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Geophysical Mapping of the Proposed Osun State Housing Estate, Olupona for Subsurface Competence and Groundwater Potential

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Abstract: Structural failure and water scarcity are one of the infrastructural challenges man faces today. The importance of foundation studies before erecting civil engineering structures such as buildings and highway cannot be overemphasized. Regardless of structure put on the surface of the earth, if the foundation or the subsurface structure is weak, such structure will eventually collapse. Groundwater exploration is gaining more importance in Nigeria owning to ever increasing demand for water supplies, as rain water and surface water are either scarce to get or got polluted by human activities. The study is therefore aimed at characterizing the subsurface for engineering competence and groundwater potential in Olupona Housing Estate, Ayedire Local Government Area, Osun State, Nigeria. An integrated geophysical mapping involving the Electromagnetic (VLF-em) and Vertical Electrical Sounding (VES) were carried out around the proposed housing estate, Olupona, Southwestern Nigeria in order to evaluate subsurface competency for engineering activities and the groundwater potential beneath the study area. Seven (7) traverses were each established for VLF-em survey in S-N and E-W orientation while Sixteen (16) VES stations were deployed along five (5) traverses in order to cover the entire study area. The data obtained were analyzed and processed qualitatively and quantitatively. The VLF-em revealed several geological features which ranged from -18.0 to 12.0 Sm^{-1}. Positive conductivity zones and negative conductivity zones were mapped in the study area. Some of the positive conductivities mapped showed that the conductive anomalies extended from surface to the depth of 40.0 m. VES analysis revealed three-to-four lithologic sequences which include topsoil, lateritic layer (not present in all), weathered layer, and fractured or fresh bedrock. H-type, HA-type and KH-type were the curve types obtained from VES data with the overburden thickness ranging from 8.0 to 51.66 m. It is concluded that the study area is underlain with thick overburden, thus making the study area unsuitable for construction of high-rise buildings. It is also affirmed that groundwater exploration is sparingly favoured in the study area.

INTRODUCTION

The importance of foundation studies before erecting civil engineering structures such as buildings and/or highway cannot be overemphasized. Regardless of structure put on the surface of the earth, if the foundation or subsurface structure is weak, such structure will eventually collapse. The type of study that is done before structures are erected is referred to as pre-impact assessment study and the one conducted after erecting a structure is called the post-impact assessment study. The importance of these studies should not be under estimated in any geological terrain. The foundation of a building is that part of walls, pillars and columns in direct contact with the ground and the one transmitting loads to the ground. The building foundation is referred to as the artificial foundation and the ground on which it stands is the natural foundation. Ground is the general term for the earth’s surface, which varies in composition within the two main groups, rocks and soils. Rocks include hard, strongly cemented deposit such as granite. The size and depth of a foundation is determined by the structure and size of the building it supports and the nature bearing capacity of the ground supporting it (Adagunodo, 2012). The nature of the soil or rocks supporting the engineering structures becomes an extremely important issue for safety, structural integrity, durability, and low maintenance cost. Foundation design (where all structures are erected) depends on the characteristics of both the structures and the soil or rock which makes the competence, strength and load capacity of the soil supporting the super structure becomes an extremely important issue for safety, structural integrity, assessment and durability of the super structure (Akintorinwa and Adelusi, 2009).

Groundwater has become immensely important for human water supply in urban and rural areas in developed and Exploration of groundwater in hard rock terrain is a very challenging and difficult task when the promising groundwater zones are associated with fractured and fissured media. In this environment, the groundwater potentiality depends mainly on the thickness of the weathered/fractured layer overlying the basement. Groundwater is a mysterious nature’s hidden treasure. Its exploitation has continued to remain an important issue due to its unalloyed needs (Venkata *et al*., 2014). The purpose of groundwater exploration is to delineate the water bearing formation, estimate their hydrological characteristics and determine the quality of water present in these formations. Geophysical methods are used to provide an indirect evidence of the subsurface formation that indicate whether the formations may possibly be aquifers. A number of geophysical exploration techniques are available which enables an insight to be obtained rapidly in the nature of water bearing layers and include geoelectric, electromagnetic, seismic and geophysical borehole logging. These methods measure properties of formation materials, which determine whether such formation may be sufficiently porous and permeable to serve as an aquifer (Anizoba *et al*., 2015). The use of geophysics for both groundwater resource mapping and for engineering studies has increased dramatically over the years due to the rapid advances in computer software's and associated numerical modeling solutions.

The electrical geophysical survey method is the detection of the surface effects produced by the flow of electric current inside the earth. The electrical techniques have been used in a wide range of geophysical investigations such as mineral exploration, engineering studies, geothermal exploration, archeological investigations, permafrost mapping and geological mapping. Using this method, depth and thickness of various subsurface layers and their water yielding capabilities can be inferred.

The very low frequency – electromagnetic (VLF-EM) technique is a passive method that uses radiation from ground-based military radio transmitters as the primary EM field for geophysical survey. These transmitters generate plane EM waves that can induce secondary eddy currents, particularly in electrically conductive elongated 2-D targets. The EM waves propagate through the subsurface and are subjected to local distortions by the conductivity contracts in this medium. These distortions indicate the variations in geoelectrical properties which may be related to the presence of groundwater. The subsurface occurrence of these conductive bodies creates a local secondary field which has its own components. Measurement of these components may be use as an indicator for locating the subsurface conductive zones.

Integrated geophysical methods which include Very Low Frequency electromagnetic (VLF) and Vertical Electrical Sounding (VES) techniques have been used in order to investigate into the subsurface of proposed Osun State Housing Estate Olupona Area of Ayedire Local Government Area, Osun State, Nigeria. This study evaluated the competency of the subsurface materials and the geologic condition of the area for suitable structures and possible potential zones for groundwater exploration. It also estimated the geo-electrical sequence and sub-surface geology of the area, the geo-electric parameters of the area, the engineering properties of the immediate near surface materials and the probable aquiferous units and the depth to the aquifer.

The Study Area, Location, Geology and Topography

The study area is the proposed location for Olupona Housing Estate which falls within Latitude 07° 36' 26.6" to 07° 36' 39.6" N and Longitude 04° 12' 0.1" to 04° 12' 10.4" E along Iwo–Ikire road of Ayedire Local Government, Osun State, Southwestern Nigerian. Olupona Housing estate and its environ is located along Iwo–Ikire road Ayedire Local Government, 2 km south of Iwo Township covering a land mass of 0.16 km². It is accessible with major road leading from Iwo, through Bowen University to Ikire while there are several minor roads and footpaths within Olupona village leading to the study area (Figure 1).

The area under investigation experiences tropical rainfall, which dominates most of Southwestern part of Nigeria. It has two distinct seasons; the wet season usually between the month of March and October and dry season which is between November and February. These two seasons define the climate of the study area. It falls within the Rainforest belt of Nigeria.

The study area is underlain with Precambrian basement complex of Southwestern Nigeria (Figure 2). The study area is underlain by quartzite and gneisses. Schistose quarzites with micaceous minerals alternating with quartzofeldsparthic ones are also experienced in the area. The gneisses are the most dominant rock type occurring as granite gneisses and banded gneisses with coarse to medium grained texture. Noticeable minerals include quartz, feldspar and biotitic. Pegmatites are common as intrusive rocks occurring as joints and as vein fillings in the area (Rahaman and Ocan, 1978). The Quartzites and gnneisses form good topographical features and was highly fractured. It strikes in a NW-SE direction. Minerological, quartzites are composed mainly of quartz (<90%) with minor amounts of muscovites, sillimanites, staurolite, garnet, hematite, graphite, tourmaline and zircon.

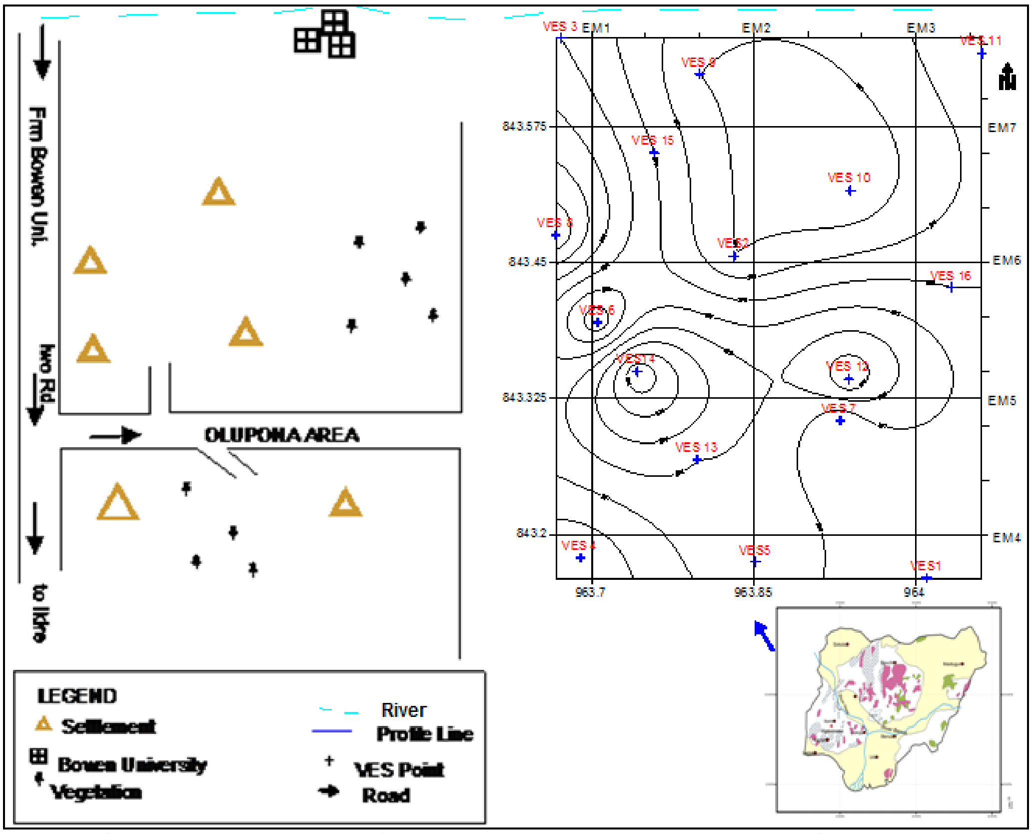

Figure 1: Base map of the study area showing the profile lines, VES points and 2-D topographical map of the study area.

