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Editorial Comment

The MJG was officially launched and approved by the Management of the Federal University of Technology, Minna in 2015 under the leadership of the pioneer Editor-in-Chief, a German-trained professor, Prof. M. I. Ogunbajo. The Editor-in-Chief worked assiduously with other editorial board members for the Maiden Edition, Volume 1 Number 1 to be a reality. He did this by sourcing for the resources to run the journal, coordinating the activities of the editorial team and soliciting for the assistance of renowned geoscientists and oil and gas industries professionals nationwide to support the journal. At the critical point of producing the edition and when the accepted papers are already in the press Prof. M. I. Ogunbajo died after a very brief illness. May his gentle soul rest in perfect peace. Amen. The contributions of this great scholar and an icon in advancing geological knowledge and capacity building will remain a reference point within the geoscience community in Nigeria and beyond, as the society will dearly miss him. Review process for the second edition, Volume 1 Number 2 was done through electronic format to enable authors respond to comments and observations by the reviewers. This has greatly smoothened the review process and improved the quality of articles compiled for the second edition.

The journal appreciates the efforts put in by reviewers for timely reviews and constructive criticism and suggestions that sometimes lead to outright rejection of papers that does not conform with the journals scope and scientific contributions.

Editorial Board.

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Hydrogeophysical Assessment of Groundwater in a Basement Complex of Southwestern Nigeria

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ABSTRACT

Hydro-geophysical investigation of fractured basement involving the Very Low Frequency Electromagnetic (VLF-EM) and the electrical resistivity methods has been carried out within Oye Ekiti town, South-western Nigeria. This study demonstrates the effectiveness of integrated geophysical investigation in groundwater potential assessment in a typical basement complex environment. This was done with a view to access the groundwater potential of the area. Fourteen (14) VLF-EM and Horizontal Profiling (HP) traverses were established. Thirty one (31) Vertical Electrical Soundings (VES) were conducted at the investigated site. The VLF-EM data were presented as profiles and 2-D images. Horizontal Profiling data were also presented as profiles while the VES data were presented as geologic sections. The VLF-EM profiles and 2-D images identified conductive zones which were confirmed by the subsurface geologic sections developed from the investigation results of the VES. The geologic sections delineated five subsurface geologic layers. These include the topsoil, laterites, sandy clay, weathered basement and fresh basement. The weathered basement constitutes the main aquifer unit within the study area. The weathered layer is generally thin and clayey. The relatively low weathered basement resistivity could indicate enhanced permeability due to significantly fractured density and tendency for moderate groundwater potential and yield through groundwater potential map.

Keywords: Hydrogeophysical, fracture, aquifers, delineation and basement rock

INTRODUCTION

Groundwater is a major source of clean drinking water and it accounts for about 98% of the world's fresh water (Montgomery, 2000). Groundwater is the water found in the subsurface. It originates from the percolation and infiltration of water into the ground after rainfall. These waters moves through pores within the ground into a convenient storage Formation called Aquifer. Groundwater is important because of its availability, low cost of development and its reliable quality (Sule *et al.*, 2013). Groundwater is therefore, a tremendous major economic resource, particularly in most cities of Nigeria where portable water is scarce (Nwankwo *et al.*, 2013). Basement structures which are products of tectonic activities are recognized to play a major role as host for mineral resources and also aid effective groundwater accumulation. Fracturing (jointing and faulting) in the basement complex rocks over the ages had generated lots of interest from geoscientists in their quest for solid minerals and groundwater development. In order to fully develop this groundwater for human use some techniques are needed to be used.

