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Application of VLF-EM response and geoelectrical sounding in groundwater investigation around an active dumpsite

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Abstract. An integrated geophysical method combining very low frequency electromagnetic (VLF-EM) and vertical electrical sounding (VES) methods were carried out around Adaland, Southwestern Nigeria, located within latitude 7^0 54' 0" and longitude 4^0 43' 0", with a view to investigate the possible impact of dumpsite on groundwater.This is the major study in the environment to offer extensive evidence regarding the suitability of obtaining quality groundwater. In this research, eight VLF-EM and twelve VES data sets were generated, which were then used to estimate the linear structure, bedrock formation, subsurface geological characteristics, and identification of leachate pathways. The VLF-EM data were analyzed by employing Karous_Hjelt and Microsoft Excel, while the VES data were investigated using the WinRESIST software. TheVLF-EM results confirmed the presence of conductive zones, which might be due to fracture, fault and contact zones or weathered basements. The lithological units acquired from the electrical resistivity results revealed four geoelectrical layers such as topsoil, weathered-based, fractured basement and fresh basement. However, the identified weathered layers and fractured basements from the geoelectrical sections and the corresponding Karous and Hjelt (K-H) pseudo sectionresults around the dumpsite, constitute the main passages for the possible impact of the open dumpsite on groundwater quality, since leachates from the dumpsite could slowly percolate downwards from the topsoil to the water table. Therefore, the impact of the dumpsite on the groundwater is caused by the inadequate clay materials, near-surface features such as fractures/faults, and lateral in-homogeneity. Thus, integrating both methods has been recommended in site characterization for accessing quality groundwater around a dumpsite environment.

Keywords: Geophysical method, leachate, dumpsite, Environments, Groundwater

1. Introduction

Like most lower-income countries, Nigeria faces difficulties enforcing programs to provide all of its citizens with adequate and sufficient potable pipe-borne water, leading people to contemplate groundwater as a possible replacement source of water for residential, commercial, and industrial uses. In addition, [1] reported that the relevance of groundwater exploration is critical since its possibleaccessibility is one of the uniqueand crucial variables whichencourage healthy and advantageous living conditions for individuals worldwide. Furthermore, [2] reported that one of the fundamental alternatives for providing drinking and agricultural water is the exploitation of groundwater. Following [3], groundwater availability study and use has grown in importance and value for geoscientists and researchers globally, particularly in environments with dumpsite facilities. However, [4] reported that a variety of population-driven socioeconomic development operations, waste production, and ineffective management continue to jeopardize water quality.

Consequently, [5] reported that individuals in lower-income countries, including Nigeria, often throw waste in residential area, since one of the most difficult obstacles that Nigeria's state and local government environmental protection groups are now facing is solid waste management. As a results, poor solid waste management can result in devastating environmental and health consequences such as recurrent epidemics, infectious illnesses, and waterborne infections reported by [6]; [7]. According to [8], there are a number of risks to groundwater resources, including waste disposal facilities that house residential and commercial waste that can have an impact on both groundwater quality and public health. Also, [9] reported that urban waste materials, mostly residential rubbish, are typically disposed of without suitable safeguards, creating a substantial danger to subterranean water resources. This research is being carried out in order to give complete evidence on the appropriateness of accessing high groundwater quality in the area of a dumpsite and its surroundings near Adaland, southern Nigeria. Similarly [10] revealed that one of the biggest environmental challenges in most Nigerian towns is waste disposal, since a large amount of waste is generated every day, and if it is not properly disposed of, it can lead to dangerous epidemic diseases. Likewise [11], emphasized that inappropriate disposal can cause groundwater pollution because rainfall that penetrates the earth might contaminate it. According to [12], after some time, the waste decomposes and generates a liquid known as leachate. The leachate which comprises both biological and chemical components percolates through the subsurface materials and pollutes the groundwater (Figure 1).