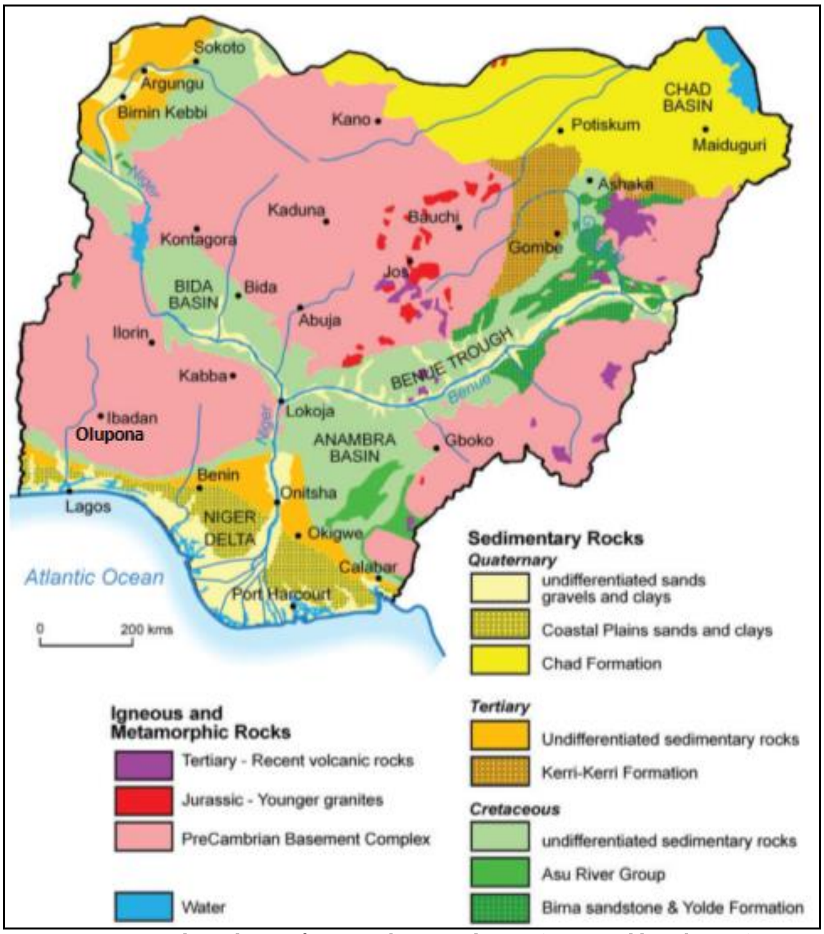

Figure 2: Geological map of Nigeria showing Olupona (MacDonald *et al*., 2005).

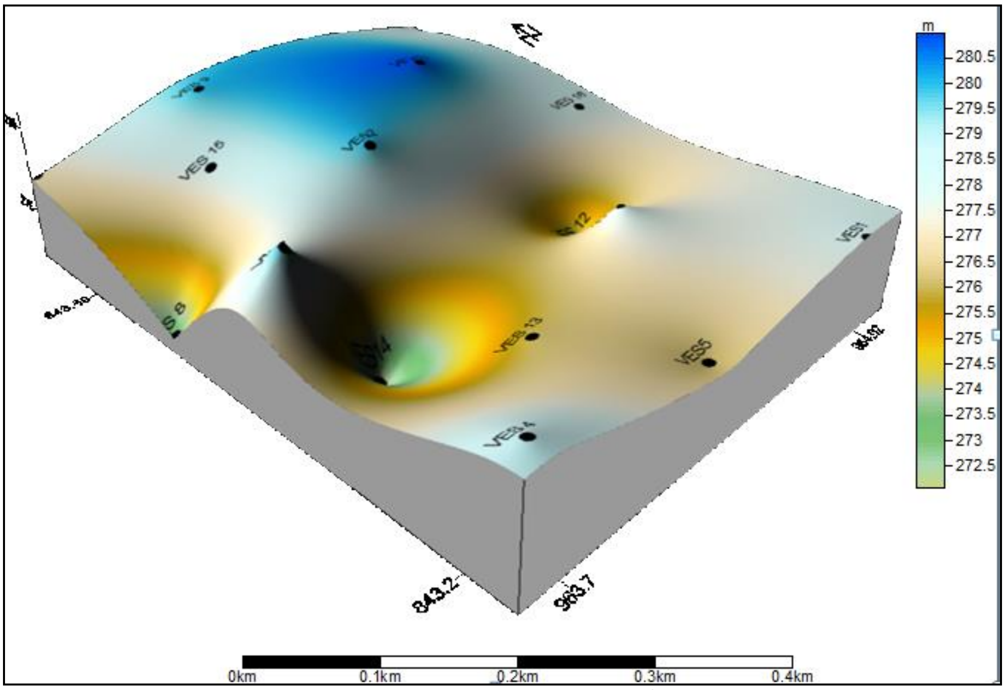

Figure 3: Three-dimensional topographical map of the study area.

The topographical map showed that the terrain of the study area is undulating with some peaks towards the tip of the western, northeastern and base of the central part of the study area. Some troughs were also noticed beside the peak of western and central region of the study area which might serve as collection zones for groundwater in the study area (Figure 3).

MATERIALS AND METHODS

Abem Wadi was used for the profiling of the VLF survey. It uses the magnetic components of the electromagnetic field generated by the military radio transmitter that uses the VLF frequency band (15-30 kHz) used mostly for long distance communication. Seven (7) VLF profiles were established, three of the profiles were taken in South-North direction which covered the total length of 300 m while the remaining four were acquired in the East-West direction which covered the total length of 400 m (Figure 1). The reading was recorded at an interval of 20 metres. The recorded values of the filtered real from the VLF were used to produce 2D profiling, contour map and surface map of the study area.

The anomalous zones from the interpreted contour and surface maps gave insight to the locations that would be sounded for further probing. Acquisition of VES data was obtained using automated resistivity meter (R-50 D.C.) which contains both the transmitter unit, through which current enters the ground and the receiver unit, through which the resultant potential difference is recorded. Sixteen (16) VES points were occupied to cover the entire study area (Figure 1).

Other materials include: two metallic current and two potential electrodes, two black coloured connecting cable for current and two red coloured cable for potential electrodes, two reels of calibrated rope, hammer for driving the electrodes in the ground, compass for finding the orientation of the traverses, cutlass for cutting traverses and data sheet for recording the field data. Global positioning system was used to record the coordinates of the sounded points and that of the entire survey area. The Schlumberger array was adopted. Maximum half-current electrode spread of 100 m was used. Sounding data were presented as sounding curves, by plotting apparent resistivity against half current electrode spread on a bi-log paper. The models obtained from the manual curve matching interpretations were used for computer iteration to obtain the true resistivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program 'WinGlink'. The software was further used for both computer iteration and modeling. Computer iterations were carried out to reduce errors to a desired limit and to improve the goodness of fit.

The results of the quantitative interpretation of the VES data were used for the preparation of the qualitative interpretation of the study. These include geoelectric sections along five profiles, isopach map and isoresistivity map. However, the quantitative and qualitative interpretation of VLF and VES results were used to prepare the subsurface competence and groundwater potential map of the study area.

RESULTS AND DISCUSSION

The results of VLF-em data are presented as filtered real signal plot, inverted 2-D maps, contour and surface maps while the electrical resistivity survey data are presented as sounding curves, geoelectric sections, isopach and isoresitivity maps. The results of VLF showed the horizontal and the vertical variation of the subsurface conductivity for traverses 1-7 (Figures 4.1 to 4.7).

VLF Interpretation

Inversion model section for traverse one

Figure 4.1 shows the plot, pseudosection and inverted 2D conductivity structure which image the subsurface beneath traverse 1. The traverse covered a total length of 300 m in a N-S direction. Four distinct zones of positive peaks (high conductivity) were observed on this model. The first zone ranged between 35-60 m with conductivity value of about 0.5 Sm^{-1}. The second zone ranged between 75-125 m (50 m width) with conductivity value of 1.5 Sm^{-1} and depth range of 5-10 m. The third zone ranged between 175-225 m (50 m width) with conductivity value of about 3 Sm^{-1} and the depth of 10-40 m. The fourth zone ranged between 239-258 m with conductivity value of 0.4 Sm^{-1}. The first and the fourth zones could be an inflection points without any geological implication. However, the second and the third zones on traverse 1 showed a conductive response greater than the previous zones. These imply that the subsurface beneath traverse one has been seriously weathered around the study area. it is evident from the model section that the subsurface beneath this traverse is incompetent especially at surface distance of 175-225 m which may be due to thick weathering or presence of subsurface geologic structure such as fracture and this zone could be a good groundwater potential.

Inversion model section for traverse two

Figure 4.2 shows inverted 2D conductivity structure which images the subsurface beneath traverse 2. This traverse covered a total length of 300 m in an N-S direction. Three distinct zones of high conductivity are observed in this model. These are between50-75 m (15 m width), the conductivity value is about 2 Sm^{-1} and the depth range between 5-10 m. The second zone with prominent and highly conductive is between 75-145 m (70 m width) with conductivity value of 2 Sm^{-1} and depth range of 5-30 m. The third zone is between 150-275 m (125 m width) with a conductivity value of 1.5 Sm^{-1} and with the depth range between 10-40 m. These imply that the subsurface beneath traverse two has been weathered around the study area. It is evident from the model section that the subsurface beneath this traverse is incompetence especially at surface distance of 150-275 m which may be due to thick weathering or presence of subsurface geologic structure such as fracture and it is a zone of good groundwater potential. However, the last positive peak on traverse 2 is interpreted as an inflection point.

Inversion model section for traverse three

These zones ranged between 30 55 m with the conductivity of 0.85 Sm^{-1}, 70-115 m with the conductivity of 1.5 Sm^{-1}, 135-165 m with the conductivity of 1.1 Sm^{-1}, 190-225 m with the conductivity of 1.0 Sm^{-1}, 275-315 m with the conductivity of 0.5 Sm^{-1}, 337-365 m with the conductivity of 1.3 Sm^{-1}. Almost all the points/stations on traverse 3 are conductive. These imply that the subsurface beneath traverse three is partially weathered. It is evident from the model section that the subsurface beneath this traverse is partially competent due to the partial weathered signatures depicted on the model. The traverse is therefore, averagely competent for engineering purposes and groundwater exploration.