The use of surface geophysical techniques has revolutionized groundwater development in the Basement Complex areas as it is employed in locating areas with high groundwater prospect. In the Basement Complex terrain, groundwater occurs in the weathered regolith (overburden aquifers) and in fractures in the fresh crystalline rocks (fractured crystalline aquifers), where thick weathered zones or fractures in fresh rocks occurs, wells and boreholes tap the groundwater for potable water supply (Eduvie, 2006). Groundwater occurrence in the crystalline basement rocks can be irregular due to the abrupt discontinuity in lithology, thickness and electrical properties of the bedrock (Olayinka and Olorunfemi 1992; Olorunniwo and Olorunfemi 1987). The application of geophysics in groundwater investigation include identification of aquifer units, delineation of depths to and thicknesses of aquifer, identification of aquitard or confining units, location of preferential fluid migration paths (fractures, faults and joints) and mapping of groundwater contamination. Previous authors who have engaged geophysical methods for groundwater investigation in crystalline basement complex terrain involving VLF, EM, electrical resistivity and borehole geophysical methods include Porsari et al., 2004, Kellett and Bauman 2004, Olorunfemi et al., 2004, Sharma and Baranwal 2005, and Omosuyi et al., 2007. This study intends to use the VLF-EM and electrical resistivity methods to identify aquifer units within the crystalline rocks of Oye town in Oye Ekiti. The objectives of the present study include the delineation of the surface sequence, identification of the aquifer type(s), mapping of groundwater accumulating geological structures such as faults and fracture zones as a means of assessing the groundwater potential of the study area.

Description of the Study Area

Oye Ekiti is located in the North eastern part of Ekiti State, South western Nigeria. It lies between geographic co-ordinates of Nothing $5^{\circ} 41' 400''^E$ and $5^{\circ} 43' 200''^E$ (UTM) and latitudes $7^{\circ} 31' 5000''N$ and $7^{\circ} 62' 500''N$ (UTM) (Fig: 1). the topographic elevation in the area ranges from 345.0 to 375.0 m above mean sea level. The study covers an area extent of about 21000 km². The study area is located within the tropical rain forest of Southwestern, Nigeria with dry and wet seasons. The wet season starts from around mid-March and ends in October with an average annual rainfall of between 1500 mm and 2100 mm while the dry season starts around November and ends in March. The average maximum temperature is about 33 °C (Iloeje, 1980). The area is accessible through Ifaki – Ikole Express road, other minor roads and footpaths interconnecting the studying area due to farming activities which is the major human activities in the area.

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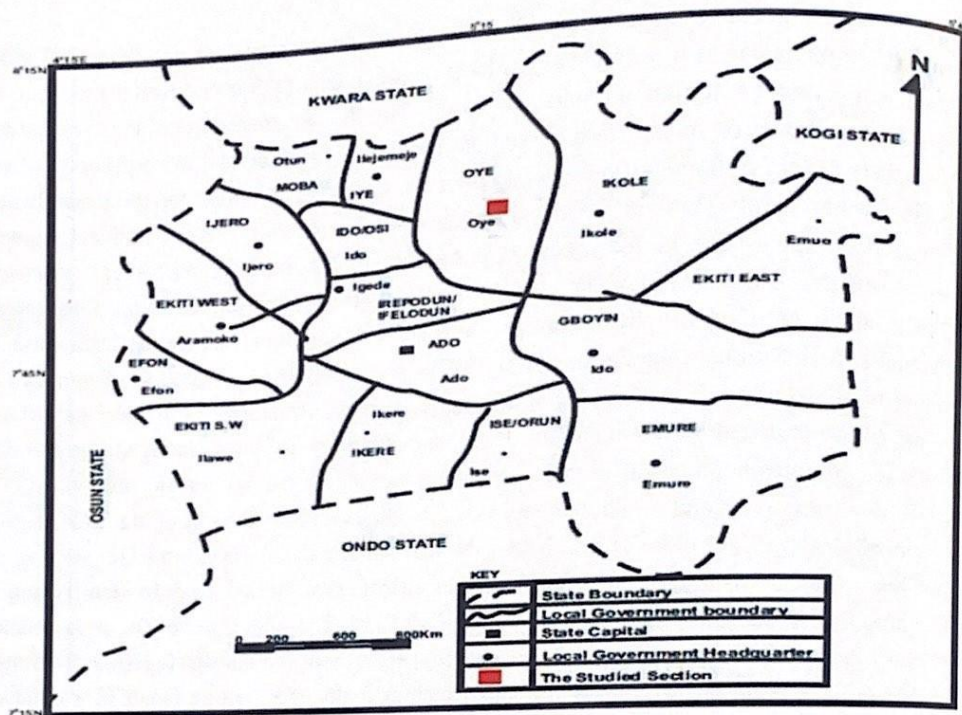


Fig 1: Description map of the study area.