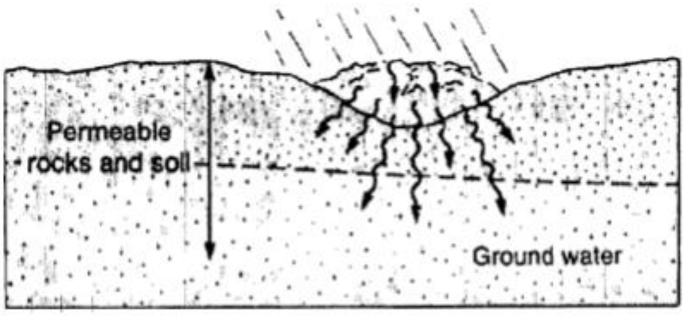

Figure 1: Showing the illustration of leachate contaminant from a dumpsite facility percolating into the groundwater as reported by [12]

Consequently, dumpsites characterization, determination of possible contaminant zones and extent of pollution have been applied using some of the geophysical methods or integrated methods for perfect delineation [13]; [14]; [15]; [16]; and [17]. Furthermore, integrated geophysical techniques are used because of their capacity to provide information on thesubsurface in a timely and cost-effective manner, ranging from the level of contamination to the porosity of the materials. Geoscientific studies utilizing geophysical techniques are used because they may offer information about the bedrock depth, saturation amount, and material porosity according to [18].

In this work, electrical resistivity and VLF-EM approaches have been used and found to be particularly suited for this research, as stated by [19], due to the conductive characteristics of most pollutants. Previous studies shows that both methodologies were used for landfill characterization and delineation, as well as waste disposal site inquiry [20]; [21]; [14]; [22]. Using electrical resistivity and VLF-EM geophysical techniques, this study attempts to detect and characterize the amount of groundwater contamination caused by leachate migration from the settlementmajor dumpsite facility. The research area's aquifer unit depths, leachate extent, and geoelectrical layers in and around the study area were also investigated.

2. Material and Method

2.1. Study Area Description

The study area is situated at Adaland between latitude 7^0 54' 0" and longitude 4^0 43' 0" in Osun State, Nigeria, within the Boripe Local Government Area as shown in Figure 2.

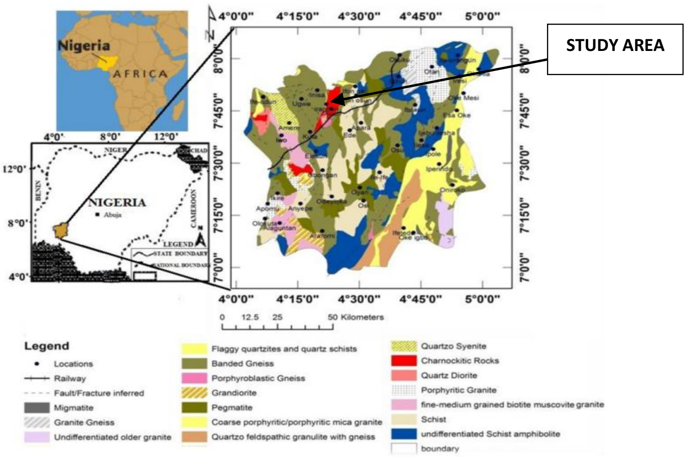

Figure 2: Showing the Location Map of the Study Area

The research area experience a warm humid climate defined across the years, with a typical average yearly temperature of 26.1 °C. As indicated in Figure 3, the research region is a limited section of the Basement complex rocks of Southwestern Nigeria, with underline by vast outcrops of mostly granite gneiss. The geology of the research region was extensively reported on by [23], [24], [25], and [26].The study area exists within the Schist belt and the Migmatite-Gneiss complex of the southwestern basement complex, with lithological shifts of coarse to fine-grained clastic, pelitic schists, phyllites, banded iron formation, carbonate rocks (marbles/dolomitic marbles) and mafic metavolcanic (amphibolites), younger metasediment rock, Banded gneiss, and granite. Furthermore, only the Ifewara fault zone is situated inside the study area.