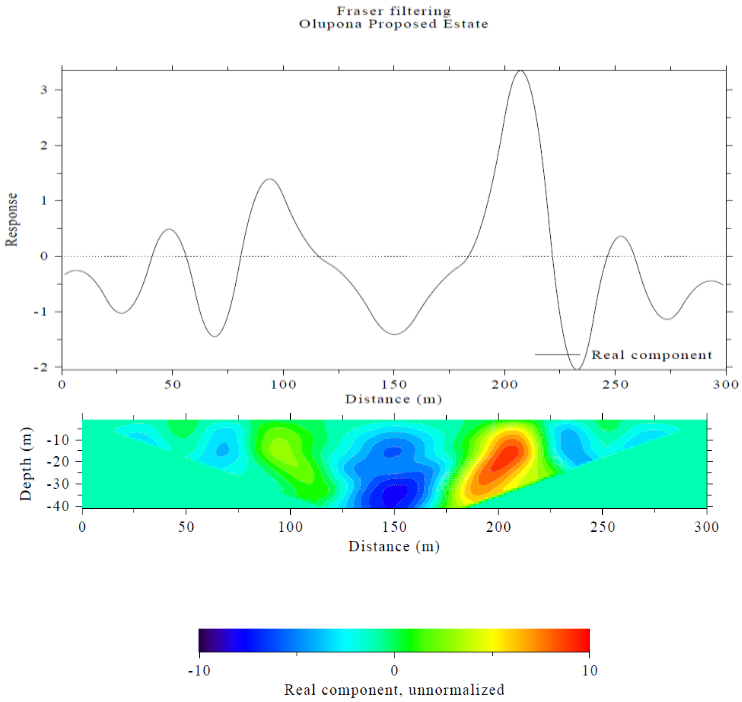

Figure 4.1: The VLF-em Inversion Model sections for Traverse 1; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

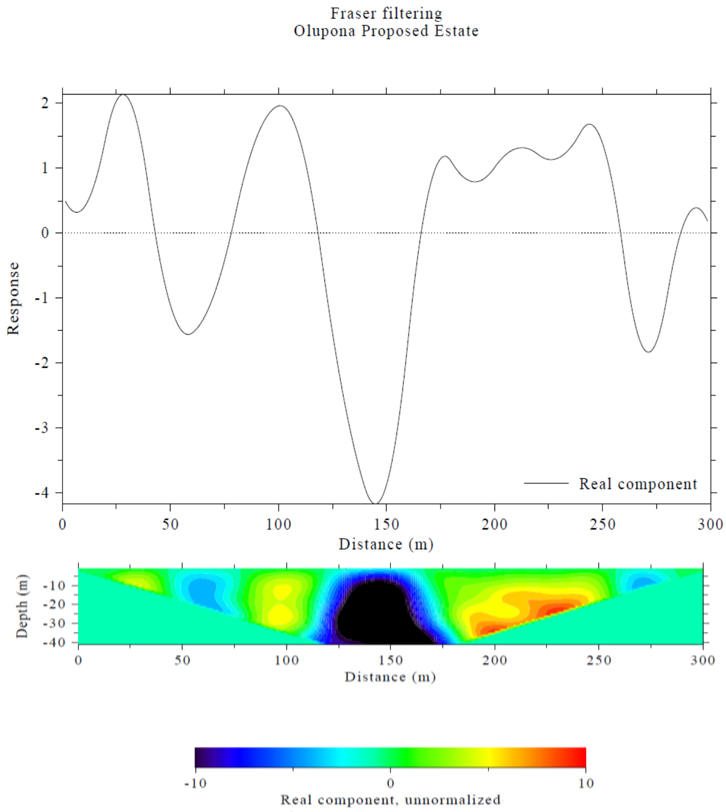

Figure 4.2: The VLF-em Inversion Model sections for Traverse 2; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

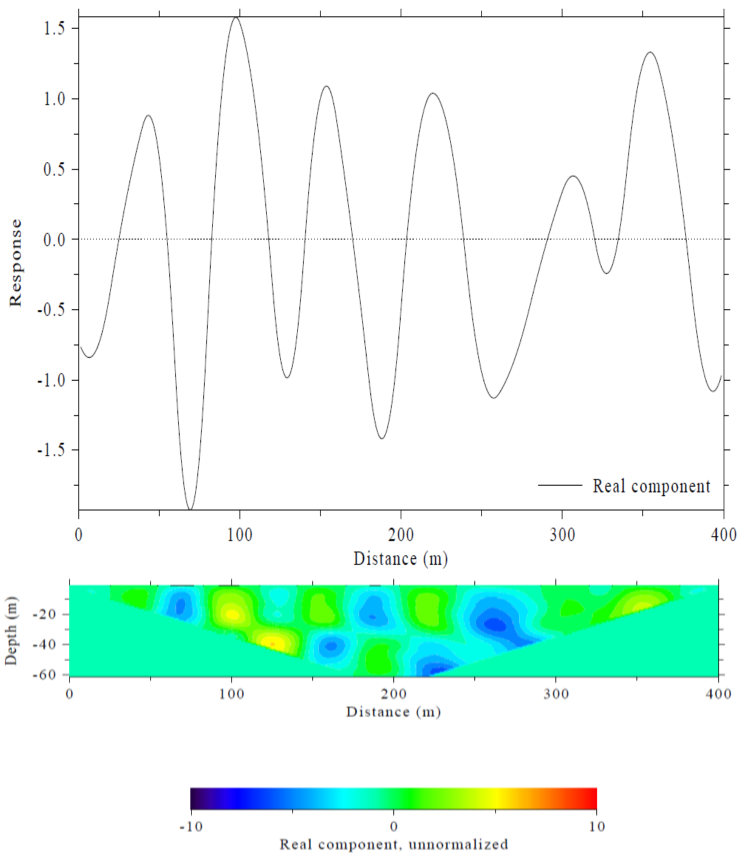

Figure 4.3: The VLF-em Inversion Model sections for Traverse 3; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

Inversion model section for traverse four

Figure 4.4 shows inverted 2D conductivity structure which images the subsurface beneath traverse 2. This traverse covered a total length of 300 m in an E-W direction. Three distinct zones of high conductivity are observed in this model. These are between 30-110 m, the conductivity value is about 1.5 Sm^{-1} and the depth ranged between 5-40 m. The second zone is between 175-225 m (50 m width) with conductivity value range between 2.25 Sm^{-1} and depth range from 5-40 m. The third zone which is partially conductive ranged between 255-275 m with conductivity value of 0.7 Sm^{-1}. These imply that the subsurface beneath traverse four at distances 5-40 m and 175-225 m are highly weathered region beneath the traverse. It is evident from the model section that the subsurface beneath this traverse at this distance is incompetent for engineering activities due to the subsurface geologic features present and it is a zone of possible high groundwater potential.

Inversion model section for traverse five

Figure 4.5 shows inverted 2D conductivity structure which images the subsurface beneath traverse 2. This traverse covered a total length of 300 m in an E-W direction. Four distinct zones of high conductivity are observed in this model. These are between 20-70 m (50 m width), the conductivity value is about 2.5 Sm^{-1} with the depth range between 5-25 m. The second zone is between 155-195 m (50 m width) with conductivity value of 1.6 Sm^{-1} and depth ranged of 5-30 m. The third zone ranged from 220-245 m with the conductivity of 0.8 Sm^{-1} while the fourth zone ranged from 260-280 m with the conductivity of 1.1 Sm^{-1}. Distance 20-70 m from starting point is interpreted as highly weathered zone while distance 155-195 m is interpreted as weathered terrain. However, the remaining two zones might be due to the near surface buried conductor. It is evident from the model section that the highly weathered and the weathered zones are incompetent for engineering activities while other zones are interpreted as competent zone for engineering structures. However, incompetent engineering zones are probable zones for groundwater exploration.

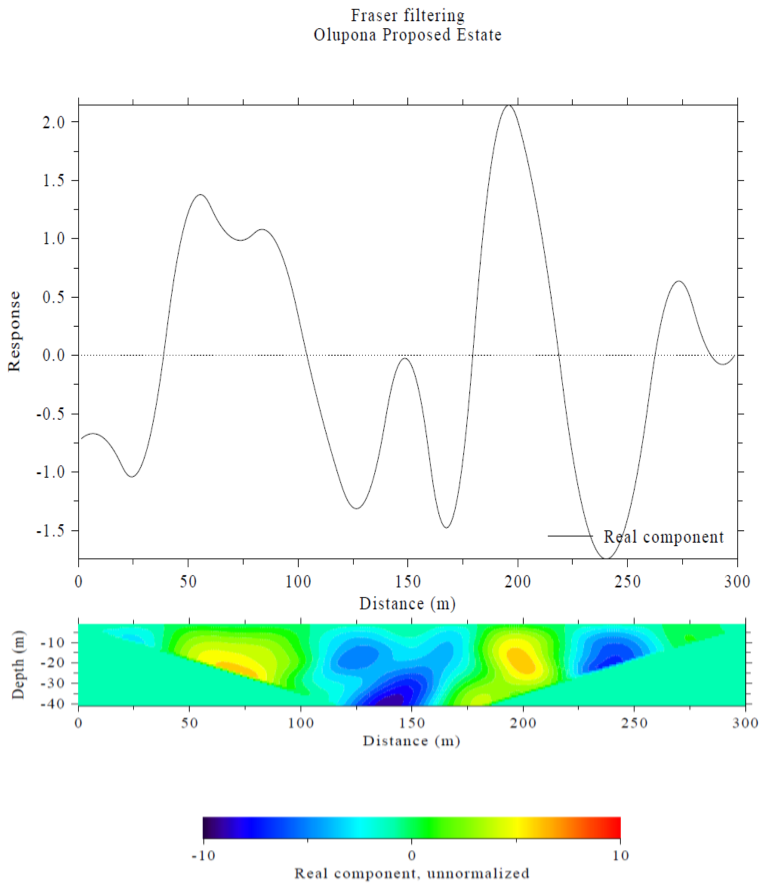

Figure 4.4: The VLF-em Inversion Model sections for Traverse 4; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