Geology and Hydrogeology

The study area is underlain by rocks of Precambrian basement complex of southwestern Nigeria (Rahaman, 1976). Oye Ekiti falls within three major lithostratigraphic units in which gneiss and granites are more pronounced. The granitic rocks dominate the area (Fig: 2). It is coarse grained corresponding to Precambrian age and called Porphyritic granite. The granites occur as intrusive in low-lying outcrops within the biotite gneiss. In basement terrain, groundwater occurs in the weathered basement and the joints, fractures or faults within the bedrock (Ademilua and Olorunfemi, 2000). The rock consists of Precambrian metasediments, migmatites, gneisses, granites and other intrusive igneous rock. The Geomorphology of the study area consisting of lowlands and extensively forested plain landform, high hills are prominent at Ire, Itapa and Osin. Oyeekiti has a low relief with undulating surface formed as a result of differential weathering and erosion and the area is surrounded by hills which are moderate heights. Some of the hills are characterized by steep sides and deep valleys, it falls within the tropical rainforest zone of southwestern Nigeria. It has tropical climate characterized by alternating dry and wet seasons. The rainy season covers a period of about seven to eight months (March -October) while the dry season extends from November to February. The average temperature is about 36°C and relative

humidity is about 75%. The average rainfall 1700mm (Akinola, 1986) and the rain serve as a main source of groundwater replenishment.

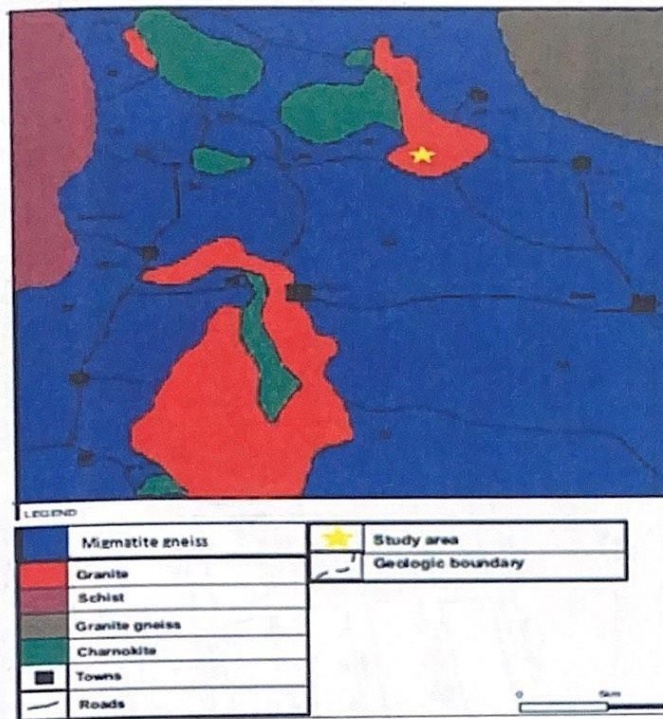
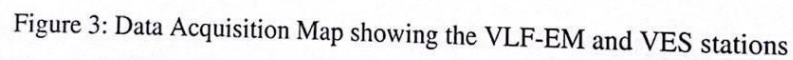


Figure 2: Geological Map of Ekiti showing the Study Area

MATERIAL AND METHOD

Fourteen (14) traverses, which ranged in lengths from 300m to 760m, were established in an approximately E – W direction across the study area (Fig. 3). Traverse 5 is 760m long while Traverse 9 is 300m long and other Traverses are range between 320m to 550m. Very Low Frequency Electromagnetic (VLF-EM) and the electrical resistivity methods were employed in the survey. The electrical resistivity survey involved (a multi-electrode spacing $a = 10\text{m}$ and 30m) Horizontal Profiling (HP) with Wenner array and Vertical Electrical Sounding (VES) with Schlumberger array. The horizontal profiling adopted a station interval of 10 m. The resistivity measurements were made with the Omega resistivity meter. The VLF-EM measurements were taken at 20 m interval along Traverse 1 while 10 m station separation was adopted along Traverses 2 to 14. The VLF-EM measurements were made using the ABEM WADI equipment. The VLF-EM method was used for locating geologic features (e.g. fractures, faults, joints and shear zones) which were subsequently investigated using the VES technique. The VLF-EM real component data were inverted into 2-D subsurface images using the KHFILT software. The multi-electrode spacing profiling was adopted so that the subsurface can be imaged at two



