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SEASONAL HYDROGEOPHYSICAL INVESTIGATION OF GROUNDWATER POTENTIAL AND AQUIFER VULNERABILITY PREDICTION IN IJEBU – ODE, SOUTHWESTERN NIGERIA

Coker J. O[1]., Akpan H.H[1]., Agbelemoge J.A[1]. and Atilade A. O[2].

[1]Department of Physics, Olabisi Onabanjo University, Ago – Iwoye, Ogun State
[2]Department of Physical Sciences, Lagos State Polytechnic, Ikorodu, Lagos State

Abstract

A Geophysical survey involving Very Low- Frequency Electromagnetic and Electrical Resistivity methods were carried out in Ijebu – Ode, to delineate various aquifer units for evaluating the seasonal effect on groundwater potential. The fieldwork was carried out in the peak of the dry season (March) and wet season (July). The VLF – EM data were acquired during the dry and wet seasons along five traverses with maximum spread length of 500m using the VLF equipment while the 2 – D data were also acquired along the five (5) traverse for both seasons with the aid of ABEM SAS1000 terrameter. The 2 – D Dipole-Dipole data was processed with DIPROWIN software while the VLF – EM data was processed with KAROUS-HJELT software. Results of the VLF – EM data for the dry and wet season's ranges from -67 to +50 mmhom^{-1}; and from -150 to +157 mmohm^{-1} The study identified weathered and fractured horizons and both constitute good aquifer zones. The aquifer thickness/depth of weathered basement during the dry season is low, ranging between 5 – 15 m compared with 12 – 25 m for the wet season. Hence, drilling of water should be done during the dry season in other to locate the exact depth of water.

Keywords: Aquifer, Conductivity, Geophysical survey, Lithology, Seasonal effect,

1.0 Introduction

Water is a basic nutrient of the human body that is critical to human life. It supports the digestion of food, absorption, transportation, and use of nutrients. Water also eliminates toxins and wastes from the body. Water is essential for the preparation of foodstuffs [1, 2]. Earth water bodies are comprised of about 10% groundwater (most water is in oceans) and about 35 times the amount of water in lakes and streams. Groundwater is a mysterious nature's hidden treasure. It is an important economic resource, particularly in most cities of Nigeria where potable water is scarce. It is about one-third of the water that local and city water departments supply to households and businesses. However, groundwater is widely used in many ways and usually served with little or no treatment and this may be true for deep boreholes [3].

Groundwater has three main uses: agriculture (irrigation), domestic consumption (source of drinking), and industrial (used for achieving sustainable development). Groundwater is a source of potable water that is usually free from biological and chemical contaminants. It requires little or no purification before usage for domestic and industrial purposes. Groundwater is not affected by drought, odour, and colouring. It has constant temperature, chemical composition, and suspended solutes that are usually absent. It has far greater storage as compared to surface water [4, 5]. Over half of the world's population depends on groundwater for drinking water supplies [6, 7, 3].

The availability of water for domestic, agriculture, and industries (small-scale industries) is a function of seasonality since groundwater yield is generally associated with seasonal variations such as climatic conditions, weather, etc. The geological terrains of Ijebu – Ode contributes to the fluctuation of groundwater level and aquifer during the wet and dry season, though Ogun State with monsoon climate is characterized by high rainfall and high evaporation. The climatic condition of Ijebu – Ode is such that the rainfall pattern is not uniform. There exist a season of surplus water and water shortage in streams,

Corresponding Author**:** Coker J.O., Email: coker.joseph@oouagoiwoye.edu.ng, Tel: +2348034350628, +2348057661122

wells, and rivers, since the annual rainfall in the geological terrains of Ijebu – Ode is not the same due to spatial and temporal variability in rainfall. Wet season favours high yield of water where shallow boreholes and wells are recharge while during the dry season the water level and aquifer discharges due to a wide variety of factors.

The need for the exploration of a basement aquifer in the study area is necessary to identify potential groundwater aquifer and this is achieved by a combination of two detailed integrated geological methods, which are the Electrical Resistivity (Dipole-Dipole) and Very Low Frequency – Electromagnetic methods. Reconnaissance EM surveys are used to locate aquiferous zones in many instances [8]. In locating groundwater, the electrical resistivity method is found to be successful and cost-effective. Apparent resistivity of the subsurface measured from the surface is a function of the current, the potential difference, and the geometry of the electrode array. The availability of water considerably controls the variation of the resistivities in the shallow subsurface in which water-bearing rocks and minerals have lower resistivities in the shallow subsurface. Electrical Resistivity measurements can indicate the level of water saturation and connectivity of pore spaces [9] and many authors have successfully applied this method in groundwater exploration [10]. Many geoscientists had carried out groundwater researches in the basement and sedimentary terrain.