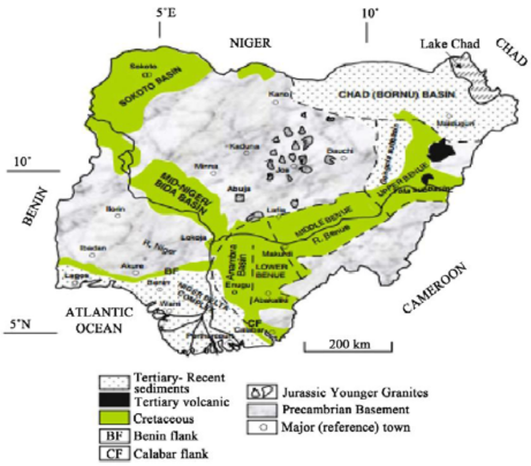

Figure 3: Showing the Basement Pattern of the study area [27]

2.2. Research Design

The Geonics VLF-EM 16 instrument which is an electromagnetic (EM) receiver employing the electromagnetic field created by military radio transmitters with Very Low Frequency (VLF) frequencies that range from 15 to 30 kHz was used. The Ohm-mega resistivity meter used has an internal power source (battery) as well as external power source. It has configuration through which electrodes and the external power source are connected. The meter measures the current passed into the ground directly in milliohms/ohms; which are displayed on the resistivity meter screen.The four connections of cables were plugged to the appropriate locations designated P_1 and P_2 for potential electrodes and C_1 and C_2 for the current electrodes as shown in Figure 4. Thus, current flows from the power source via the cables to the electrodes into the ground (C_1 and C_2) and back through a similar route (P_1 and P_2) as reported by [28].

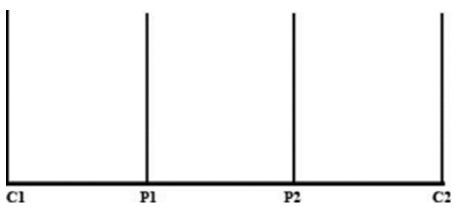

Figure 4: Current-Potential Electrode Configuration as reported by [29]

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In this study, eight traverses were generated from the VLF measurement in N-S, E-W, S-N and W-E direction, with a 2 m inter-traverse spacing (Figure 5). The traverse length ranges from 0 to 100m and cuts through the research area. The vertical electrical sounding approach was also used in this study, which entails measuring vertical differences with regard to a fixed center of array. This study employed the Schlumberger array electrode configuration, with a total of twelve (12) VES stations (Figure 5).

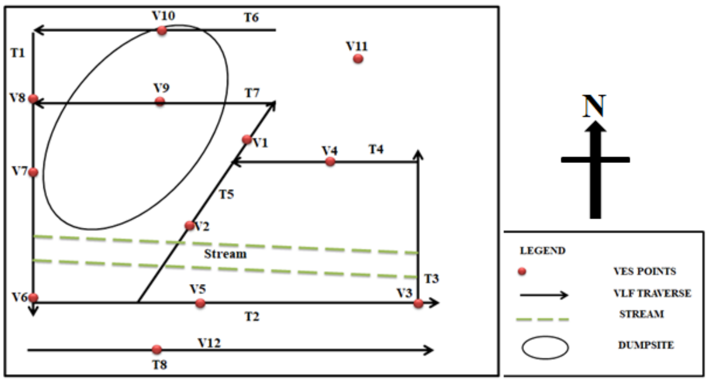

Figure 5: Field Base Map

The acquired VLF data was given as profiles and maps andwere also shown as 2D sections using the KHFILT program [30]; KHFfilt version 1.0). Field curves, pseudo-sections, geoelectrical sections were used to display the VES field data. The VLF data gathered during the study were evaluated using a qualitative approach that comprises visual evaluation of profiles and sections for conductive zones. The vertical electrical sounding (VES) data interpretation is completely quantitative using the partial curve matching technique [31]. The computer iteration(s) were carried out using Winresist version 1.0 [32]. The geoelectrical parameters gained through iteration were utilized to create the geoelectric sections.

