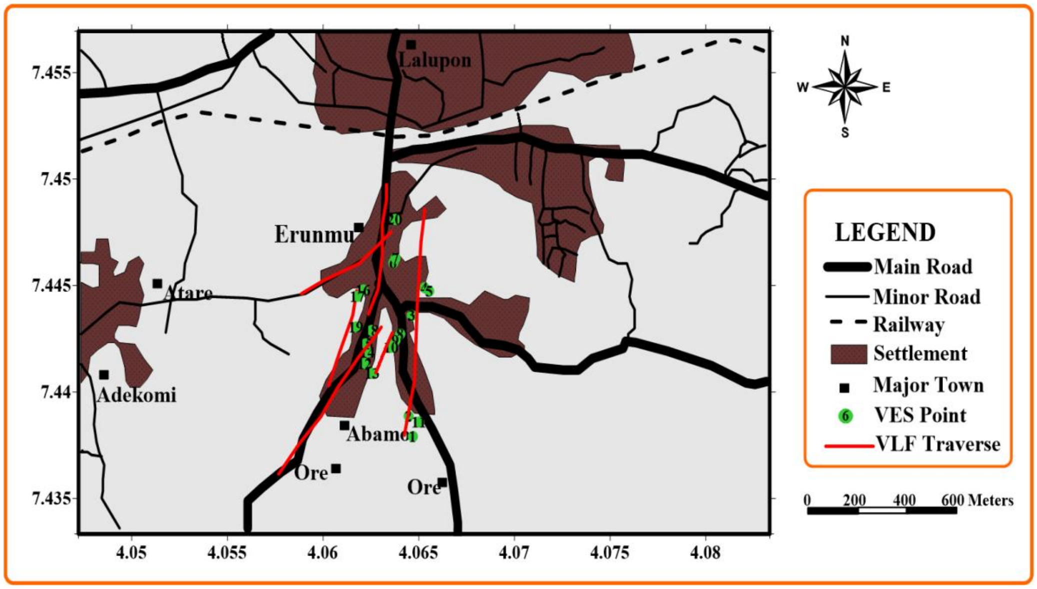


Fig. 2. Location map of the study area (Erunmu and its environs)

3. RESULTS AND DISCUSSION

Qualitative and semi-quantitative interpretations of the VLF-measurements profiles were made to map occurrence of localized alterations of conductive and resistive rocks as well as contacts among materials of different conductivity. Figs. 3-7 shows typical inverted current density pseudo sections and smoothened real components obtained using the Karous-Hjelt' 2D-inversion program named KHFfilt Version 1.1a. The pseudo sections are displayed as the equivalent current density estimated from the filtered real component of the VLF data. The colour pane indicates a bluish to green colour for the resistive medium, while yellowish to red colour range indicates conductive medium. The locations of the conductors are specified by cross over points in the in-phase and a positive peak in the filtered-real (current density) plots as shown in Figs. 3a, 4b, 5c, 6d and 7e, while location and identification of proper cross over points are enhanced in the Fraser filtered data in Figs. 3-7.

The Fraser filtered data improves identification of the conductive anomalies and removes false impression from the false cross-over points that usually make interpretation of the measured data difficult.

Along profile 1, the current density profile shows existence of two anomalies located at 30m and 340m. A shift in the location of the two anomalies is indicated in the in-phase component plot. The first anomaly has the appearance of an anomaly over a conductive zone with southward orientation and is shallower in depth. The corresponding filtered real using Fraser filter helps to delineate the location of these anomalies as well as collapsing the false cross over points that usually makes interpretation of the measured data difficult. Series of shallow and near surface bodies, which were recognized as conductive bodies on the pseudo -section (Fig. 2): have low amplitude.

VLF results tend to be rather noisy, being distorted by minor anomalies due to small local (usually artificial) conductors and electrical interference. Noise can be reduced by adding together results recorded at closely spaced stations and plotting the sum at the mid-point of the station group. This is the simplest form of low-pass filter.Two common types of filtering designed to carry out these operations are; The Fraser filter uses four equal-spaced consecutive readings. The first two are added together and halved. The same is done with the second two and the second average is then subtracted from the first. The more complicated Karous–Hjelt filter utilizes six readings, three on either side of a central reading that is not itself used. The ABEM WADI instrument automatically displays K–H filtered data unless ordered not to do so.

The interpretation of WADI data is generally based on the filtered real part with the aid of the Karous-Hjelt filter, which enables the distribution of the current density responsible for the secondary magnetic field to be displayed as the isovalue maps and interpreted as maps of current density [18]. The filter therefore provides a pictorial indication of the depth of the various current concentrations and hence the spatial dispositions of subsurface geological features, such as mineral veins, faults, shear zones and stratigraphic conductors [19]. Filtered data used to contour the K–H filter can also be used to compute current-density pseudo-sections. Information on the nature of overburden can be deduced from the filtered imaginary part. However, VLF data cannot be used to determine patterns of simultaneous current flow at different depths.

Along profile 2, there is no anomaly observed on the pseudo-section displayed (Fig. 4). The Fraser filter shows that the real component has no peak along the profile line. There are no conductive zones along the profile. The graph plotted on the excel show that there is no positive peaks for the profile and it shows that the place is highly resistive. Profile 3, with (Fig. 5) Showing a single anomaly which is seen at 73 m along the profile line on the plotted graph, on the Fraser filter plot and on the pseudo-section. The characteristic amplitude of these anomaly revealed that the conductors are relatively nearer to the surface and is at the point where it was identified i.e. it does not spread.

Along profile 4, the appearance of 2 conductive sections at distances of about 120 to 160 and 400 to 470m corresponding to 2 sharp positive peaks in Fig. 6, while the figure revealed existence of five anomalies with relative cross over distance at approximate 140, 220, 400, 420 and 450 m. It was discovered that some of the anomalies occur relatively at intermediate depth while the anomalies between 400 and 450 are shallower in appearance (Fig. 6).