Hydrogeophysical techniques using Electromagnetic (VLF – EM) and Dipole–Dipole Resistivity methods were conducted by [11] in Akure, Southwestern Nigeria which falls within the basement complex of Nigeria. They aimed at providing a model for the delineation of groundwater potential and vulnerability in the study area. The result obtained, identify two aquifer zones with resistivity values ranging from 20 – 310 Ωm and 100 – 300 Ωm respectively. The areas of high conductivity were revealed by a two-dimensional map of the filtered real component that is indicative of linear features that can serve as a reservoir or conduit for groundwater.

Electrical Resistivity and Very Low-Frequency Electromagnetic techniques were employed by [12] to delineate fractured zones for groundwater exploration within the permanent site of Olabisi Onabanjo University, Ago-Iwoye, Southwestern Nigeria. The VLF – EM survey was carried out at 10metres interval along eight (8) traverses at East-West direction ranging from 230 – 500 m in length. The plot of filtered real and filtered imaginary showed eight fractured zones close to the surface or subsurface were further delineated by using the electrical resistivity method. The two methods help in identifying and delineating of prospective groundwater area.

2.0 Geology and Topography of Ijebu – Ode

The areas considered in this work are located within Ijebu – Ode. The environment covers Pogil, Oke Erin, and Oke Ariyo all situated within Ijebu – Ode Local Government Area. Ijebu – Ode lies between latitude 6^0 $49^{|}$ $9.98^{||}$N (6.81944^0N) and longitude 3^0 $55^{|}$ $2.32^{||}$E (3.91731^0E) of the Greenwich meridian with a total area of 192km^2. It has a population of 222,653 projected by the 2006 census. Ijebu – Ode and its environments are within a transition zone of the basement rock and the cretaceous sediment of the Dahomey basin in South-west Nigeria (figure 1). The study area is within Ijebu – Ode the Precambrian basement complex and the area is accessible in terms of the transportation network that consists of major and minor roads with footpaths.

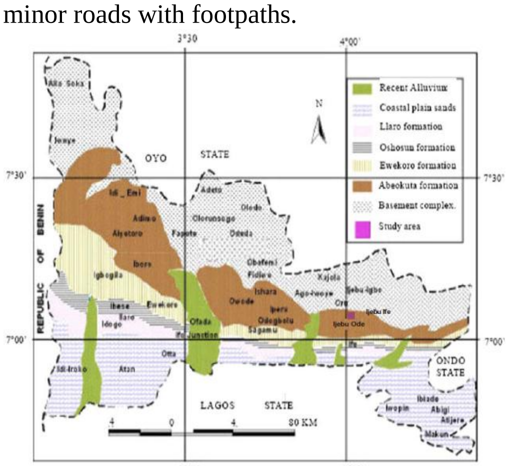


Fig 1: Geological map of Ogun state [13]

The topography of Ijebu – Ode is approximately 3,218.68 m^2 contains modest variations in elevation with a maximum elevation change of 89.00 m and an average elevation above sea level of 66.45 m. The topography of Ijebu – Ode is irregular as shown in figure 2, hence the region is said to be rolling, wavy, or undulating. This topography influences the drainage pattern in terms of elevation and depression of landforms.

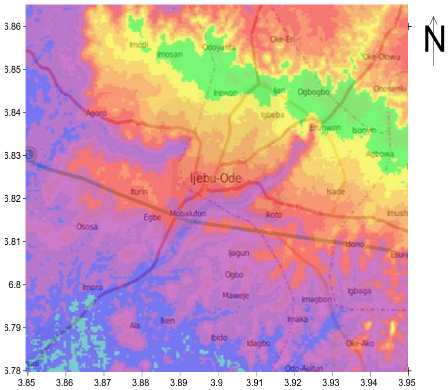


Fig 2: Topographical map of Ijebu – Ode [14].