3. Results and Discussion

Figures 6a-h illustrates profiles of raw real components and Q-factor values in percentages plotted versus station positions at regular intervals. The positive peak anomaly response of the Q-factor values in the profiles has been interpreted as conductive zones, which might have been caused by geological features such as fractures, faults, geologic contacts, or damaged basement [33]. The negative peak anomaly responses are evidence of resistive zones, which might be due to hardrock basement throughout the research region. The shifting positive peak, which is a measure of anomaly changes in the subsurface, varies significantly across the research region, showing varied conductivity variations in the subsurface materials.

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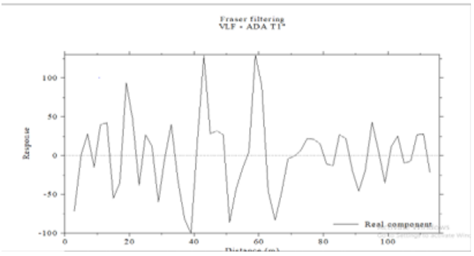

Figure 6a: VLF Profiles along Traverse 1

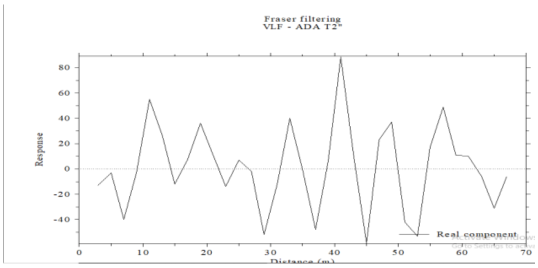

Figure 6b: VLF Profiles graph along Traverse 2

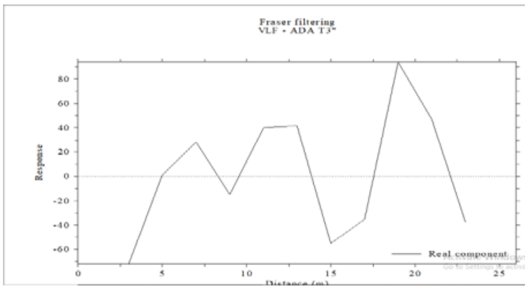

Figure 6c: VLF Profiles graph along Traverse 3

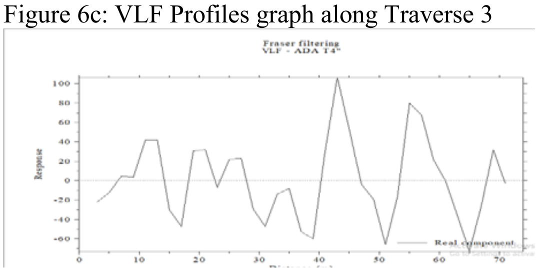

Figure 6d: VLF Profiles graph along Traverse

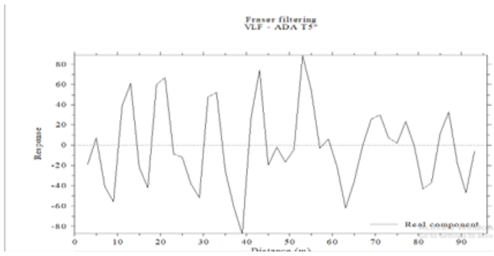

Figure 6e: VLF Profiles graph along Traverse 5

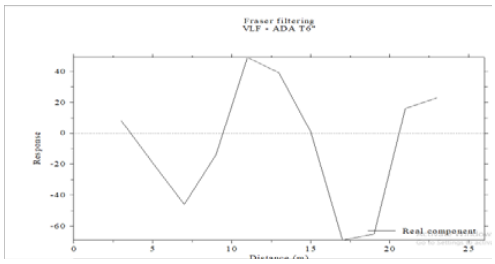

Figure 6f: VLF Profiles graph along Traverse 6

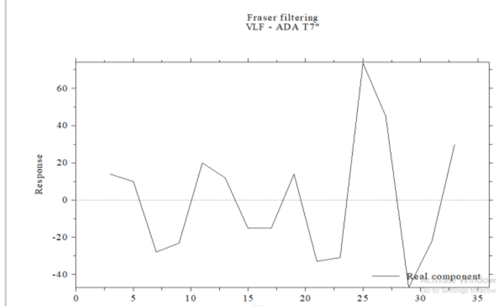

Figure 6g: VLF Profiles graph along Traverse 7

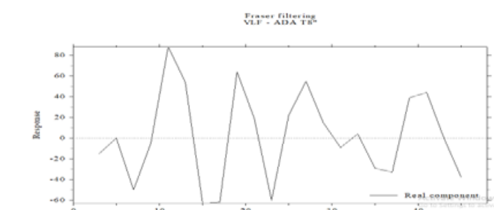

Figure 6h: VLF Profiles graph along Traverse 8

The KHF FILT (Karous-Hjelt and Fraser Filter software) was used to create the matching 2D models of the K-H pseudo sections for the traverses encompassing the study area. The conductive (fractured) targets are represented by increasing red color codes from left to right. On the 2D sections, features with variable degrees of trending in different directions were identified as shown in figure 7a-h. The inverted model along Traverse 1 shows that the peaks manifest as anomalous conductive zones at 80m to 120m, hence the inverted model reveals a resistive zone at the distance of 20-22m, 22-25m, 40m and 60-63m which is clearly observed on the VLF-EM profile. The resistive zone is suspected to be lateritic/hardpan/basement formation hence no significant structural feature. The corresponding inverted model along Traverse 2 confirms the peak as an anomalous conductive zone between 0-10 m, and 25-30 m and reoccurred at 60-70 m as weathered and saturated zones. The inverted model obviously reveals a resistive zone at 10-25 m and reoccurred 40-42 m respectively, which is typical of lateritic/basement formation.