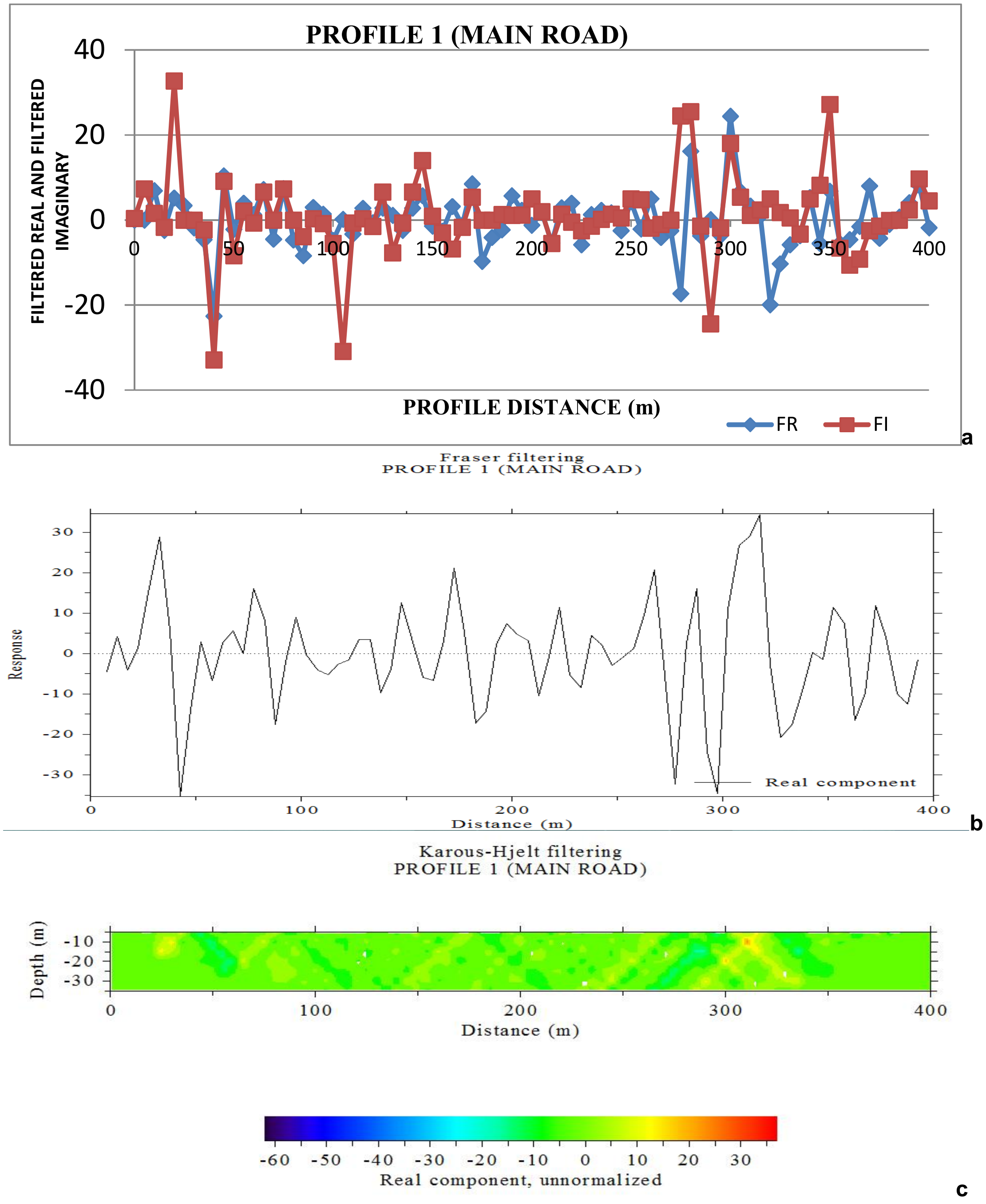


Fig. 3. The graph of the Filtered Real and Filtered Imaginary, smoothed in-phase Fraser filter and Inverted 2-D pseudo sections of the VLF-EM real component data for the profile 1

Profile 5, with E-W orientation shows characteristic anomalies indicating a source in Fig. 7, which was later recognized as extensive on the pseudo-section at a deeper depth which is encountered at between 75 and 105 m. The anomalies were also identified with similar signature the characteristic amplitude of these anomalies revealed that the conductors are relatively at a deeper depth. The pseudo current density section also revealed a deeper conductive zone.