3.0 Materials and Methods

Electrical Resistivity (Dipole-Dipole) and Very Low-Frequency Electromagnetic techniques were employed in this research work. The VLF – EM method is used primarily as a reconnaissance tool as large areas of land can be covered rapidly with other geophysical methods combine with it. Very Low-Frequency radio communication signals are used to determine the electrical properties of shallow bedrock and near-surface soils.

The major equipment used in the field to obtain and acquire data using the very low-frequency electromagnetic method is the ABEM WADI VLF TRANSMITTER which is used to delineate the study areas into positions with relatively average to high conductivity to detect overburden thickness consider as potential groundwater zone. Having identified the traverses, the VLF equipment or device was scan and tested to obtain a clear reception being a piece of sensitive radio equipment before use. Measurements were repeated twice to minimize contamination of the VLF band by natural high-frequency radio noise from the ionosphere, presence of buried cables, and other metallic conductors. Data was acquired from 5 traverses each in Ijebu – Ode making a total of ten traverses by a crew of two persons. Ten traverses were covered in Ijebu – Ode for a very low-frequency electromagnetic method at 10m fixed spacing, covering a traverse length of 500 m for each traverse (figure 3).

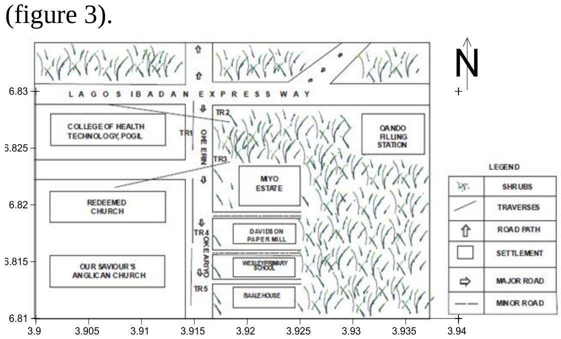


Fig 3: Location map showing VLF-EM traverse of the study area.

During the field survey, the VLF – EM equipment was scanned and tested to obtain a clear reception, being a sensitive device before use. Once we obtained clear reception, transmitter readings and GPS coordinates were taken at 10 m fixed spacing. Ten traverses were covered at the study area covering a traverse length of 500 m for each. Measurements were repeated twice to minimize contamination of the VLF band from the high-frequency radio noise coming from the ionosphere or because of buried cables and other metallic conductors.

The basic field equipment used for the VLF – EM method was ABEM WADI VLF transmitter (figure 4), a portable computer (laptop), measuring tape, and a GPS. VLF – EM device or the ABEM WADI VLF transmitter equipment, nominal weight equipment that is used to conduct a reconnaissance survey by a single operator where large areas of land can be rapidly covered. The equipment is a state of the art in that it stores all data onboard in an expansive memory so that many days' data can be saved at one time. It does not need ground contact; survey operation is very fast with no wasting of time. Highly resistive conductive overburden, which has proven to be a zone of conductive bodies of fluid (groundwater), can be detected when the target strikes are in the direction of the transmitter.

Fig 4: ABEM WADI VLF transmitter equipment

On the other hand, similar reading or data were obtained using the dipole-dipole array; equipment used in the field is ABEM SAS1000 terrameter which measures and displays the ground resistance. Apparent resistivities were computed and some practical limitations were considered. One of the major problems encountered during the fieldwork was limited space for electrodes layment where we encountered rocky hard terrain. We tried as much as possible to avoid locating the Centre of spread at positions where buildings, farmland and other structures could limit the space for the fieldwork. This notwithstanding we were able to reach up to the desired spread length of 160m. The presence of buried cables and other metallic conductors could constitute electrical noise; none of the electrodes was located near such conductors. Although it may be necessary to carry out the electrical resistivity work when the ground is wet, because waterlogged soil may result in enormously high conduction near the ground surface. On the other hand, 10 traverses were covered in the study area using the dipole-dipole array, covering a traverse length of 160 m at 5 m fixed spacing as shown in figure 5

The Dipole-dipole array is widely used in resistivity survey because of the low electromagnetic coupling between the current and potential difference in the circuit. A dipole is a paired electrodes located close to each other (figure 6. It is better horizontal data coverage than a Wenner array.