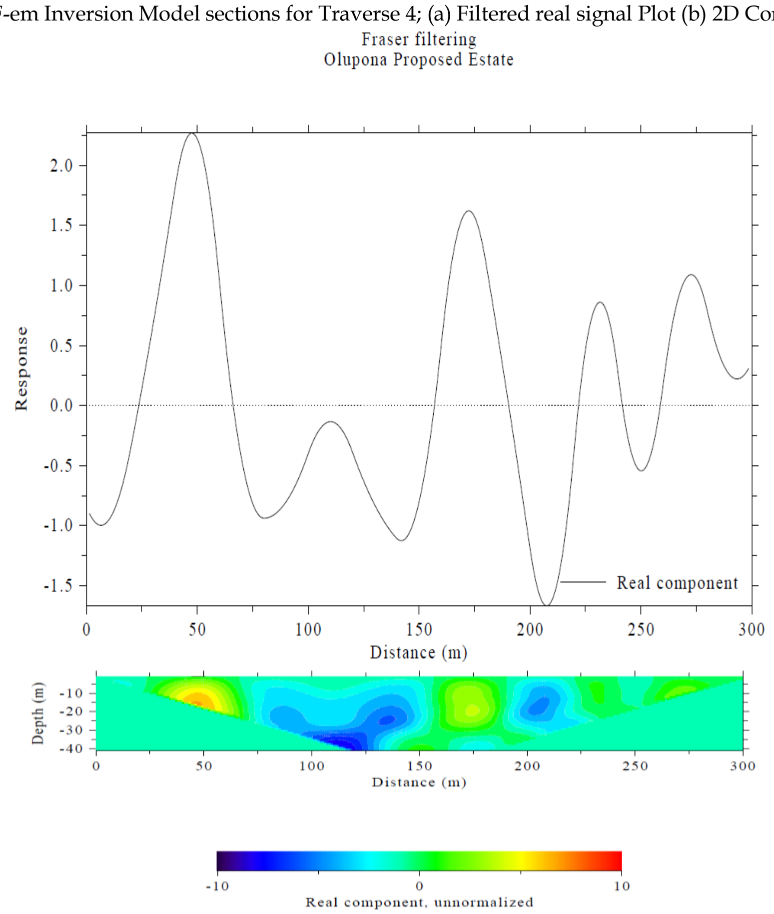

Figure 4.5: The VLF-em Inversion Model sections for Traverse 5; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

Inversion model section for traverse six

Figure 4.6 shows inverted 2D conductivity structure which images the subsurface beneath traverse 2. This traverse covered a total length of 300 m in an E-W direction. Three distinct zones of high conductivity are observed in this model. These are between 25-100 m (75 m width), the conductivity value is about 1.6 Sm^{-1} and the depth range between 10-30 m. The second zone is between 130-210 m (80 m width) of 2.0 Sm^{-1} and depth ranged between 10 to greater than 40 m deep. The third zone is between 230-260 m with conductivity value of 1.9 Sm^{-1}. The third zone conductivity might be due to near surface buried object while conductivity of first and second zones is interpreted as weathered and highly weathered zone respectively. These imply that these conductive zones are incompetent for engineering activities while non-conductive zones are competent zones for engineering purposes. However, the incompetent zone for engineering activities serves as prospective zones for groundwater exploration.

Inversion model section for traverse seven

Figure 4.7 shows inverted 2D conductivity structure which images the subsurface beneath traverse 2. This traverse covered a total length of 300 m in an E-W direction. Three distinct zone of average conductivity is observed in this model. These zones are 12-87 m with the conductivity value of 1.0 Sm^{-1}, 120-200 m with the conductivity of 1.1 Sm^{-1}, and 220-285 m with the conductivity of 1.25 Sm^{-1}. The depth of the first conductive zone extends up to 30 m, the second zone extends beyond 40 m while the third zone extends up to 15 m. These imply that traverse six is poorly weathered. It is evident from the model section that the subsurface beneath this traverse is stable and relatively competent and it is a zone where groundwater potential could be possibly low.

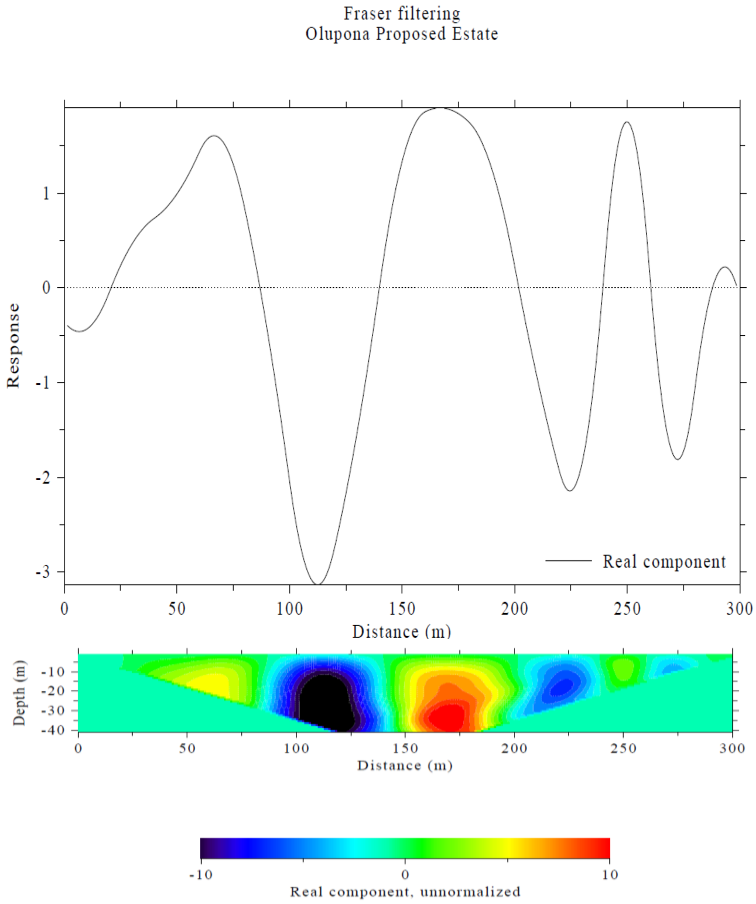

Figure 4.6: The VLF-em Inversion Model sections for Traverse 6; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

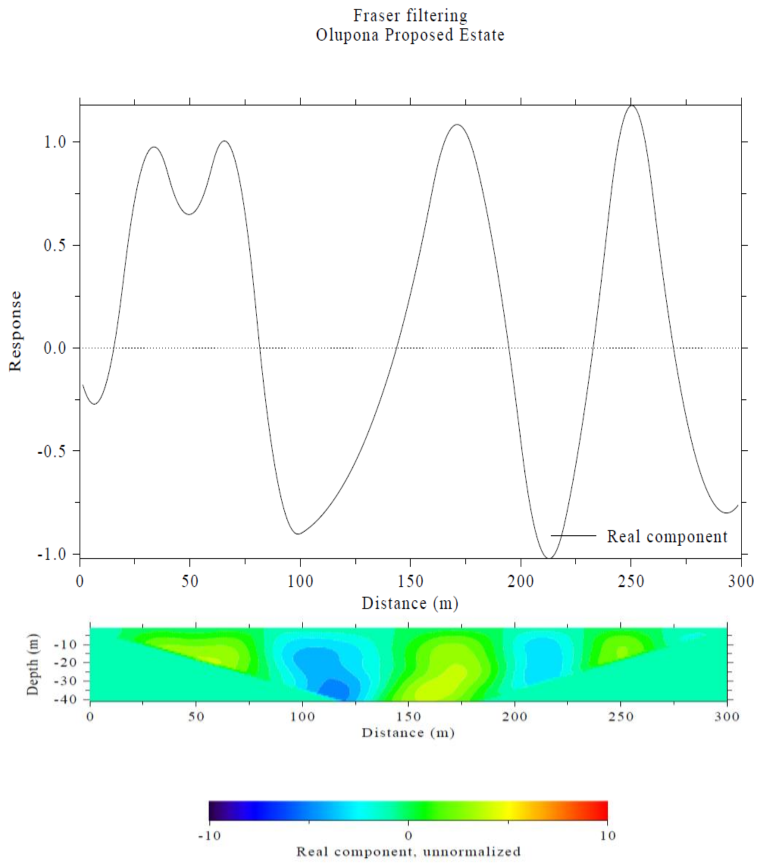

Figure 4.7: The VLF-em Inversion Model sections for Traverse 7; (a) Filtered real signal Plot (b) 2D Conductivity Structure.

Subsurface Conductivity Imaging

The conductivity contour map (two-dimensional map) constructed from the VLF data obtained from the study area is presented in Figure 5a while its corresponding surface map (three-dimensional map) is presented in Figure 5b. The constructed 2D map showed low and negative conductivities between -18 to 0 Sm^{-1} while the observed positive conductivities range between 0 to 12 Sm^{-1}. The negative conductivity zones are the competent and stable zones while the positive conductivity zones are the incompetent zones but could be explored for groundwater prospect.

The three-dimensional map (Figure 5b) is the subsurface image representation of the VLF data which revealed the magnitude of the conductivity clearer than the two-dimensional map (Figure 5a). From the 3-D map, the incompetent zones are the areas with peaks on the map. These are: southern, southeastern, eastern and western part of the study area. However, the competent zones are the areas with low conductivity signatures on the map. The incompetent zones are the fractured zones (shallow/deep fracture) which are better sites for hydrogeological purposes. The competent zones are the poorly weathered zones which are better sites for erection of heavy structures.

VES Interpretation

Electrical Resistivity Depth Sounding Curves

The sixteen (16) depth sounding curves obtained in the study area are grouped on the basis of layer resistivity combinations. The type curves are H, KH and HA. H is the most prevalent of all multi-layer curves and accounts for 96.2% of the total. The KH accounts for 1.3% and HA type curve accounts for about 2.5% (Table 1). Five fractured bedrock and eleven fresh bedrock culminating to 31.25 % and 68.75 % of the fractured-to-fresh bedrock percentage were obtained from the study area. Table 2 shows summary of computed assisted VES interpretation results. Three-to-four lithologic layers were identified. These include the topsoil, lateritic layer (not present in all), weathered layer (clayey sand/ sandy clay) and fractured/fresh bedrock. Five (VES 3, 5, 10, 12 and 14) out of the sixteen obtained VES curves are presented in Figure 6.1a-6.1e.