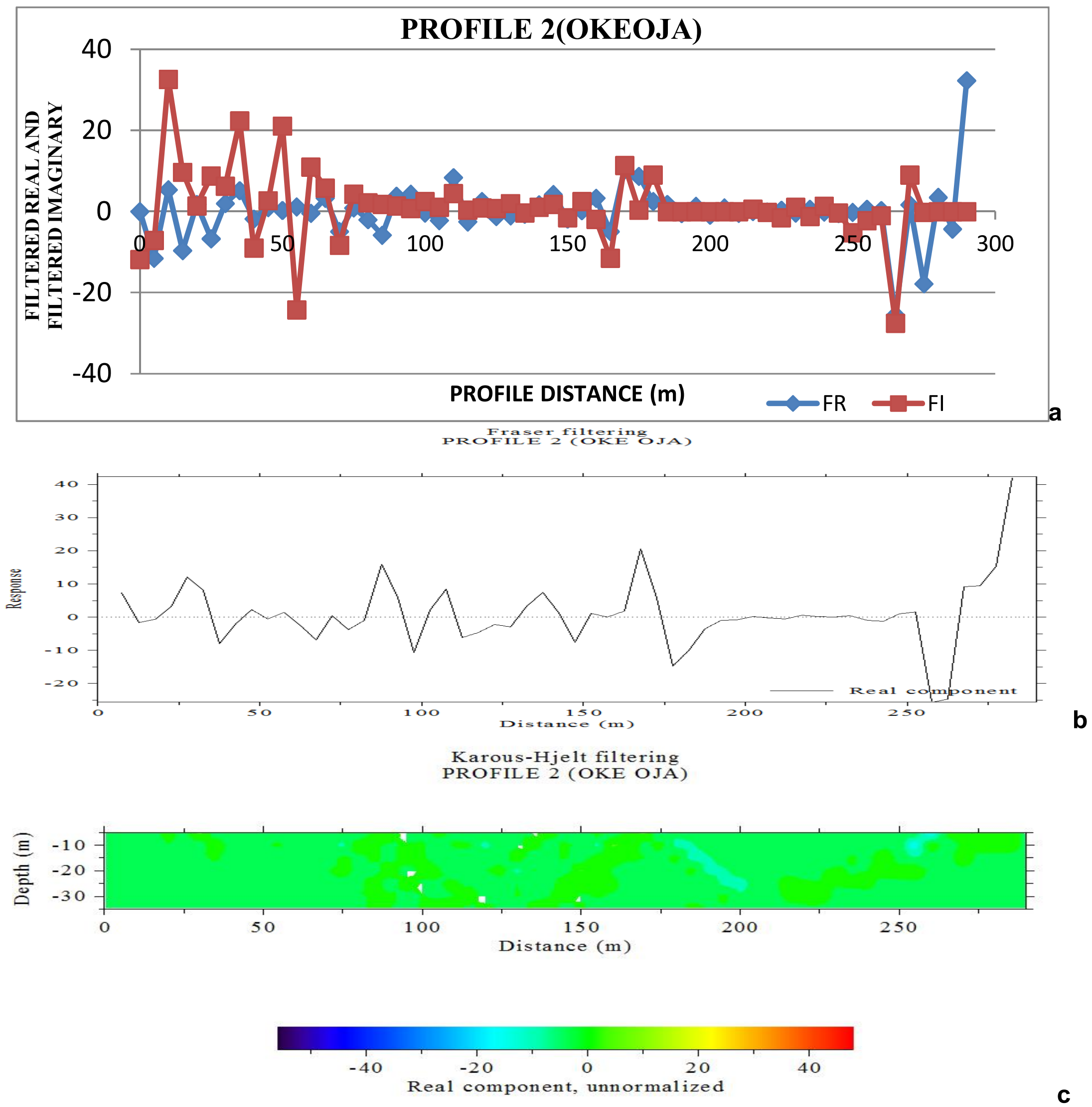
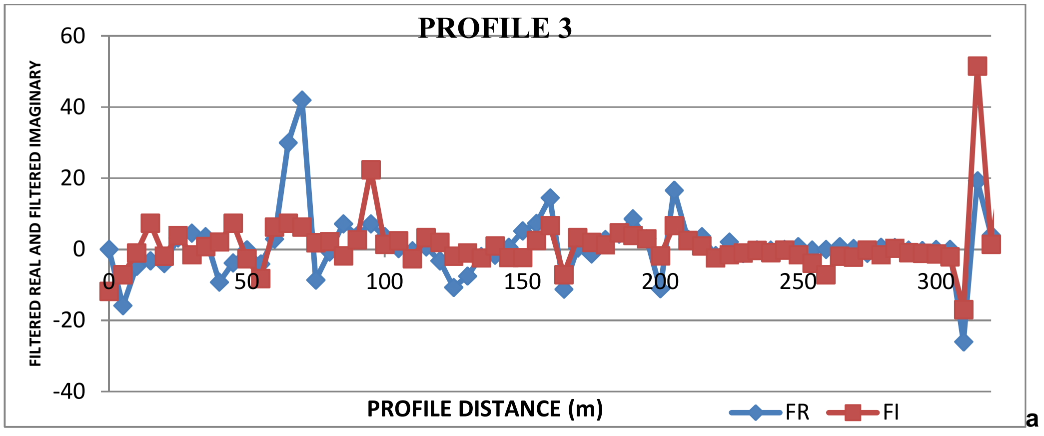


Fig. 4. The graph of the filtered real and filtered imaginary smoothed in-phase fraser filter and Inverted 2-D pseudo sections of the VLF-EM real component data for the profile 2



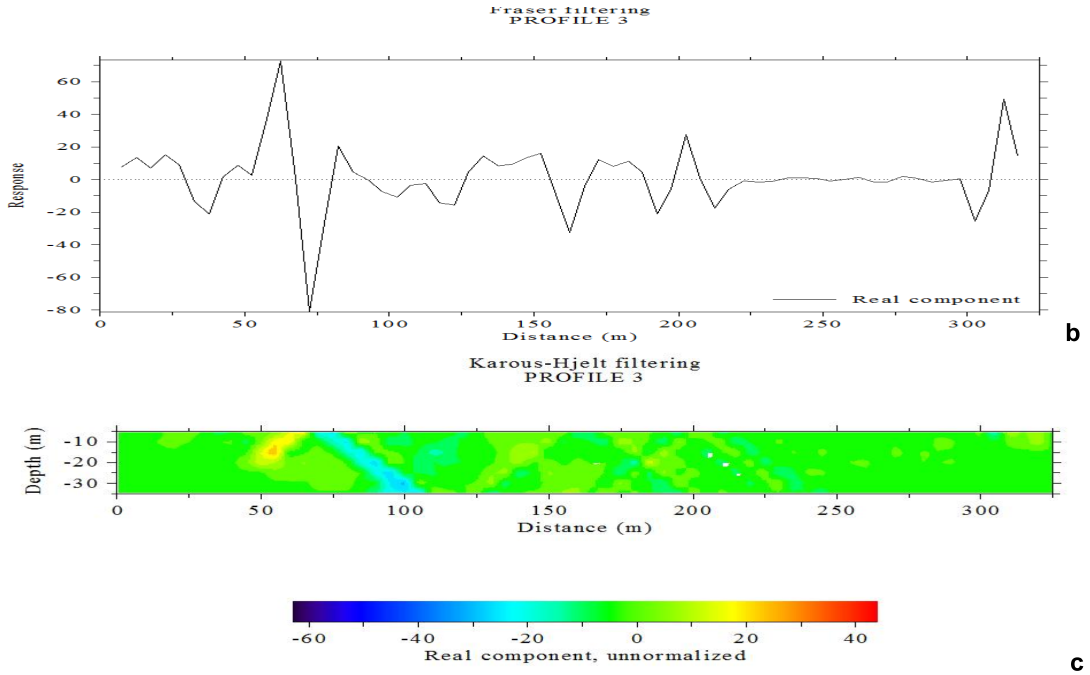
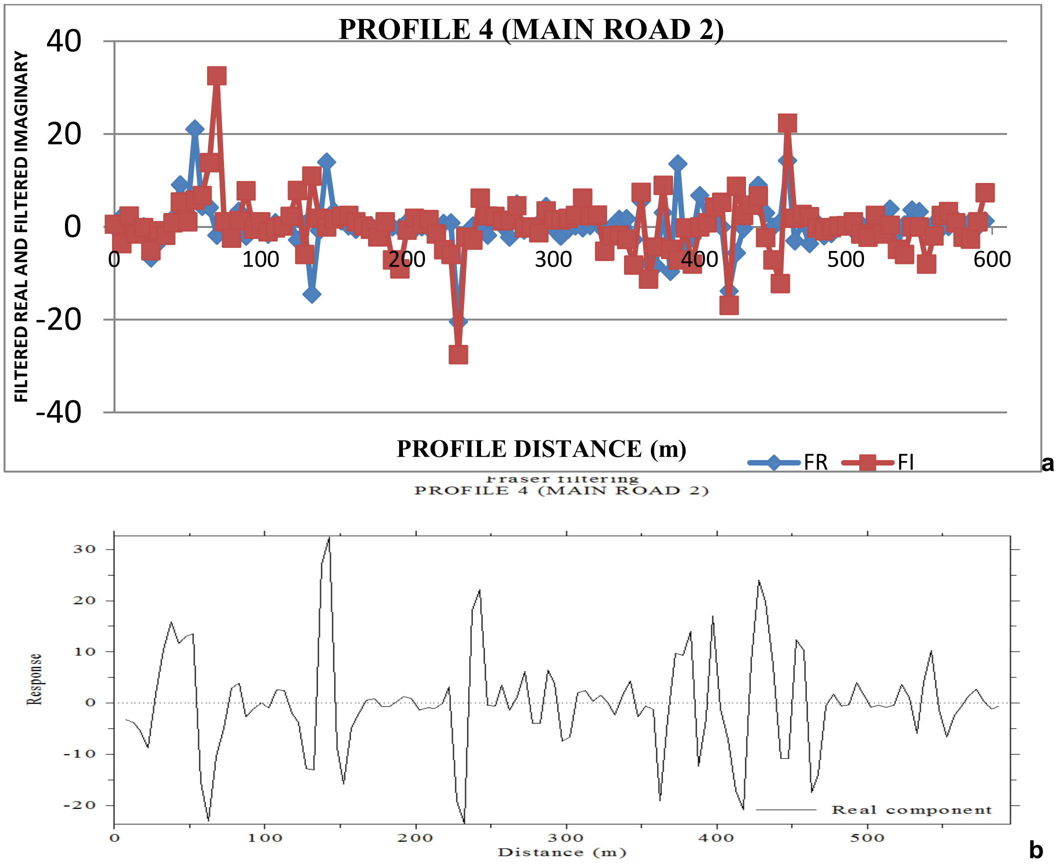