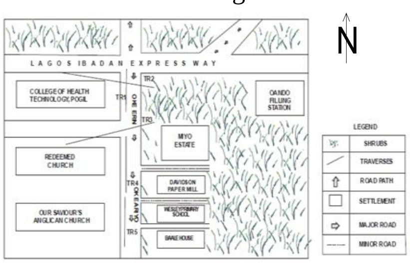


Fig 5 Location map showing dipole-dipole traverse of the study area

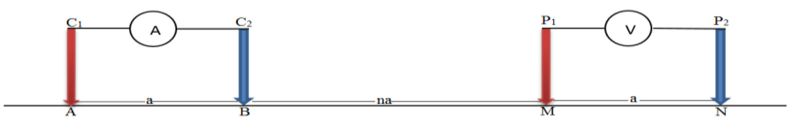
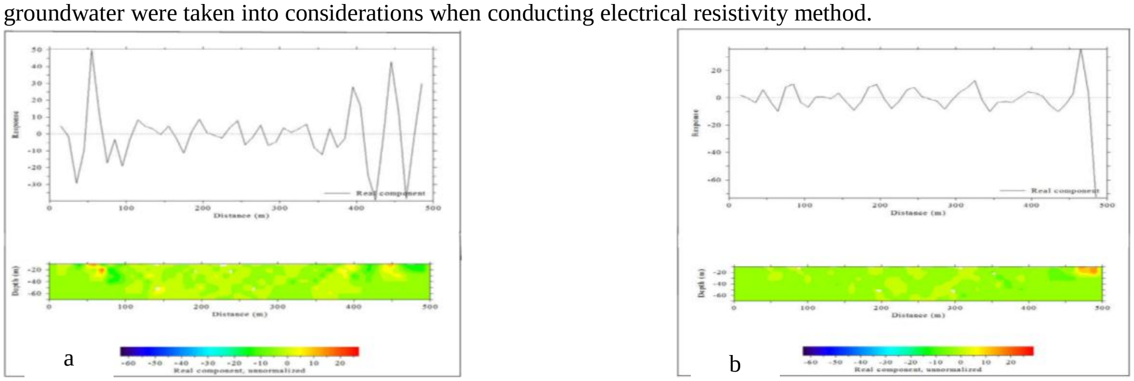


Fig 6: Dipole–dipole fixed layout

4.0 Results and Discussion

4.1 Very Low Frequency (VLF) method during Dry Season

Figure 7(a) – 7(e) shows the pseudo-section VLF results generated from the interpreted data on profiles 1 – 5 respectively. Traverse 1 – 5 results show similar characteristics. The real component varies from -60% to + 20% in all the profiles. The conductivity of the sections also varies between – 5 and +5mmhom^{-1} for all profiles. From the sections, the subsurface layer is indicative of similar conductivity values ranging between –5 and +5mmhom^{-1}. Thus, no distinct anomalous region is identified that could favor groundwater exploration in profile 1 – 5 during the dry season nevertheless, the points on the transverse identified as relative conductive zones for potential groundwater were taken into considerations when conducting electrical resistivity method.