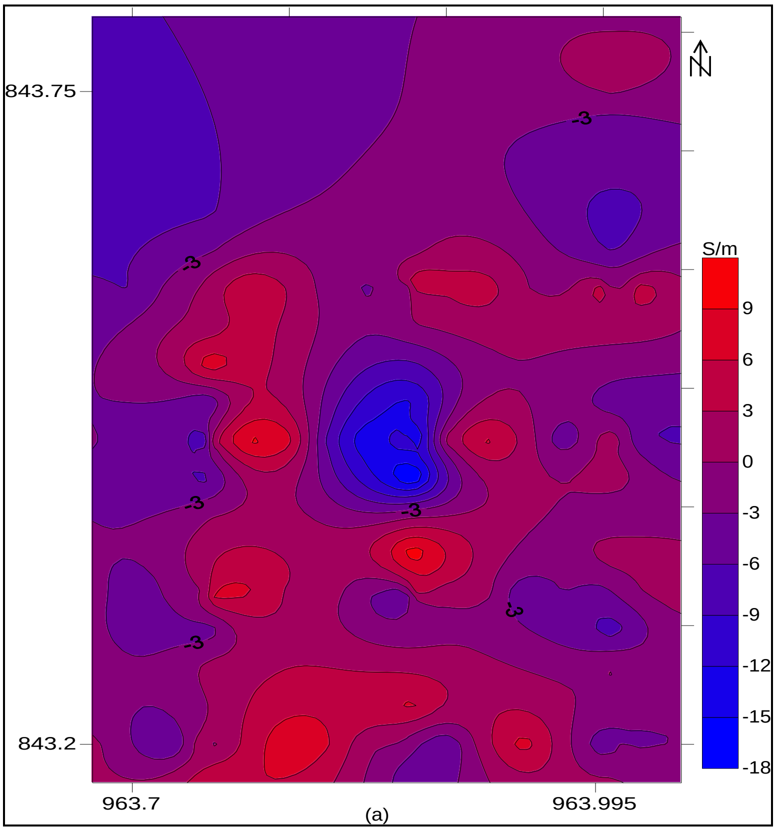

Figure 5a: VLF-EM Filtered Real 2D Conductivity Plot of the Study Area.

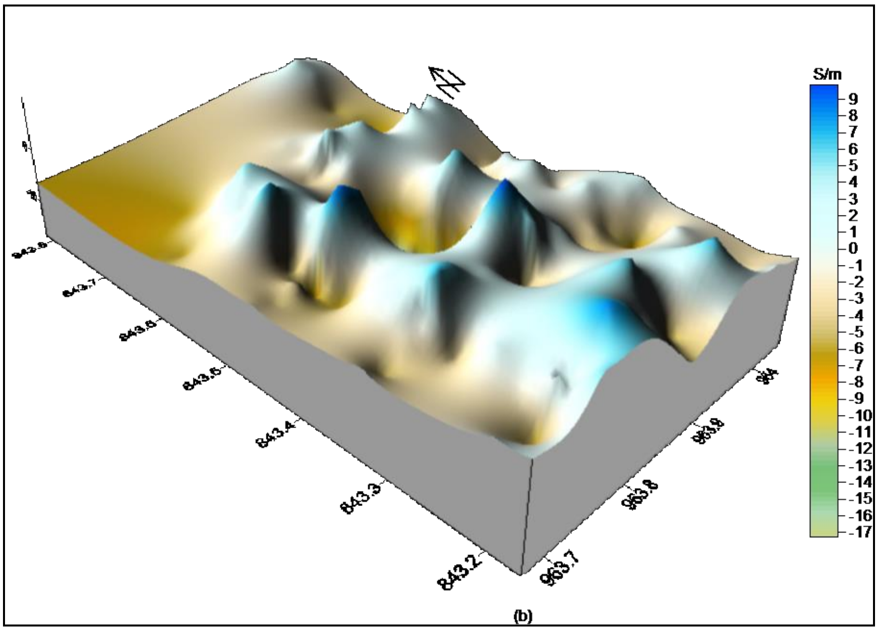

Figure 5b: VLF-EM Filtered Real 3D Conductivity Surface Plot of the Study Area.

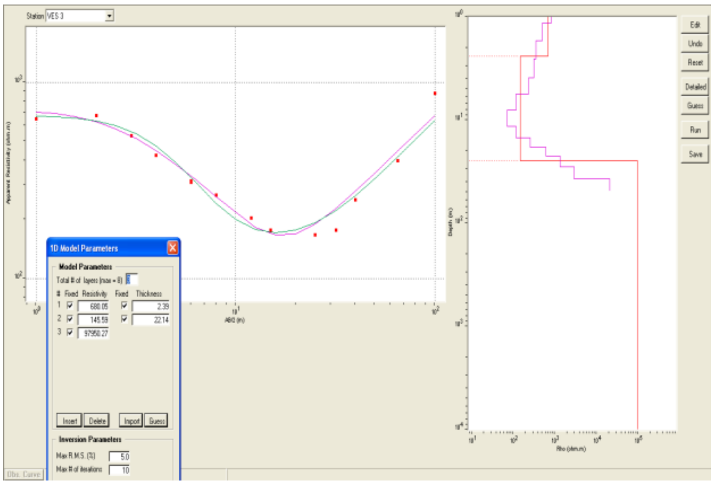

Figure 6.1a: Model Curve of VES 3.

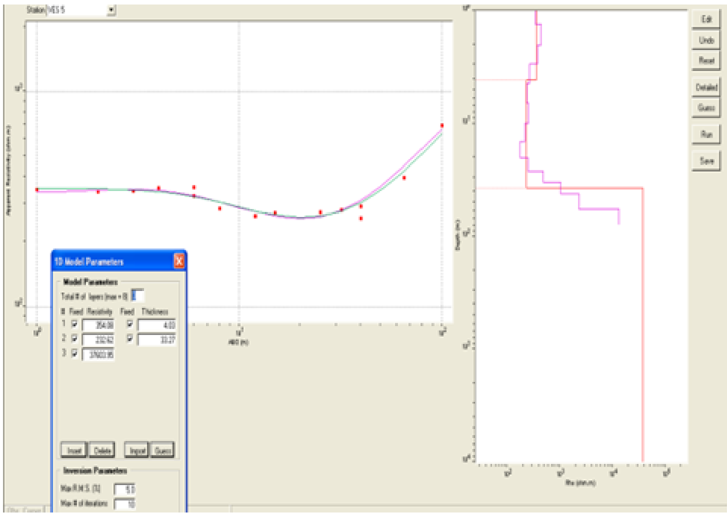

Figure 6.1b: Model Curve of VES 5

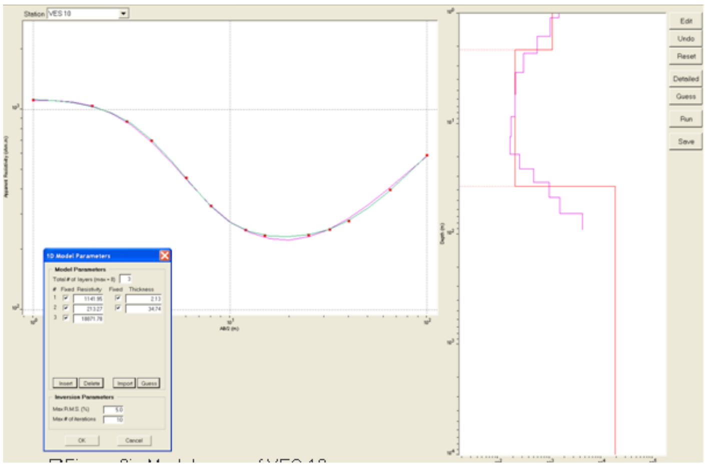

Figure 6.1c: Model Curve of VES 10

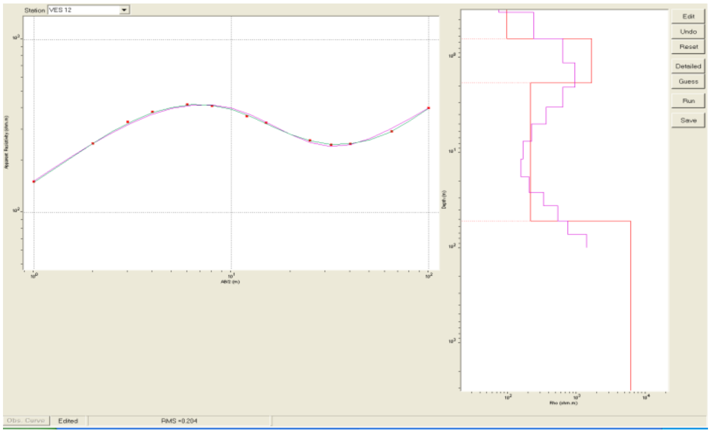

Figure 6.1d: Model Curve of VES 12

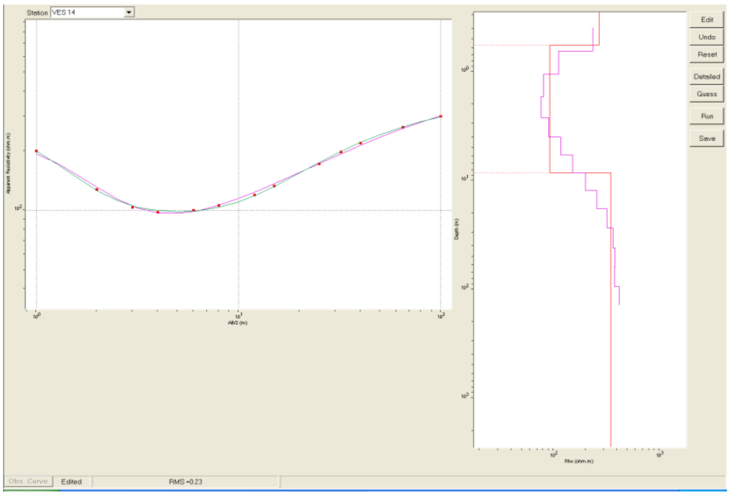

Figure 6.1e: Model Curve of VES 14

The Geo-electric Sections

The depth sounding interpretation results (Table 2) are presented as geoelectric sections. This was carried out so as to provide an insight into the geological sequence and structural disposition beneath the study area. Five geoelectric traverses were mapped in order to cover the VES points in the study area. The geoelectric sections along traverses 1, 2, 3, 4 and 5 are as presented in Figures 7.1 to 7.5. Thin overburden and fresh bedrock are the best requirements for subsurface competency in terms of engineering purposes while thick overburden and fractured bedrock are the best requirements for hydrogeologic purposes.

Table 1: Classification of Resistivity Sounding Curves.