Very Low frequency Electromagnetic Meter

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confirmed by peaks positive by Fraser filtering are characteristic of fractures in the basement which are important for groundwater accumulation. The inversion of the VLF-EM Fraser filtered real component resulted in current-density pseudosections (Fig 4) which do not show any linearity expected of a fractured zone. Closer observations of the current density pseudosections for all the fourteen traverses show high conductivity zones even at greater depth and thus suggest the presence of clay which may reduce the yield of the aquifer. The depth of investigation of the VLF-EM technique varies between 40 m along traverses 6, 8 and 9 to 150 m at traverse 5. Traverse 5 shows evidence of fracturing which extends from a distance of 250 m to 400 m along the traverse. It is best to prospect for groundwater in these zones. High conductivity of zones, which are possible presence of clayey material and poor groundwater potential are observable of groundwater accumulation are represented by bright (yellow-red) colour relative to the coloured scale on the current density pseudosections (Figs 4).

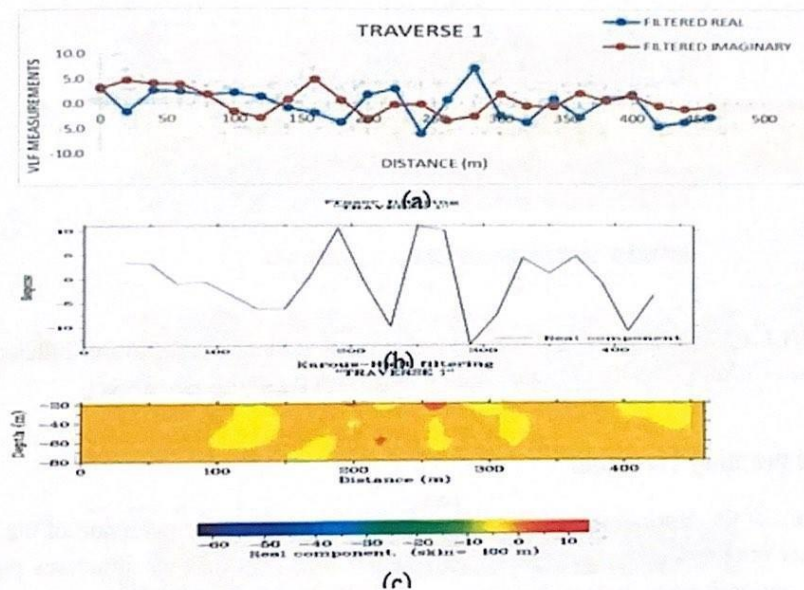


Figure 4a: (a) VLF-EM filtered real and filtered imaginary components, (b) Fraser Filtered Real and (c) Current Density Pseudosection along Traverse 1

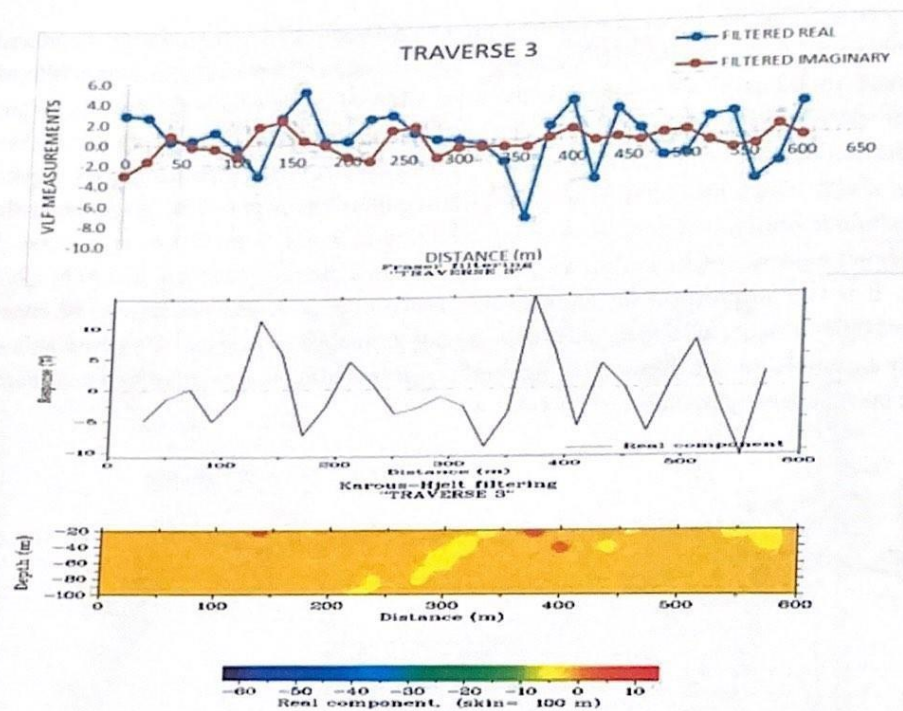


Figure 4c: VLF-EM filtered real and filtered imaginary components, (b) Fraser Filtered Real and (c) Current Density Pseudosection along Traverse 3