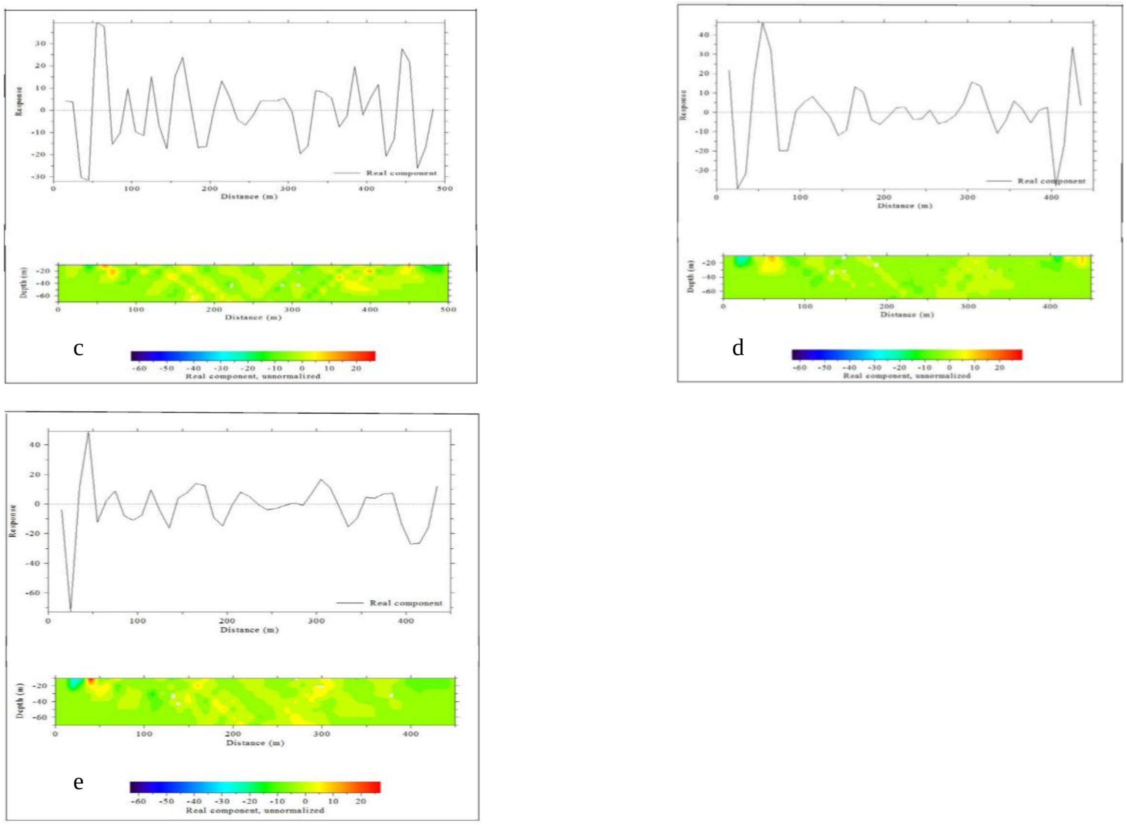


Fig 7: 2D Pseudo-section of the VLF along Traverse 1 – 5 for Dry Season

4.2 Electrical resistivity dipole–dipole during a dry season

The lithologic unit as interpreted from the inverted electrical resistivity for profiles 1 – 5 during the dry season was presented in figure 8(a) – 8(e). The electrical resistivity sections for profile 1 are located at the northwestern part, profile two, and three are located in the northeastern part and profile 4, and 5 at the southwestern part of the area of study. The traverse length for profile 1 to 5 is 140m each.

Profile 1 (fig. 8a) shows the layers of the subsurface, the topsoil has resistivity values ranging between 110 and 484 Ωm at depths 0 to 5m interpreted as clayey sand. Underneath the first layer is a greenish colouration with resistivity value ranging between 29 and 71 Ωm has a depth varying between 5 to 15m. There are patches of bluish colouration with low resistivity value ranging between 12 and 29 Ωm interpreted weathered layer. Profile 2 (fig. 8b) has almost the same pattern with profile 1 except the bluish colour found at the corner of southwestern part of the map covering distances between 0 and 55 m at a depth greater than 10 m with resistivity values ranging between 17 and 87 Ωm interpreted weathered layer.

Profile 3 (fig. 8c) has low resistivity values ranging between 118 and 343 Ωm at depths 0 to 10 m interpreted as clayey sand. Underneath the first layer is a greenish colouration with resistivity value ranging between 14 and 41 Ωm interpreted as the fractured basement except a pocket of clay with a very low maximum resistivity value of 14 Ωm at distance between 40 and 55 Ωm. The total profile coverage of profile 4 (fig. 8d) is occupied by greenish colouration with very low resistivity values ranging between 8.9 and 34 Ωm interpreted as clay. The topsoil layer has resistivity (from 169 – 740 Ωm) covering a distance ranging from 0 to 50 m interpreted as sandy clay to sand. Profile 5 (fig. 8e) has a continuous high resistivity values ranging between 108 and 21309 Ωm covering the entire topsoil at depths 0 – 5 m. Underneath the topsoil layer is a greenish colouration with resistivity value ranging between 31 and 109 Ωm occupying the profile except two portions with special features (bluish colouration) found at both the central and southeastern part of the profile with resistivity values ranging between 9.2 and 31 Ωm interpreted weathered layer.