Fig. 5. The graph of the Filtered Real and Filtered Imaginary, smoothed in-phase Fraser filter and Inverted 2-D pseudo sections of the VLF-EM real component data for the profile 3



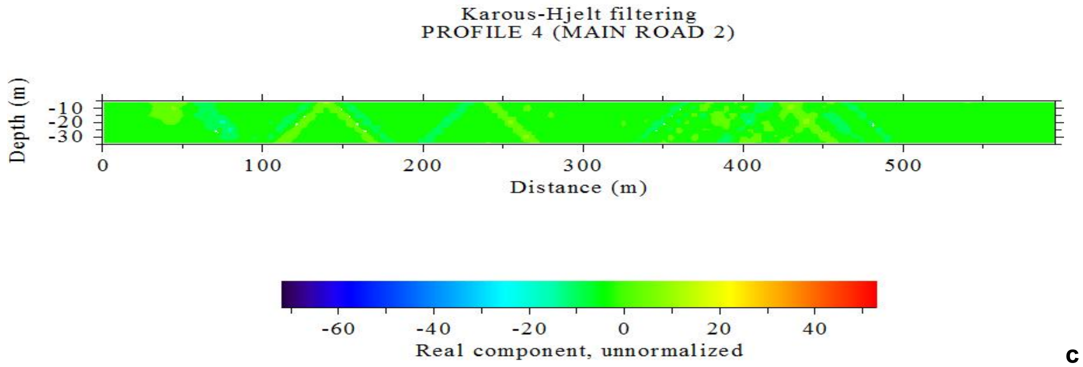


Fig. 6. The graph of the Filtered Real and Filtered Imaginary, smoothed in-phase Fraser filter and Inverted 2-D pseudo sections of the VLF-EM real component data for the profile 4