The inverted model along Traverse 3 shows that none of the peaks demonstrates as anomalous conductive zones between 15 m and 25 m. It shows that the traverse is generally resistive, relatively homogenous and without any significant structural feature. The inverted model obviously reveals a resistive zone at 5-9 m, 15-17 m and appear at 18-23 m respectively, which is typical of lateritic/basement formation. The inverted model along Traverse 4 shows that the anomaly that manifest at 5-7 m, 20 m, 35-60 m and 70-80 m is an anomalous conductive zone, while however, the model reveals a resistive zone between 10-20 m, 35-40 m and 55-70 m. The inverted model along Traverse 5 shows that the anomalies are reliable conductive zone 0-10 m, 18-20 m and 30-35 m respectively. Hence, the model further reveals patches of resistive zone along the transverse of 8-10 m and 45-50 m, respectively. The inverted model along Traverse 6 shows that the anomalies are reliable conductive zone shown on 25-30 m and 70-72 m. Hence, the model further reveals patches of resistive zone along the transverse line 15-25 m and 45-70 m respectively. The anomalous conductive zones are suspected to be lineament structures while the resistive features are presumed to be lateritic/hardpan/basement formation.

The inverted model along Traverse 7 shows that the anomalies are reliable conductive zone shown on 25-30 m and 70-72 m. Hence, the model further reveals patches of resistive zone along the transverse line 15-25 m and 45-70 m respectively. Generally, the anomalous conductive zones are suspected to be lineament structures while the resistive features are presumed to be lateritic/hardpan/basement formation. The inverted model along Traverse 8 shows that the anomalies are reliable conductive zone shown on 25-30 m and 70-72 m. Hence, the model further reveals patches of resistive zone along the transverse line 15-25 m and 45-70 m respectively. Generally, the anomalous conductive zones are suspected to be lineament structures while the resistive features are presumed to be lateritic/hardpan/basement formation.