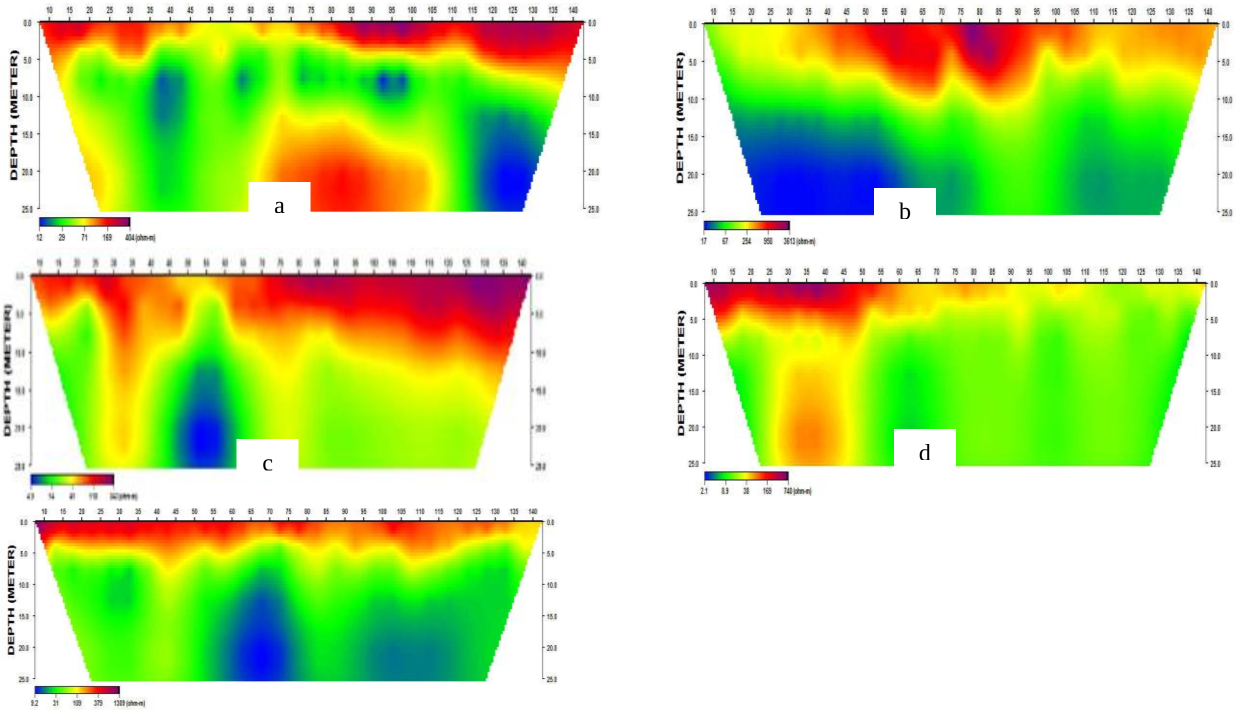
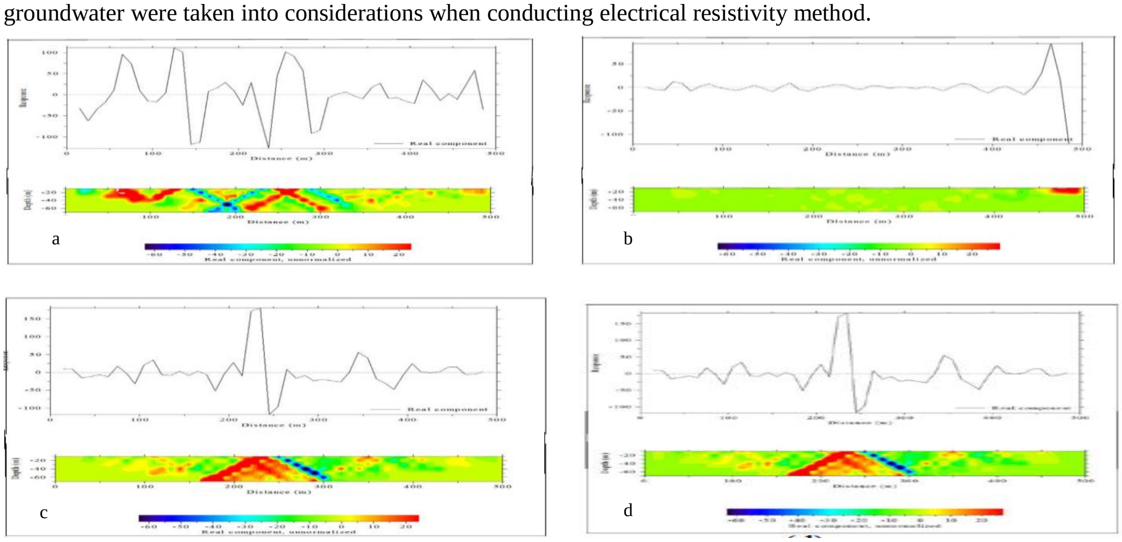