Horizontal Profiling Technique

The field data of the Horizontal profiling survey are presented. The inversion of the horizontal profiling data obtained along traverses 1-11 resulted in 2-D resistivity structures presented in Figure 5. Low resistivity values in some zones which are probable zones of groundwater accumulation are represented by light colour (yellow-green-light blue) relative to the coloured scale on each of the 2-D resistivity structure. Higher resistivity zone represented by lighter colour (red) relative to the coloured scale on each of the 2-D resistivity structure indicate poor aquifer potential while purple indicate very poor aquifer potential. Dark colour (deep blue) indicate very low resistivity which suggest the presence of clay and thus poor aquifer potential. Low resistivity values in some zones which are probable zones of groundwater accumulation occur at distance between 80 m-240 m and between 15 m-230 m along traverses 2 and traverse 4 respectively (Fig 5). Along traverse 8, the low resistivity zone occurs at distances ranging between 15 m-30 m and also between 55 m-345 m. The low resistivity zone is extensive along traverse nine extending from a distance of 40 m to 80 m and then extends further from 165 m to 800 m along the traverse. On traverse 10, the low resistivity zone occurs at distances ranging

between 20 m-80 m and also occur between 150 m-300 m. also, along traverse 11 low resistivity values in some zones which are probable zones of groundwater accumulation occur at distance between 20 m-145 m. High resistivity zones which rather suggest poor aquifer potential are more prominent along traverse 1 and traverse 3. The depth of investigation here is 19.9 m.