Types of Curves	Resistivity Model	Number of Stations	Curve Type Percentage (%)
H	$\rho_1 > \rho_2 < \rho_3$	13	96.2
KH	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	1	1.3
HA	$\rho_1 > \rho_2 < \rho_3 < \rho_4$	2	2.5
	Total	16	100

Table 2: Interpreted Results of Resistivity Curves in the study area.

VES	Resistivity (Ω m)	Thickness (m)	Depth (m)	Curve Type	Lithology
1	311 133 99563	1.31 28.52 -	29.83	H	Topsoil Weathered layer/ Sandy Clay Fresh bedrock
2	299 57 19789	1.56 18.33 -	19.89	H	Topsoil Weathered layer/ Clayey sand Fresh bedrock
3	688 146 97988	2.39 22.14 -	24.53	H	Topsoil Weathered layer/Sandy clay Fresh bedrock
4	433 158 397 2441	5.27 16.02 14.38 -	35.67	HA	Topsoil Weathered layer/ Clayey sand Weathered basement Fresh bedrock
5	354 233 37604	4.03 33.27 -	37.30	H	Topsoil Weathered layer/ Sandy clay Fresh bedrock
6	393 107 27147	0.72 17.33 -	18.05	H	Topsoil Weathered layer/ Clayey sand Fresh bedrock
7	581 188 517	0.69 7.90 -	8.59	H	Topsoil Weathered layer/ Sandy clay Fractured basement
8	554 183 429	0.73 7.95 -	8.68	H	Topsoil Weathered layer/ Sandy clay Fractured basement
9	637 161 1765	0.99 24.27 -	25.26	H	Topsoil Weathered layer/ Sandy clay Fresh bedrock
10	1142 213 18872	2.13 34.74 -	36.87	H	Lateritic topsoil Weathered layer/ Sandy clay Fresh bedrock
11	253 101 14782	1.17 23.99 -	25.16	H	Topsoil Weathered layer/ Sandy clay Fresh bedrock
12	98 1664 213 6053	0.63 1.21 49.82 -	51.66	KH	Topsoil Lateritic layer Weathered layer/ Sandy clay Fresh bedrock
13	400 91 275 988	4.64 3.22 20.24 -	28.10	HA	Topsoil Weathered layer/ Clayey sand Weathered basement Fractured basement
14	269 92 347	0.57 7.87 -	8.44	H	Topsoil Weathered layer/ Clayey sand Fractured bedrock
15	246 100 692	1.25 14.00 -	15.25	H	Topsoil Weathered layer/ Clayey sand Fractured bedrock
16	205 60 4265	2.47 21.96 -	24.43	H	Topsoil Weathered layer/Clayey sand Fresh bedrock

Geo-electric Section along Traverse One

The geo-electric section along this traverse relates VES 3, 15, 2, 12, 7 and 1 along SE-NW orientation. It shows a maximum of four subsurface layers (Figure 7.1). The first layer constitutes the topsoil with layer resistivity varying between 98 and 688 Ohm-m. The layer thickness ranges from 0.69 to 2.39 m. The second layer which constitutes the lateritic zone has resistivity values 1668 Ohm-m. The depth of this layer is 1.21 m. The third layer which constitutes the weathered layer that is made up of either clayey sand or sandy clay has resistivity values that range between 57 and 213 Ohm-m. The depth of this layer ranges between 7.90 to 49.82 m. The fourth layer is presumably the bedrock. This layer showed intercalation of fresh bedrock and fractured bedrock respectively. Its layer resistivity values range between 517 to 99563 Ohm-m. Along this profile basement depressions are observed towards the central and the north-western region of the profile.

Geo-electric Section along Traverse Two

The geo-electric section along this traverse relates VES 8, 6, 14, 13, and 5 along NW-SE orientation. It shows a maximum of three subsurface layers (Figure 7.2). The first layer constitutes the topsoil with layer resistivity varying between 269 and 554 Ohm-m. The layer thickness ranges from 0.57 to 7.86 m. The second layer which constitutes the weathered layer that is made up of either clayey sand or sandy clay has resistivity values that range between 91 and 275 Ohm-m. The depth of this layer ranges between 7.87 to 33.27 m. The third layer is presumably the bedrock which is made up of fractured and fresh bedrocks. Its layer resistivity values range between 347to 37604 Ohm-m. Along this profile basement depressions are observed towards the northwestern side of the profile.

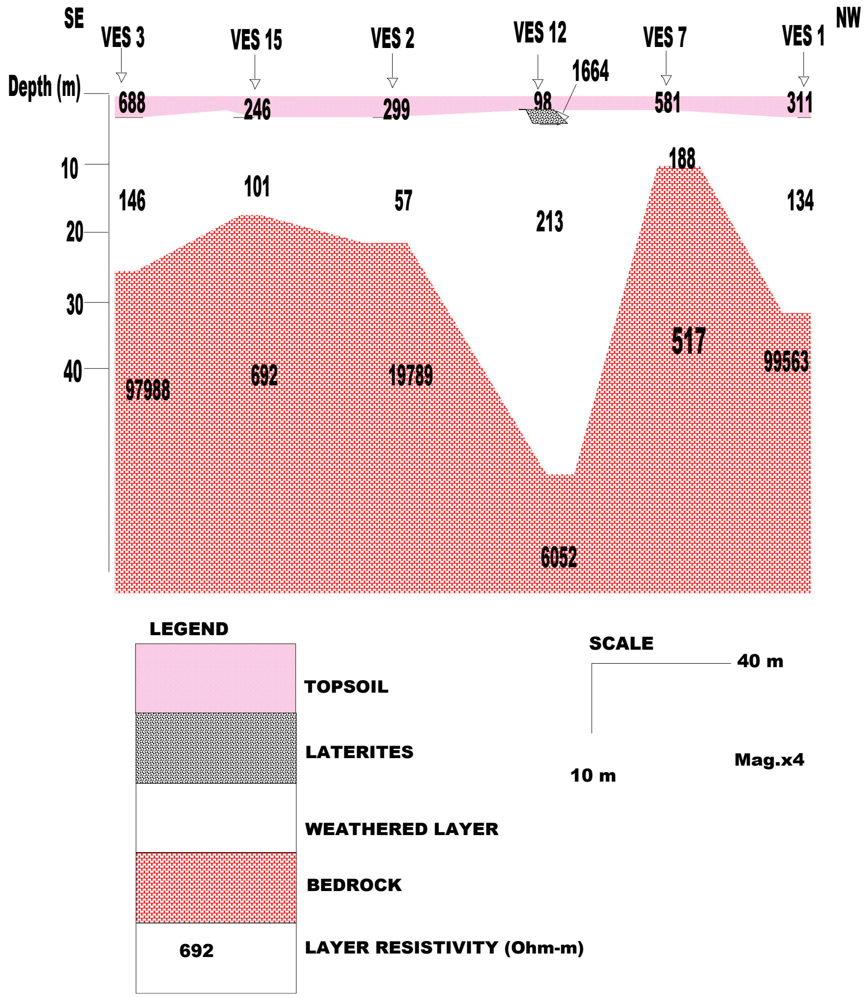

Figure 7.1: Geo-electric Section along Traverse 1.

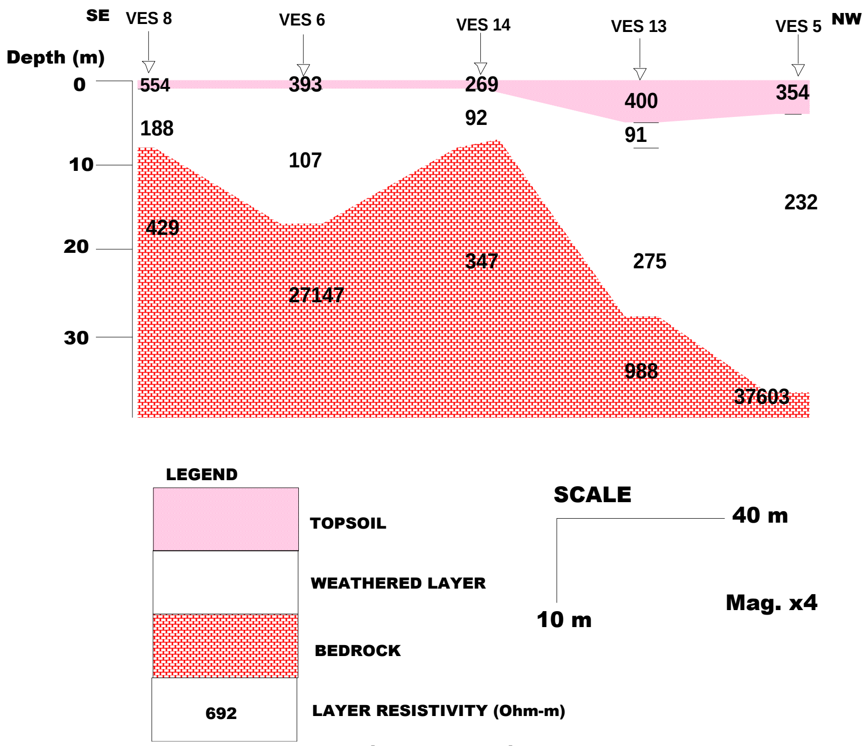

Figure 7.2: Geo-electric Section along Traverse 2.

Geo-electric Section along Traverse Three

The geo-electric section along this traverse consists of VES 5, 12, 10, and 11 along SE-NW orientation. It shows a maximum of four subsurface layers (Figure 7.3). The first layer constitutes the topsoil with layer resistivity varying between 98 and 354 Ohm-m. The layer thickness ranges from 1.17 to 4.03 m. The second layer which constitutes the laterites layer has resistivity values from 1142 to 1668 Ohm-m. This is present at the central region of the profile. It started from second layer beneath VES 12 and showed as an outcrop towards the middle of the profile. This interpretation was inline with what was observed during the geophysical survey of this study. The depth of this layer ranged from 1.21 to 2.13 m. The third layer which constitutes the weathered layer has resistivity values that range between 101 and 233 Ohm-m. The depth of this layer ranges between 23.99 to 49.82 m, which is made up of clayey sand/sandy clay. The fourth layer is presumably the bedrock which is made up of fractured and fresh bedrocks. Its layer resistivity values range between 6052 to 37604 Ohm-m. Along this profile basement depression is observed between the southeastern part and the central region of the profile.