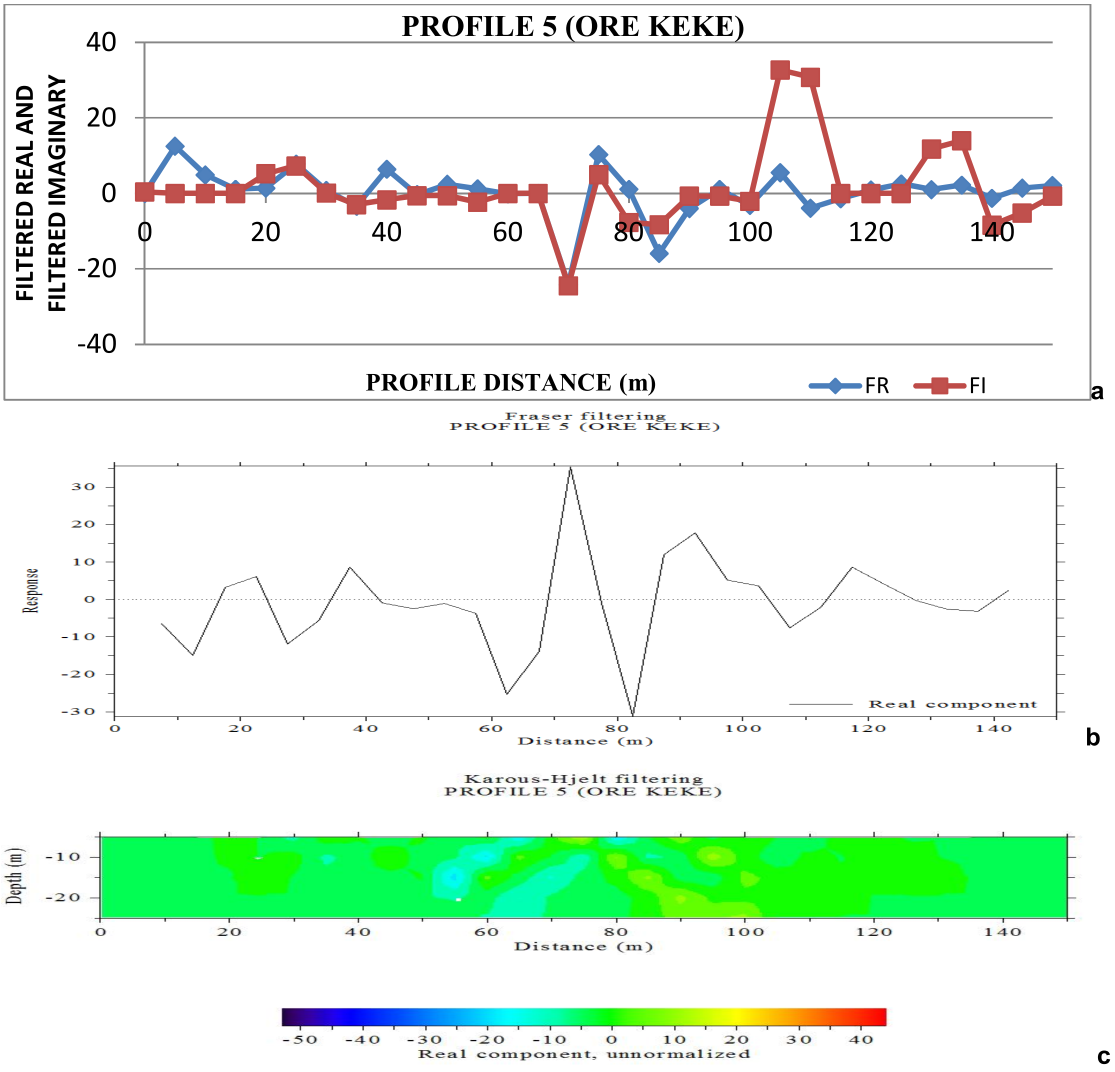


Fig. 7. The graph of the Filtered Real and Filtered Imaginary, smoothed in-phase Fraser filter and Inverted 2-D pseudo sections of the VLF-EM real component data for the profile 5

3.1 Iso-value Maps of the Real

Fig. 8 presents the outputs of the filtered real component data as maps of the Fraser-filtered in-phase and equivalent Karous-Hjelt filtered (current density) maps. The maps clearly show the rock types in the area as indicated by various zones with varying conductivity contrast. Although, it is difficult to differentiate the rocks based on the observed anomalies, however, the identification of location and lateral extent of these rock types can be easily realized from these maps. The current density map showed that the conductive zone in the area can be found in the southwestern part of the map. The map clearly showed that the porphyroblastic gneiss that underlain the area investigated do not have conductive zones within it and this means that weathering of the basement is not deep. The southwestern part of the map may be considered for groundwater development in that area because of the conductivity of the rock in the area. The 3-D map of the isovalues of the current density gives the disposition of the conductivity of the area investigated and it show that the area is resistive and there is little or no conductive zone in the area. Electrical resistivity method was used by [20] for groundwater investigation in parts of the Basement terrain in Southwest Nigeria and concluded also, that the weathered layer and the fractured Basement constitute the aquifer zones.

Very low frequency electromagnetic and vertical electrical sounding techniques was used by [21] in delineating aquifer zones in Modakeke area, Ife, Osun State. Electrical resistivity method was used by [22] in investigation of geo-electric and hydro-geologic characteristics of areas in Southwest Nigeria. Electromagnetic surveys by VLF-WADI Resistivity sounding was used by [23] to interpret the geologic structures and groundwater movement through fractures rock.

The manual interpretation and computer iteration of the VES data produced the dominated curve type in the area investigated is the H which is typical of basement complex while the A type is about 20% of the total curves. Hydro-geologically, the topsoil is not important because the degree of water saturation in this layer is very low and cannot be utilized for groundwater. The fractured basement layer which is present in less than 15% of the study area is very relevant in groundwater prospecting when it is thick enough the layer could support borehole drilling.

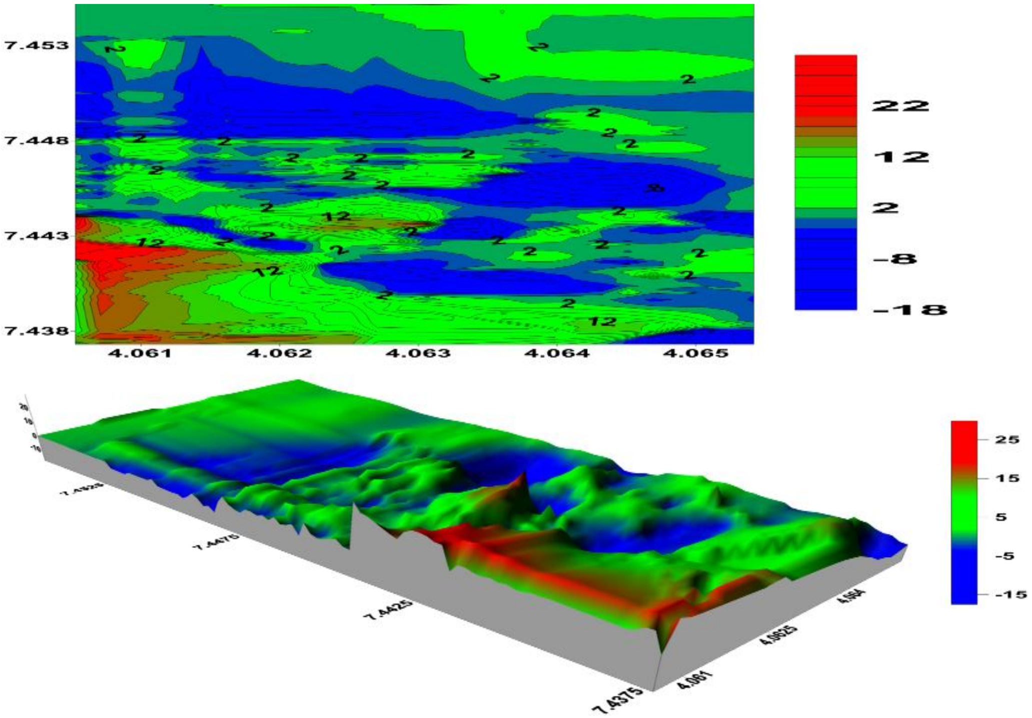


Fig. 8. Isovalue maps of the real of the study area

3.2 Vertical Electrical Sounding (VES) Curves

The VES curve types is predominantly the H-type and some A-type which typified basement terrain. The H-type show a system of three geo-electric layers of the topsoil, weathered basement and fractured/fresh basement while the A-type showed two geo-electric layers of the topsoil and the fresh basement. The figures presented below show the interpreted curves that were generated after curve matching and computer iteration using Resist 1.1 version.