Fig 8: 2-D Dipole – Dipole Resistivity profile for Traverse 1 – 5 during dry Season

4.3 Very Low-Frequency Electromagnetic (VLF - EM) methods during Wet Season

Figure 9(a) – 9(d) shows the pseudo-section VLF - EM results generated from the interpreted data along with profile 1 – 5. The real component varies between -60% and + 20% for all profiles. Traverse 1 indicates two possible anomalous zones (conductive zones) suspected to be weathered and fractured zones at a lateral distance of 50 – 140m and 210 – 300m that could favour groundwater exploration. These zones are indicated by highly conductive values between + 20mmhom^{-1} and above at depth range of 20 – 60m indicated in red color on the profile. The conductivity of traverse 2 varies between – 5 and + 2mmhom^{-1}. From the section, the subsurface layer is indicative of similar conductivity values ranging between – 5 and + 2mmhom^{-1}. Thus, no distinct anomalous region is identified that could favor groundwater exploration.

The conductivity of traverse 3 and 4 vary in the same manner between – 10 and + 30mmhom-1. From the section, conductive zone (between + 10 and + 30mmhom^{-1}) is identified at distance (lateral distance) of 160 – 300m form depth ranging from 20 – 60m. This zone is suspected to be a fractured layer on the profile that could favor groundwater exploration. The conductivity of traverse 5 vary between – 25 and + 25mmhom^{-1}. From the section, the conductive zones (between + 15 and + 25mmhom^{-1}) are identified at a distance (lateral distance) of 300 – 350m form depth ranges between 20 and 60m. This zone is suspected to be a fractured layer in yellow to red colour on the profile that could favor groundwater exploration. The points on the transverse identified as the high conductive zones for potential groundwater were taken into considerations when conducting electrical resistivity method.



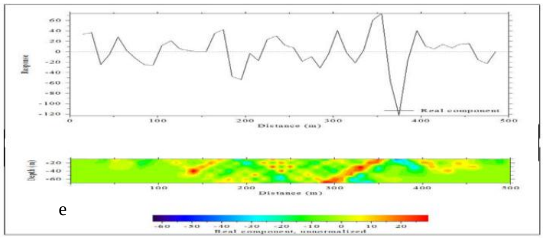


Fig 9: 2D Pseudo-section of the VLF - EM along Traverse 1 to 5 for Wet Season

4.4 Electrical resistivity (dipole-dipole) during a wet season

The lithologic unit as interpreted from the inverted electrical resistivity profile during the wet season is presented in figure 10(a) – 10(e). The traverse length is 140m and the same area investigated during the dry season measurements were used for all the profiles.

Profile 1 (figure10a) shows relatively low resistivity value at the topsoil ranging between 159 and 401 Ωm at depths 0 – 5 m and underlain by sandy clay with resistivity value of 83 Ωm (greenish colouration). Clay material (bluish colouration) is found between distances 115 - 140m with a very low maximum resistivity value of 25 Ωm and with depths between 10 and 25 m. The inverted model resistivity of profile 2 (Figure 10b) shows the continuously spread of the sand materials with resistivity value less than 1473 Ωm at depths between 0 and 15 m. At a distance of 60m and 75m, a pocket of clay materials was found with low resistivity values ranging between 2 and 14 Ωm interpreted as the weathered layer.

In profile 3 (figure 10c) only one significant of conductive body (bluish colouration) is found at a distance between 40 - 55m, with resistivity values ranging between 5.4 and 14 Ωm interpreted as the weathered layer. This profile is similar in pattern to profile 2 having continuous topsoil with resistivity values ranging between 115 and 319 Ωm. The similarity in the two profiles is as a result of same geology of the study area [13] Profile 4 (figure 10d) has a topsoil with resistivity values ranging between 217 and 664 Ωm at distances 0 and 60 m. The remaining entire profile was covered with a greenish colouration except at a distance of 60 and 85m which shows a bluish colouration with a very low resistivity values ranging between 7.7 and 23 Ωm interpreted as weathered layer. Profile 5 (figure10e) shows relatively high resistivity value at the topsoil ranging between 254 and 732 Ωm at depths 0 – 5 m and underlain by sandy clay with resistivity value of 88 Ωm (greenish colouration). Clay materials (bluish colouration) are found between distances 60 – 80 m and 90 - 105 m with very low resistivity value ranging between 9.9 and 29 Ωm with depths between 10 and 25 m interpreted as weathered layer.