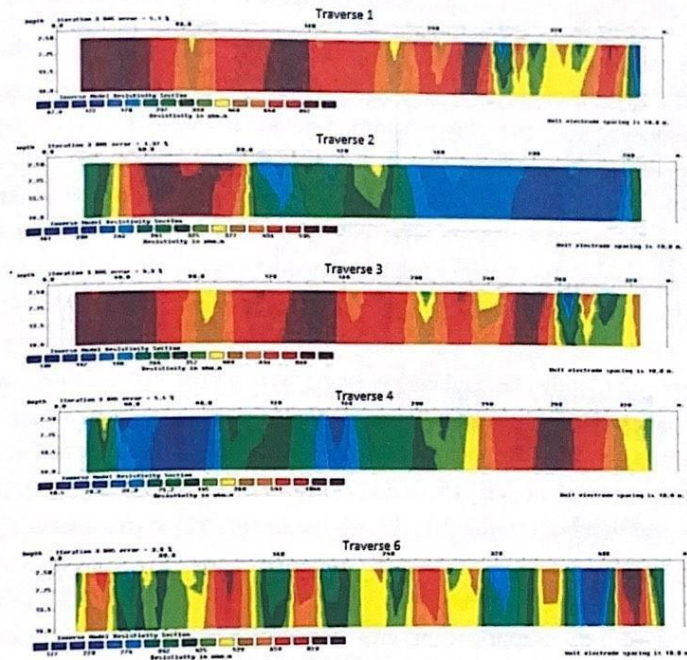


Figure 5a: Inverse Model Resistivity Section

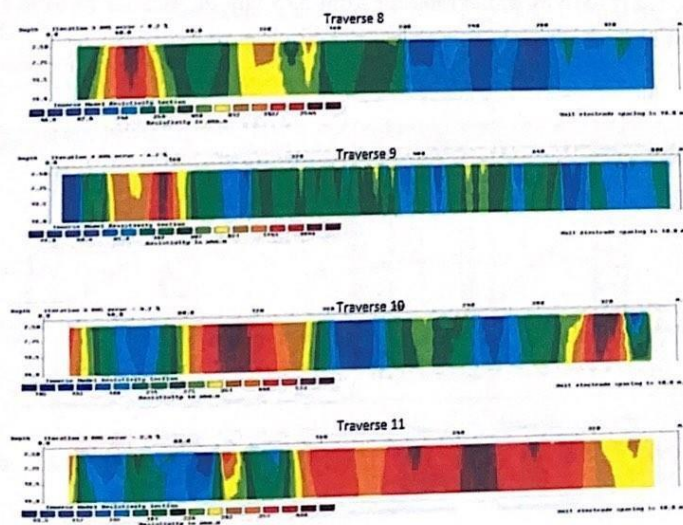


Figure 5b: Inverse Model Resistivity Section

Vertical Electrical Sounding (VES) Technique

Vertical electrical soundings was carried out in the study area in order to obtain geologic model from the resistivity data, the VES data were inverted using software IP2Win developed by Alexey Bobachev, Moscow State University, Russia. The 1D profiles generated from inversion of the resistivity data VES1-VES8 are presented in Figure 6,

Summary of the computer iteration results is presented in fig6. Analysis of the 1D resistivity profile produced a system of three to five geo-electric layers which are the top soil, lateritic layer, clayey soil(sandy clay and clayey sand), weathered basement which overly the fresh basement. The topsoil apparent resistivity values vary from 12.3 Ωm at VES21 – 411 Ωm at VES25. The thickness of this layers varies from 0.204 m at VES28 to a maximum of 5.31 m at VES1. The second layer is the lateritic layer whose apparent resistivity ranges from 5.85 Ωm - 2779 Ωm at VES21 and VES15 respectively. The thickness of the lateritic layer varies from 0.413 m at VES15 to 10.40 m at VES25. The second layer is not present at VES1, VES4, VES5, VES8, VES11, VES16 and VES18 where only 3 geoelectric layer were delineated. The third layer is the clayey soil (Sandy clay and clayey sand) layer whose apparent resistivity depends on the percentage clay present and ranges from 45.8 Ωm at VES29 to 626 Ωm at VES15. The thickness of these layer varies from 3.10 m to 7.11 m at VES29 and VES27 respectively. The third layer is only present at VES15, VES27 and VES29 where 5 geoelectric layer were delineated. The fourth layer is the weathered basement which represents the deep seated aquiferous layer in the area. The layer resistivity varies from vary from 26.3 Ωm - 876 Ωm at VES20 and VES4 respectively while its thickness varies from 4.04 m at VES17 to 71.5 m at VES9. This layer is very important in groundwater accumulation. In hard rock terrains composite aquifers of the weathered basement zone and fractured basement are known to give the highest groundwater yield (Oyedele and Olayinka, 2012).The last layer is the basement which has apparent resistivity value ranging from 535 Ωm at VES 23 to 6176 Ωm at VES9. The resistivity pseudosection of the layer are presented in Figure 6.

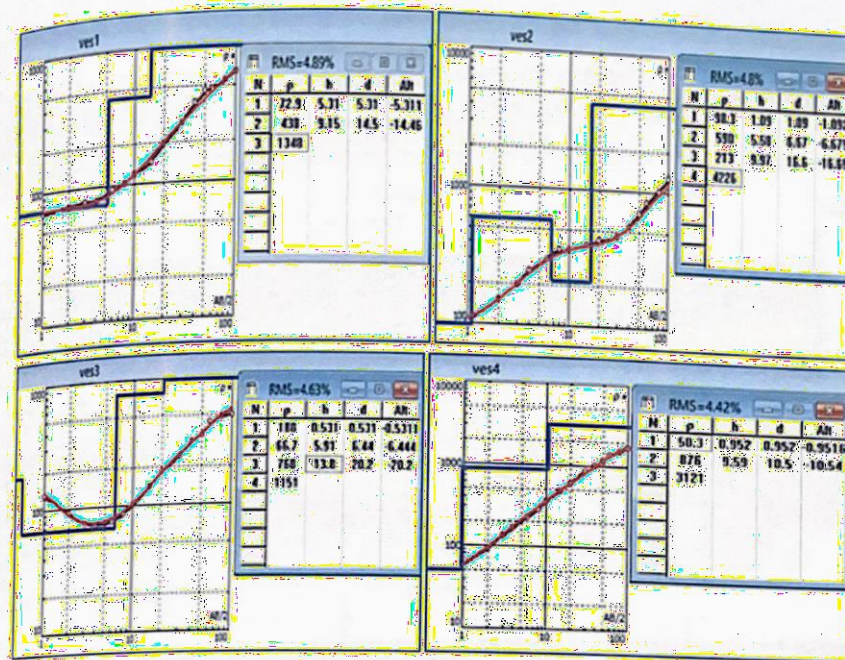


Figure 6a: 1-D Profiles Generated from Inversion of the Resistivity Data VES1-VES4