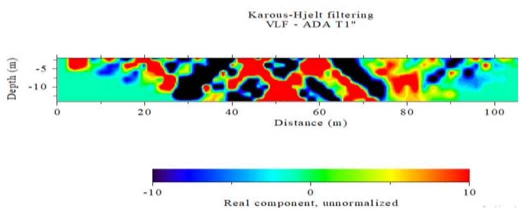

Figure 7a: K-H pseudo section along Traverse 1

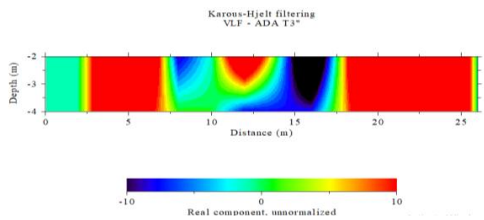

Figure 7c: K-H pseudo section along Traverse 3

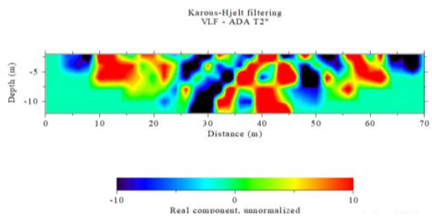

Figure 7b: K-H pseudo section along Traverse 2

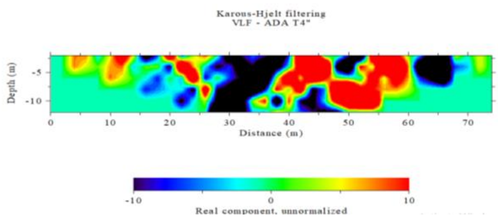

Figure 7d: K-H pseudo section along Traverse 4

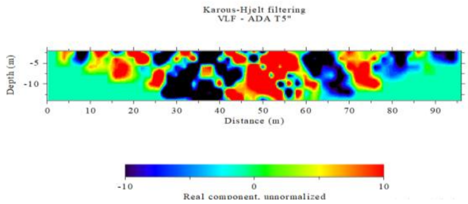

Figure 7e: K-H pseudo section along Traverse 5

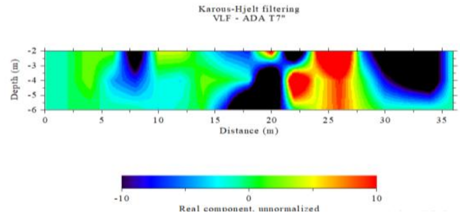

Figure 7g: K-H pseudo section along Traverse 7

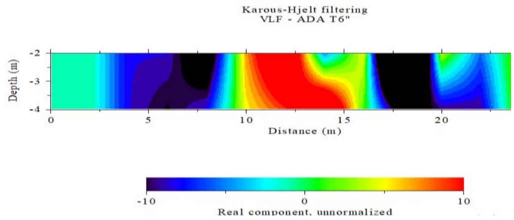

Figure 7f: K-H pseudo section along Traverse 6

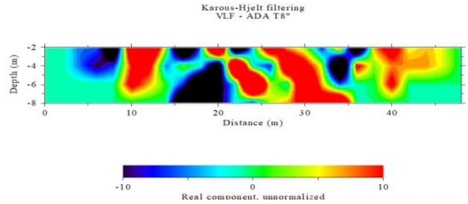

Figure 7h: K-H pseudo section along Traverse 8

The analysis of VES delineates four vital geological layers, such as: topsoil, weathered layer, fractured basement, and fresh basement. The sounding curves were classified based on their characteristics, which reflected the underlying layers [34] as shown in Figures 8a-8l.