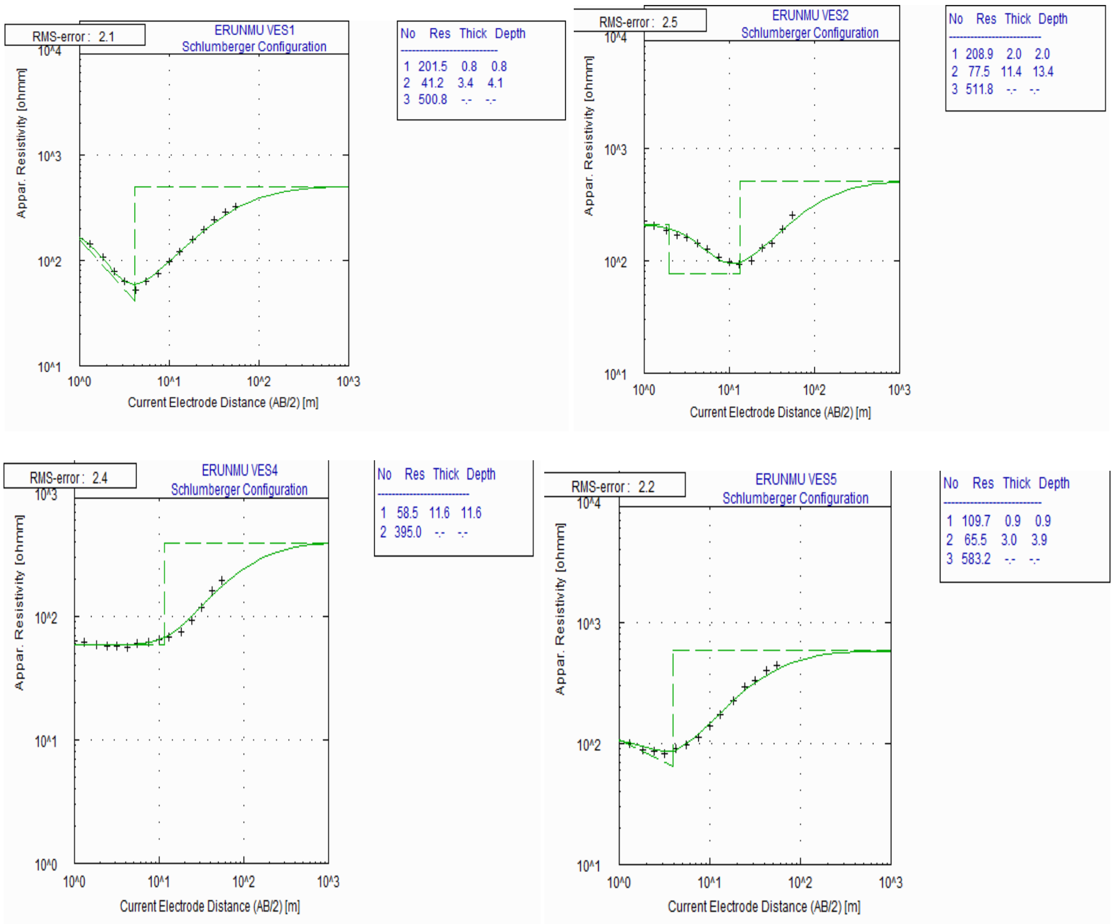
3.3 Isopach Map of the Overburden

Fig. 12 shows the overburden thickness for the surveyed area. The overburden as used in this work includes all materials above the presumably fresh bedrock. The map shows overburden thickness ranging between 2 and 13.4 m. The overburden is relatively not too thick around the southern part 10–13.4 m and the overburden in the central and the far north eastern part is very shallow while the overburden generally in other area is shallow [16].

Generally, the overburden of the study area is dominantly shallow when compared to the range given by [24] and [25]. The groundwater abstraction from the weathered or fractured basement may not be too feasible because of the occurrence of shallow overburden and the little or no existence of fractured zone in the investigated area.

3.4 Bedrock Relief Map

Fig. 13 shows the contour map of the bedrock elevation for the VES points. This bedrock relief map shows the basement topography, its structural resolution and also the degree of weathering of the basement. The hydrogeologic importance of this has been identified by [24].



No	Res	Thick	Depth
1	201.5	0.8	0.8
2	41.2	3.4	4.1
3	500.8	-.-	-.-

No	Res	Thick	Depth
1	208.9	2.0	2.0
2	77.5	11.4	13.4
3	511.8	-.-	-.-

No	Res	Thick	Depth
1	58.5	11.6	11.6
2	395.0	-.-	-.-

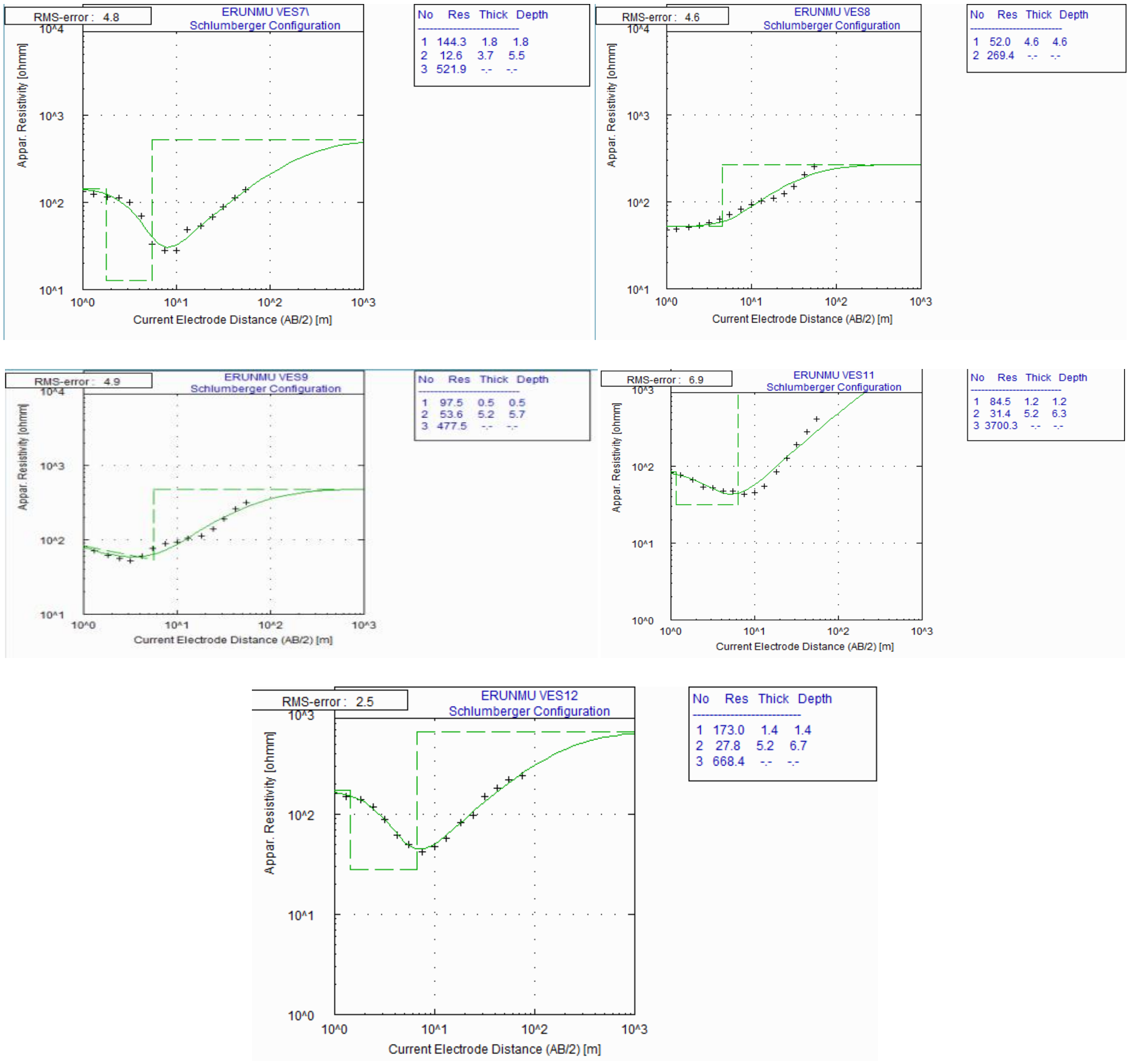
No	Res	Thick	Depth
1	109.7	0.9	0.9
2	65.5	3.0	3.9
3	583.2	-.-	-.-