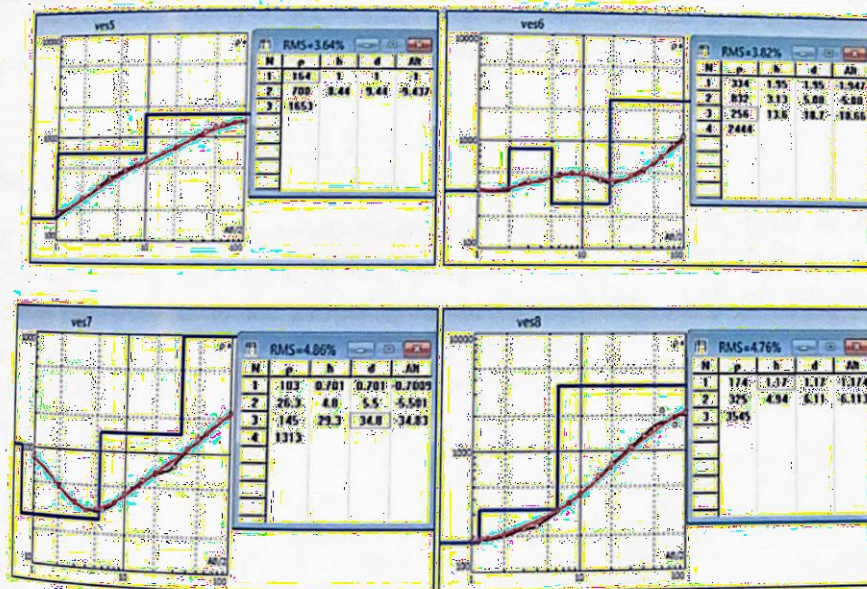


Figure 6b: The 1D Profiles Generated from Inversion of the Resistivity Data

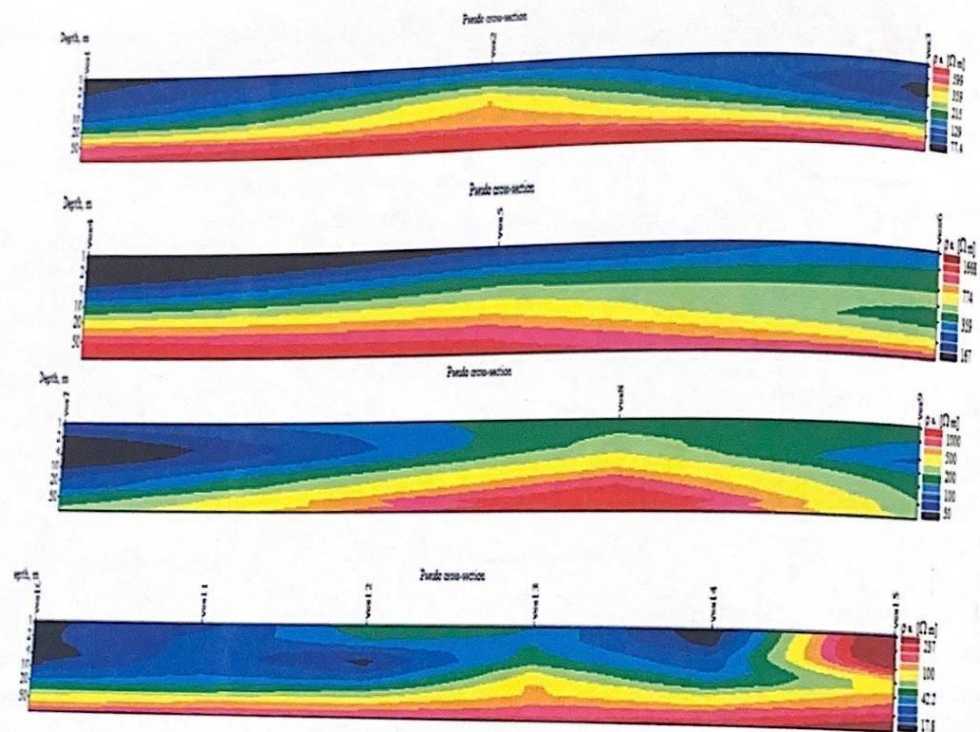


Figure 6c: Resistivity Pseudosection along Traverses 1-4

Correlation of Results

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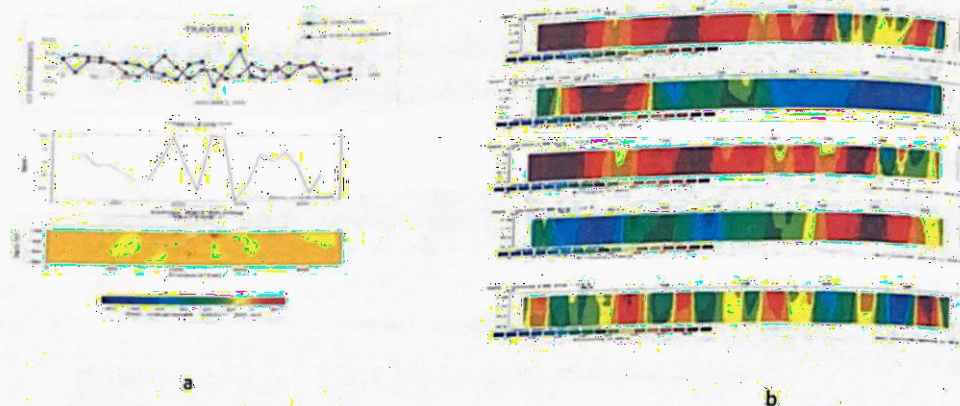


Figure 7: VLF responses (a) and Resistivity 2D-inversions (b)

CONCLUSION

It can be concluded from the interpretation of the analysis and interpretation of data obtained from the study as follows: Reconnaissance survey carried out in the study area using very low frequency electromagnetic method (VLF-EM) and horizontal profiling to identify point for detail Vertical Electrical Sounding (VES) shows that low resistivity zones occur on all the traverses but are characteristically not extensive in any of the traverses. On the resistivity section low resistivity values in some zones which are probable zones of groundwater accumulation occur at distance between 80 m-240 m and between 15 m-230 m along traverse 2 and traverse 4 respectively. Along traverse 8, the low resistivity zone occurs at distances ranging between 15 m-30 m and also between 55 m-345 m. Furthermore, the low resistivity zone is extensive along traverse nine extending from a distance of 40 m to 80 m and then extends further from 165 m to 800 m along the traverse. The number of lithological layers in the study area varies from 3-5. This layer correspond to the topsoil, laterites, sandy clay, weathered basement and fresh basement. The topsoil apparent resistivity values vary from 12.3 Ωm – 411 Ωm .