Geo-electric Section along Traverse Four

The geo-electric section along this traverse consists of VES 3, 9 and 11 along W-E orientation. It shows a maximum of three subsurface layers (Figure 7.4). The first layer constitutes the topsoil with layer resistivity varying between 253 and 688 Ohm-m. The layer thickness ranges from 0.99 to 2.39 m. The second layer which constitutes the weathered layer has resistivity values that range between 101 and161 Ohm-m. The depth of this layer ranges between 22.14 to 24.27 m, which is made up of clayey sand/sandy clay. The third layer is presumably the fresh basement. Its layer resistivity values range between 1765 to 97988 Ohm-m. Along this profile no basement depression is observed.

Geo-electric Section along Traverse Five

The geo-electric section along this traverse consists of VES 4, 12 and 16 along SW-NE orientation. It shows a maximum of four subsurface layers (Figure 7.5). The first layer constitutes the topsoil with layer resistivity varying between 98 and 433 Ohm-m. The layer thickness ranges from 0.63 to 5.27 m. The second layer which constitutes the lateritic zone which falls towards the central part of the profile with the resistivity values of 1668 Ohm-m. The depth of this layer is 1.21 m. The third layer which constitutes the weathered layer has resistivity values that range between 60 and 397 Ohm-m. The depth of this layer ranges between 14.38 to 49.82 m. The fourth layer is presumably the fresh basement. Its layer resistivity values range between 2441 to 6053 ohm-m. Along this profile basement depression is observed towards central part of the profile.

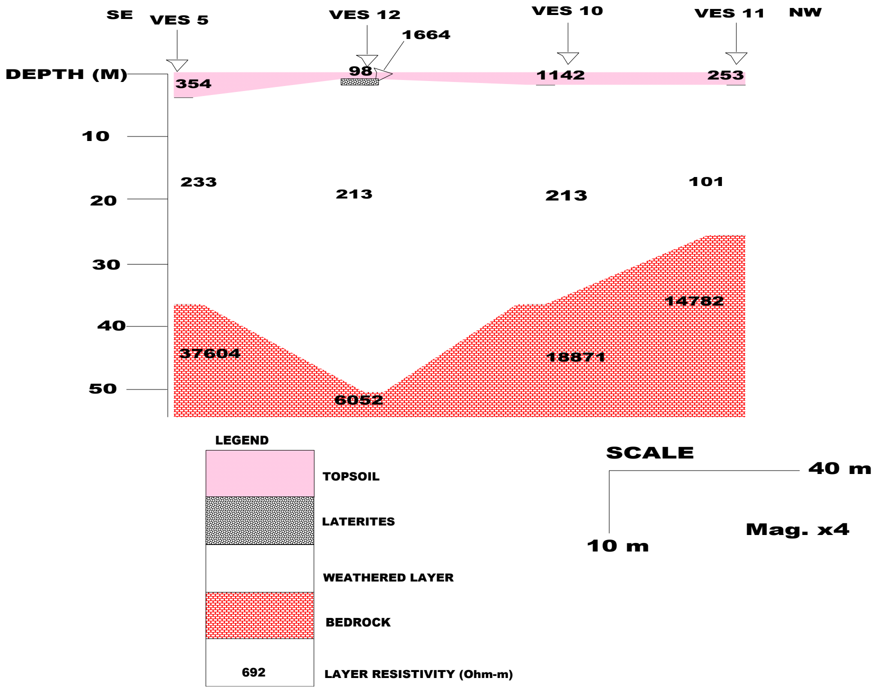

Figure 7.3: Geo-electric Section along Traverse 3.

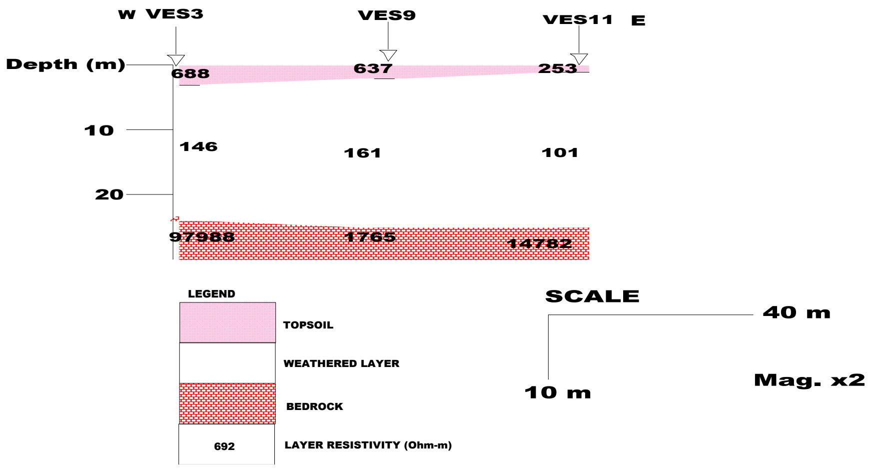

Figure 7.4: Geo-electric Section along Traverse 4.

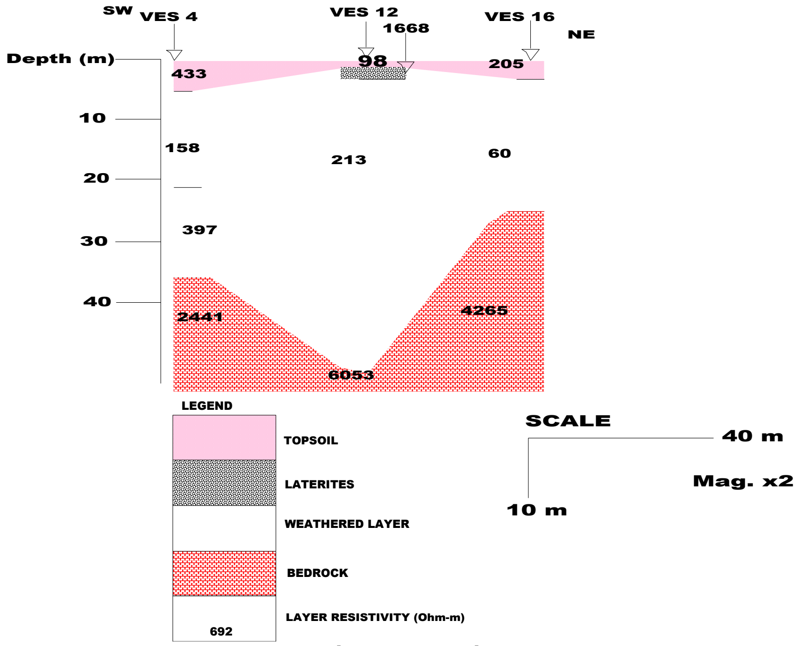

Figure 7.5: Geo-electric Section along Traverse 5.

Isopach Map

The depths to the basement (overburden thickness) beneath the sounding stations were plotted as shown in Figure 8. This was done to enable a general view of the aquifer geometry of the surveyed area and to ensure the degree of subsurface competency. The overburden includes the topsoil, the lateritic horizon and the clay/weathered layer. Overburden thickness of the study area varied from 8.44 to 51.66 m. Areas with thick overburden corresponds to basement depression and is known to have high groundwater potential particularly in the basement complex area (Sunmonu *et al*., 2012) while areas with thin overburden corresponds to basement elevation which are good for erection of heavy structures (Adagunodo *et al*., 2013).

At the Eastern part of the study area, there is a thick weathering which trend in a N-S direction. The thickness range between 35 and 52 m; this zone gradates into a shallow overburden at the southern part of the study area. Also, thick overburden is also experienced at the South-western and Western Part of the study area with the depth range between 25- 32 m. It is evident from the map that areas of thick weathering are incompetent for engineering structures but good sites for groundwater location.

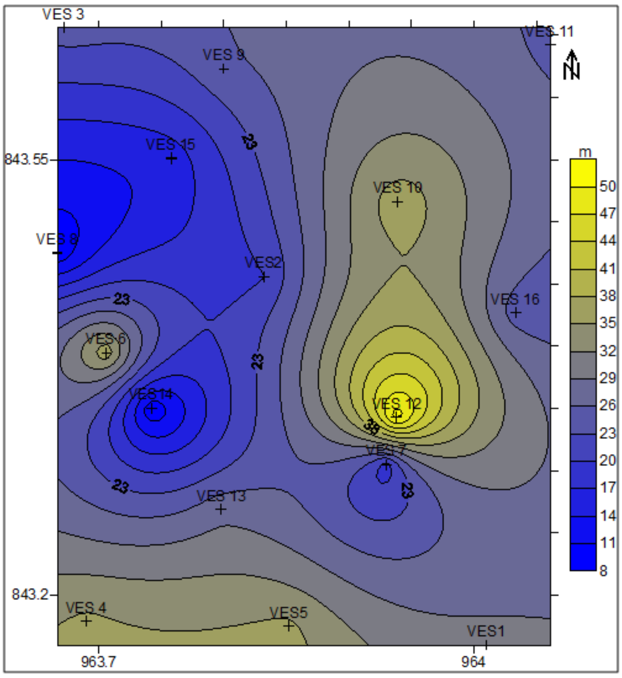

Figure 8: Isopach map of overburden of the study area derived from VES data.

Isoresistivity Map of the Weathered Layer

Isoresistiviy map shows variation in the weathered layers resistivity distribution beneath the surface area. Figure 9 showed the areas of high weathered layer resistivity and that of low resistivity layer.The weathered layer isoresistivity map was produced in order to distinguish high water-bearing weathered layer from low water-bearing ones, to ensure the competency of subsurface beneath the study area and to find out whether or not the degree of weathering /saturation varies from point to point in the study area. Sunmonu *et al*. (2012) has used isoresitivity of the weathered layer to investigate on groundwater potential while Adagunodo *et al*. (2012) used the same approach to interpret subsurface geoelectrical parameters for engineering purposes.

The resistivity value of the aquifer is highest (>400Ωm) in the southwestern part. The high resistivity value associated with these parts is possibly due to the sandy nature of the aquifers. The other parts of the study area have low aquifer resistivity in the region. These low values are probably due to the highly weathered nature of the weathered basement layer, tending towards clay and thus incompetent for engineering structure but would be useful for hydrogeologic purposes.