Fig. 9. The Layer model interpretation for VES 1, 2, 4, 5

Table 1. Interpreted resistivity result for vertical electrical sounding VES

VES no	Layers	Resistivity (Ohms-m)	Layer thickness (M)	Depth (M)	Curve types	Reflection coefficient	Probable lithology
1	1	202	0.8	0.8	H	0.85	Topsoil
	2	41	3.4	4.1			Clayey
	3	501	-	-			Fresh Basement
2	1	209	2.0	2.0	H	0.74	Topsoil
	2	78	11.4	13.4			Sandy Clay
	3	512	-	-			Fresh Basement
3	1	239	0.7	0.7	H	0.66	Topsoil
	2	116	10.5	11.2			Sandy Clay
	3	558	-	-			Fractured Basement
4	1	59	11.6	11.6	A	0.75	topsoil
	2	395	-	-			fresh basement
5	1	110	0.9	0.9	H	0.80	Topsoil
	2	66	3.0	3.9			Sandy Clay
	3	583	-	-			Fresh Basement
6	1	76	2.2	2.2	H	0.91	Topsoil
	2	30	9.0	11.2			Clayey
	3	606	-	-			Fresh Basement
7	1	144	1.8	1.8	A	0.95	Topsoil
	2	13	3.7	5.5			Clayey
	3	522	-	-			Fresh Basement
8	1	52	4.6	4.6	A	0.69	Topsoil
	2	269	-	-			Fractured Basement
9	1	98	0.5	0.5	H	0.79	Topsoil
	2	54	5.2	5.7			Clayey
	3	478	-	-			Fresh Basement
10	1	89	2.5	2.5	A	0.45	Topsoil
	2	232	-	-			Fractured Basement
11	1	85	1.2	1.2	H	0.98	Topsoil
	2	31	5.2	6.3			Clayey
	3	3700	-	-			Fresh Basement

VES no	Layers	Resistivity (Ohms-m)	Layer thickness (M)	Depth (M)	Curve types	Reflection coefficient	Probable lithology
12	1	173	1.4	1.4	H	0.92	Topsoil
	2	28	5.2	6.7			Clayey
	3	668	-	-			Fresh Basement
13	1	136	1.1	1.1	H	0.64	Topsoil
	2	76	10.3	11.4			Sandy Clay
	3	355	-	-			Fractured Basement
14	1	301	1.2	1.2	H	0.84	Topsoil
	2	54	5.6	6.8			Clayey
	3	601	-	-			Fresh Basement
15	1	211	1.3	1.3	H	0.98	Topsoil
	2	18	2.7	4.0			Clayey
	3	1662	-	-			Fresh Basement
16	1	166	1.0	1.0	H	0.88	Topsoil
	2	55	4.8	5.8			Clayey
	3	858	-	-			Fresh Basement
17	1	72	1.2	1.2	H	0.64	Topsoil
	2	66	7.3	8.5			Sandy Clay
	3	305		--			Fractured Basement
18	1	158	1.5	1.5	H	0.97	Topsoil
	2	19	2.8	4.3			Clayey
	3	1409	-	-			Fresh Basement
19	1	224	2.6	2.6	H	0.91	Topsoil
	2	33	8.5	11.1	H		Clayey
	3	783	-	-			Fresh Basement
20	1	156	1.2	1.2	H	0.96	Topsoil
	2	40.5	4.8	6.0			Clayey
	3	2103.7	-	-			Fresh Basement



No	Res	Thick	Depth
1	144.3	1.8	1.8
2	12.6	3.7	5.5
3	521.9	-.-	-.-

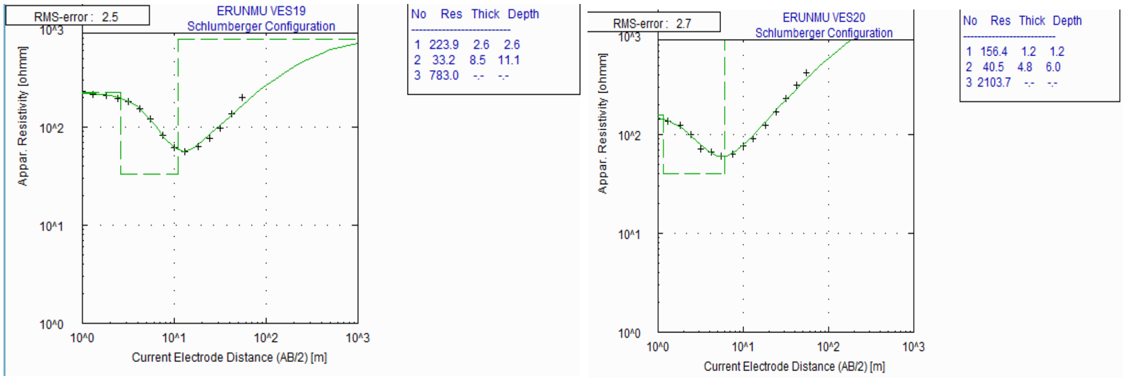
No	Res	Thick	Depth
1	52.0	4.6	4.6
2	269.4	-.-	-.-