The thickness of this layers varies from 0.204 m-5.31 m. The second layer is the lateritic layer whose apparent resistivity ranges from 5.85 Ωm -2779 Ωm . The thickness of the lateritic layer varies from 0.413 m-10.40 m. The second layer is not present at VES1, VES4, VES5, VES8, VES11, VES16 and VES18 where only 3 geoelectric layer were delineated. The third layer is the clayey soil (Sandy clay and clayey sand) layer whose apparent resistivity depends on the percentage clay present and ranges from 45.8 Ωm -626 Ωm . Also, the thickness of these layer varies from 3.10 m to 7.11 m. The third layer is only present at VES15, VES27 and VES29 where 5 geoelectric layer were delineated. The fourth layer is the weathered basement with

varying from 26.3 Ω m-876 Ω m while its thickness varies from 4.04 m-71.5 m. The last layer is the basement which has apparent resistivity value ranging from 535 Ω m-6176 Ω m. The weathered basement represents the aquiferous layer in the study area. This layer is very important in groundwater accumulation. The variation in apparent resistivity of this layer is probably due to varying degree of saturation resulting from topographical gradient. Very Low Frequency Method (VLF) shows no zones of linear structure which may be interpreted as fracture. There virtually no cusp on the resistivity profile to define a fractured zone. The only exception is traverse 5 which show evidence of deep seated linear structure but this could not be confirmed by Vertical Electrical Sounding (VES).

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