Subsurface Competency and Groundwater Potential Map

The subsurface competency and groundwater potential map of the study area was produced from the comprehensive results of VLF and VES data in order to know the suitable areas for construction of heavy structures as well as promising zones for groundwater exploration. The base of the western part (blue colour) of the study area interpreted as highly resistive zone depict the most suitable region for the construction of heavy structures. The resistive zones marked with purple colour (northwestern, northern, northeastern, and eastern part of the study area) nearly covered half of the study area are good for the constructions of either low-rise buildings or high-rise buildings underlain with artificial basement. The conductive zones marked with wine colour (central, bases of NW and NE zones, southwestern and southern part of the study area) are recommended for construction of low-rise buildings and paradventure groundwater exploration if need arises in such area. However, the highly conductive zones marked with red colour (towards the bases of NW and SW parts of the study area) are strictly recommended for groundwater exploration.

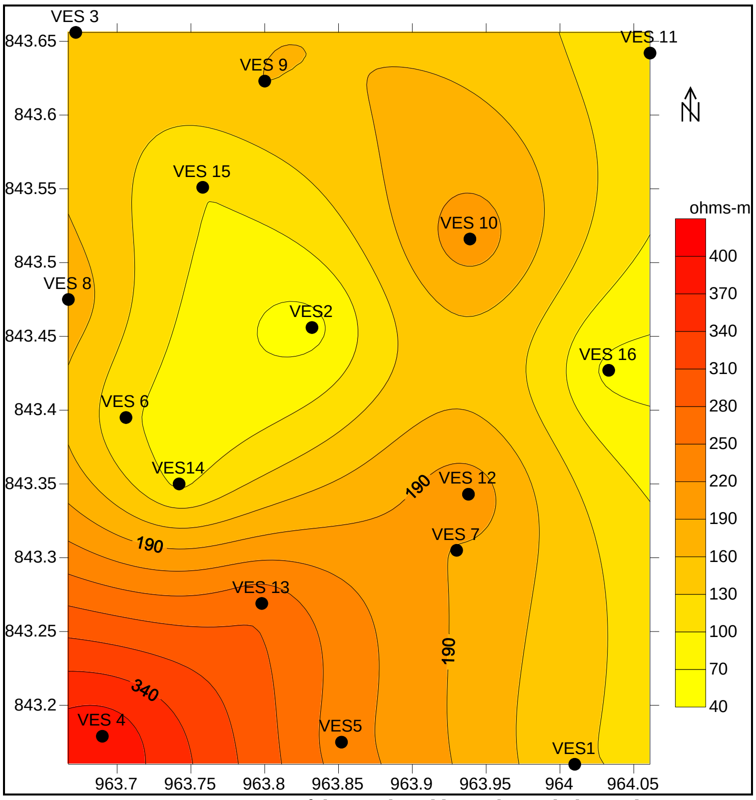

Figure 9: Isoresistivity Map of the weathered layers beneath the Study Area.

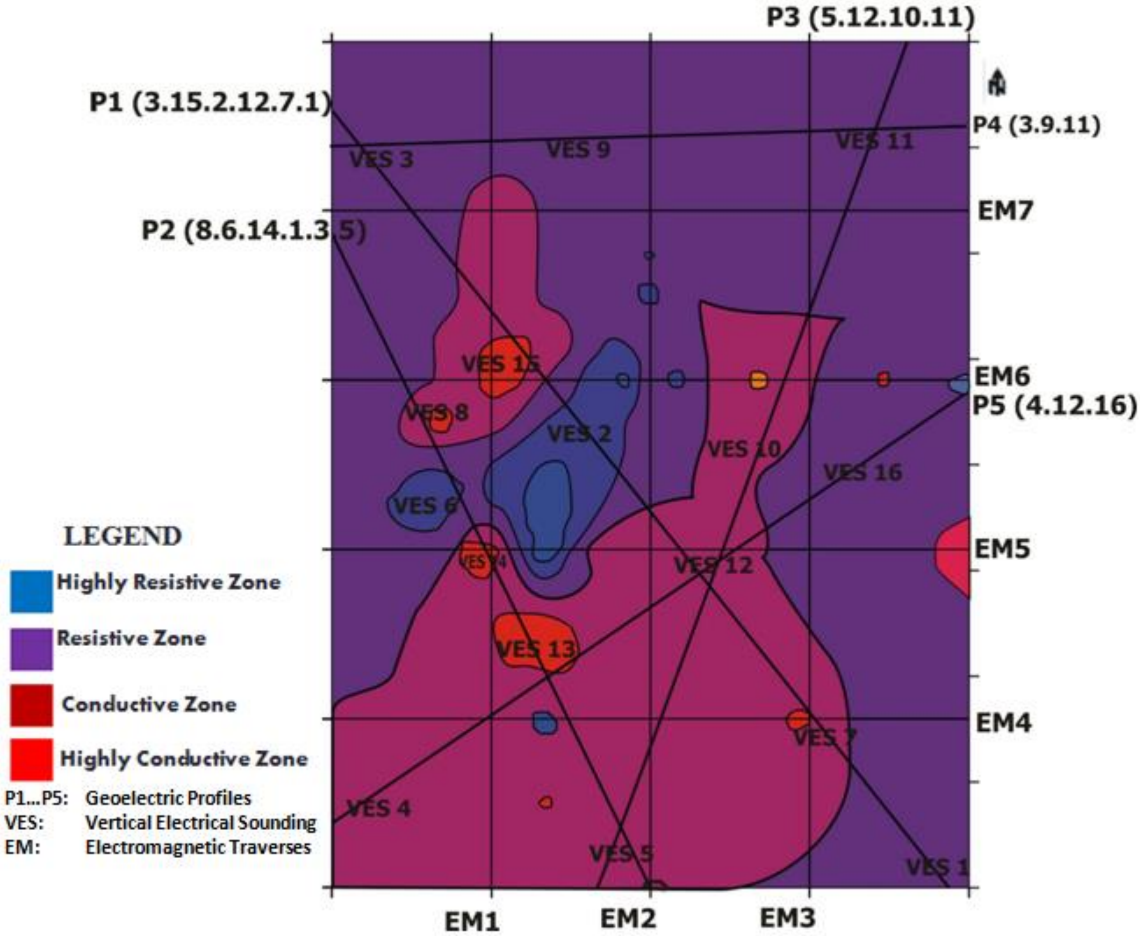

Figure 10: Final subsurface map of the study area.

CONCLUSION

The integrated geophysical mapping for subsurface competence and groundwater potential assessment of the housing estate at Olupona, Southwestern Nigeria has been carried out. The qualitative and quantitative interpretations of the VLF and VES data have provided adequate information as regards the subsurface conductivity and geo-electrical parameters.

VLF-em was used to map conductive zones/fractured zones. VLF-em data were acquired along seven profiles using Abem Wadi with inter station spacing of 20 m while the data were interpreted using Karous-Hejelt. Twenty-six distinct conductivity zones were delineated from the 2D conductivity structure which corresponds to the positive peaks on the VLF curves in the study area.

VES analysis revealed three-to-four lithologic sequences which include topsoil, lateritic layer (not present in all), weathered layer, and fractured or fresh bedrock. H-type, HA-type and KH-type were the curve types obtained from VES data with the overburden thickness ranging from 8.0 to 51.66 m. Though fractured bedrock occupied 31.25 % while fresh bedrock occupied the remaining 68.75 %, the bedrock are averagely covered with thick overburden which is unsuitable for construction of heavy structures but would be useful for small scale groundwater exploration (Sunmonu *et al*., 2012; Sunmonu *et al.*, 2015) such as development of hand-dug well and hand-pump well. The isopach map of the overburden and the isoresistivity map of the weathered layer revealed the area is of good groundwater potential and thus incompetent for engineering structures.

In conclusion, the base of the western part of the study area is interpreted as competent zone for construction of high-rise buildings. Northwestern, northern, northeastern and eastern parts of the study area are recommended for the construction of either low-rise buildings or high-rise buildings underlain with artificial basement. The central, bases of NW and NE zones, southwestern and southern part of the study area are recommended for construction of low-rise buildings and paradventure groundwater exploration if need arises in such area. However, the highly conductive zones delineated towards the bases of NW and SW parts of the study area are strictly recommended for groundwater exploration which affirmed that groundwater exploration is sparingly favoured in the study area also.

The results of the research work are expected to enhance our knowledge of the sub-surface geologic/geo-electric and possible structures that may control the subsurface competence and groundwater potentials around the study area. This outcome of the investigations would be useful for government policy makers and structural contractors for consumption.

REFERENCES

Adagunodo, T.A. (2012). Interpretation of ground magnetic and vertical electrical sounding data in the study of basement pattern of an industrial estate in Ogbomoso, Southwestern Nigeria. *M.Tech. Thesis Unpublished*. Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

Adagunodo, T.A.; Sunmonu, L.A.; Oladejo, O.P. and Ojoawo, I.A. (2013). Vertical Electrical Sounding to determine fracture distribution at Adumasun area, Oniye, Southwestern Nigeria. *IOSR Journal of Applied Geology and Geophysics*, 1(3), 10-22.

Akintorinwa, O.J. and Adelusi, F. (2009). Integration of Geophysical and Geotechnical Investigations for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, SW, Nigeria. *Journal of Applied Sciences*, 2(3), 241-254.

Anizoba, D.; Orakwe, L.; Chukwuma, E. and Ogbu, K. (2015). Delineation of potential groundwater zones using geo-electrical sounding data at Awka in Anambra State, South-eastern Nigeria. *European Journal of Biotechnology and Bioscience*, 3(1), 01-09.

MacDonald, A.; Davies, J.; Calow, R. and Chilton, J. (2005). Developing Groundwater Resources. A guide to rural water supply. *ITDG publishing*.

Rahaman, M.A. and Ocan, O. (1978). On the Relationship in the Precambrian Migmatite Gneises of Nigeria. *Journal of Mining Geo*., 15(1), 23–32.

Sunmonu L.A., Adagunodo T.A., Adeniji A.A., Oladejo O.P. and Alagbe O.A. (2015). Geoelectric Delineation of Aquifer Pattern in Crystalline Bedrock. *Open Transactions on Geosciences*. 2(1) 1–16.

Sunmonu, L.A.; Adagunodo, T.A.; Olafisoye, E.R. and Oladejo, O.P. (2012). The groundwater potential evaluation at Industrial Estate Ogbomos Southwesetrn Nigeria. *RMZ-Materials and Geoenvironment*, 59(4), 363-390.

Venkata, Rao G.; Kalpana, P. and Srinivasa, Rao R. (2014). Groundwater investigation using geophysical methods-a case study of Pydibhimavaram Industrial area. *International Journal of Research in Engineering and Technology*, 3(16), 13-17.