No	Res	Thick	Depth
1	97.5	0.5	0.5
2	53.6	5.2	5.7
3	477.5	-.-	-.-

No	Res	Thick	Depth
1	84.5	1.2	1.2
2	31.4	5.2	6.3
3	3700.3	-.-	-.-

No	Res	Thick	Depth
1	173.0	1.4	1.4
2	27.8	5.2	6.7
3	668.4	-.-	-.-

Fig. 10. The Layer model interpretation for VES 7, 8, 9, 11 and 12



No	Res	Thick	Depth
1	223.9	2.6	2.6
2	33.2	8.5	11.1
3	783.0	-.-	-.-

No	Res	Thick	Depth
1	156.4	1.2	1.2
2	40.5	4.8	6.0
3	2103.7	-.-	-.-

Fig. 11. The Layer model interpretation for VES19 and 20

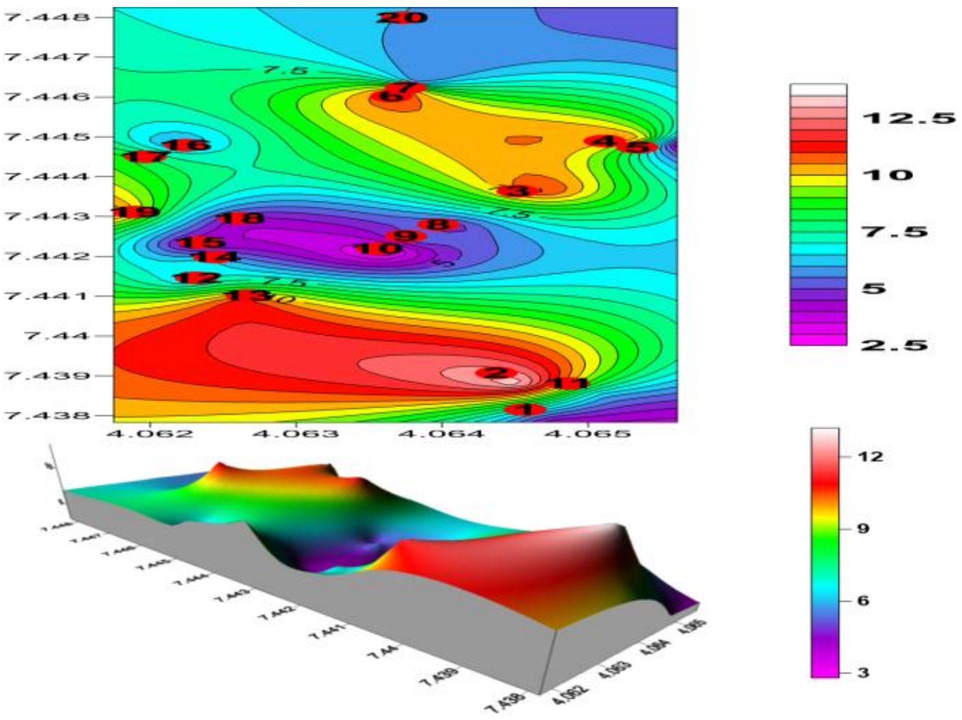


Fig. 12. The contour and the 3-D map of the overburden thickness of the area investigated

Topographic depressions and ridges are identified in the bedrock relief map. The depressions are characterized by the thick overburden as seen in the southern part of the map while ridges are noted for thin overburden cover as seen in the central and the northern part of the map. In addition to been characterized by thick overburden, basement depressions also constitute groundwater collecting troughs, especially the water displaced from the bedrock crest.

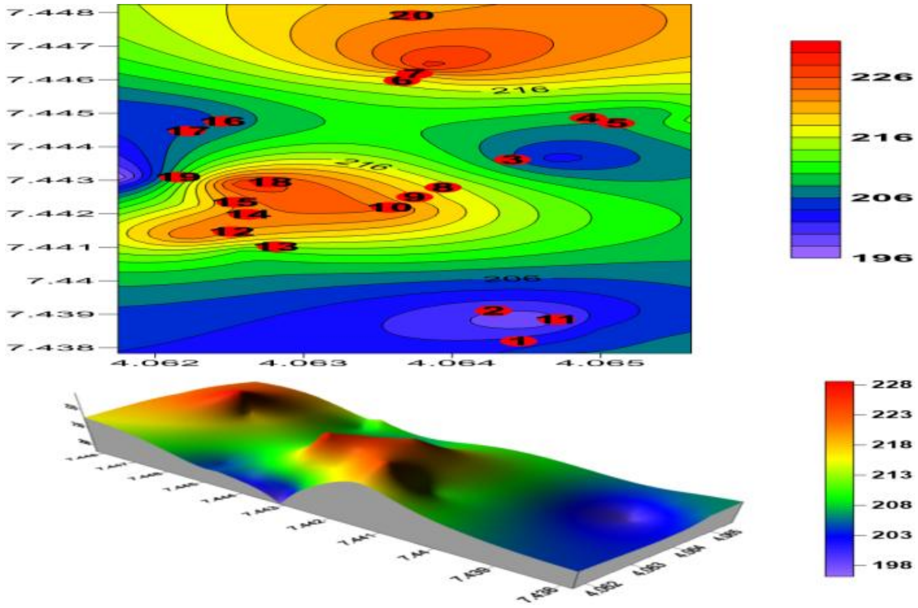


Fig. 13. The contour and the 3-D map of the bedrock relief of the area investigated

4. CONCLUSIONS

Based on the electrical resistivity survey conducted in the study area, groundwater potential producing zones have been delineated. The study reveals that about 90% of the study area has poor groundwater potential.The major drive was the fact that the area has a history of failed wells and boreholes due to lack of pre-drilling geophysical survey, thus resulting in shortage of potable water. Therefore, this effort aims at using geophysics to delineate part of the basement where sustainable amount of groundwater can be found. This was done using VLF – EM and electrical resistivity (VES) methods of survey.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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