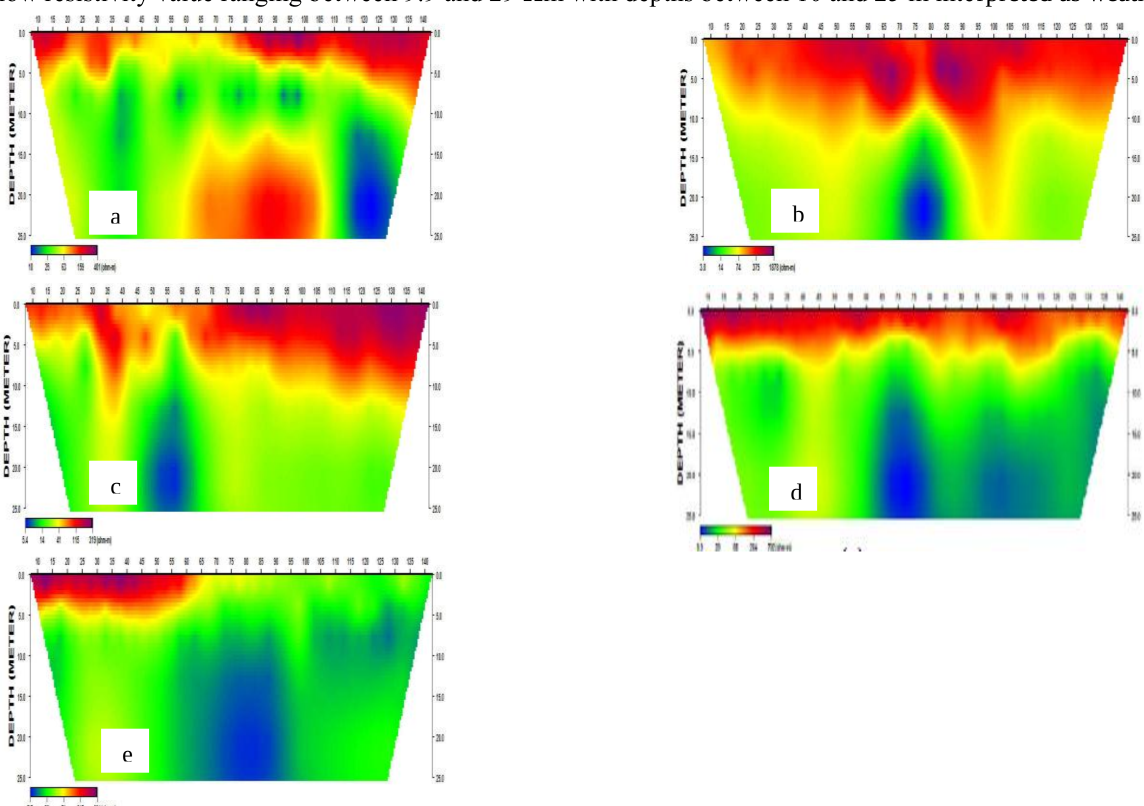


Fig 10: 2-D Dipole–Dipole Resistivity profile for Traverse 1 to 5 during wet Season

5.0 Conclusion

The results of this work show that the value of weathered layer resistivity of Ijebu – Ode during the dry season is generally high between 9.2 – 87 Ωm compared with that of wet season between 2 – 29 Ωm. Similarly, the aquifer thickness/depth of weathered basement during the dry season is low, ranging between 5– 15 m compared with 12 – 25 m for the wet season. The low resistivity values and high depth values recorded during the wet season could be as a result of influence pore water or due to the rock material and composition The variation in resistivity can be attributed to variation in moisture content in conjunction with the changes in surface conditions [15, 16]. It could also be due to the presence of a weathered zone since weathering in basement rocks enhances groundwater with potential.

6.0 Acknowledgement

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