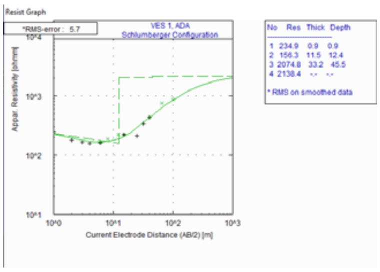

Figure 8a: Showing the Sounding Curve along VES 1

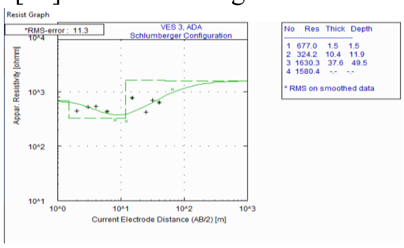

Figure 8c: Showing the Sounding Curve along VES 3

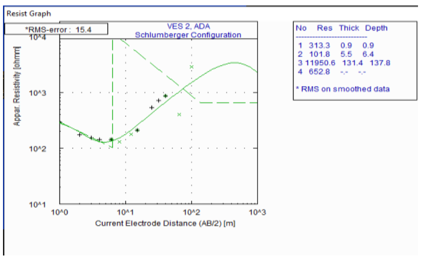

Figure 8b: Showing the Sounding Curve along VES 2

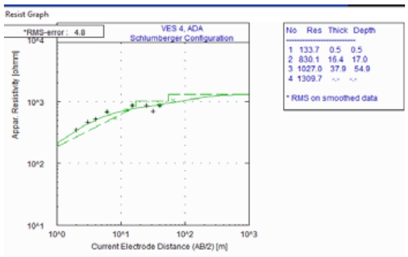

Figure 8d: Showing the Sounding Curve along VES 4

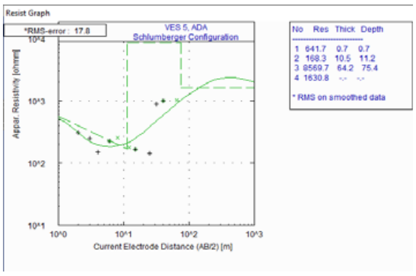

Figure 8e: Showing the Sounding Curve along VES 5

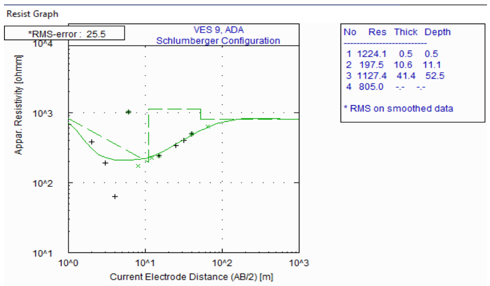

Figure 8i: Showing the Sounding Curve along VES 9

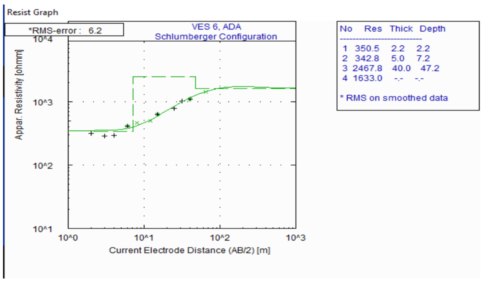

Figure 8f: Showing the Sounding Curve along VES 6

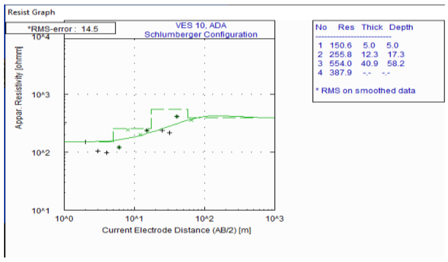

Figure 8j: Showing the Sounding Curve along VES 10

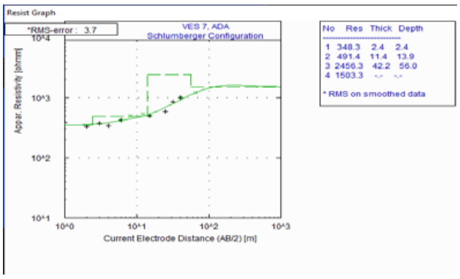

Figure 8g: Showing the Sounding Curve along VES 7

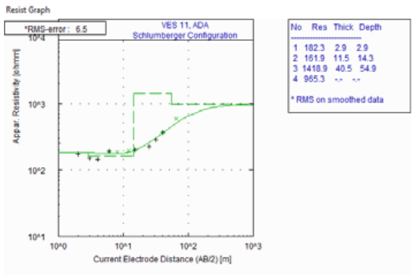

Figure 8k: Showing the Sounding Curve along VES 11

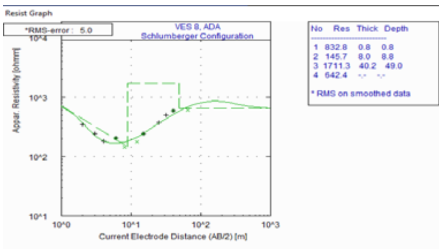

Figure 8h: Showing the Sounding Curve along VES 8

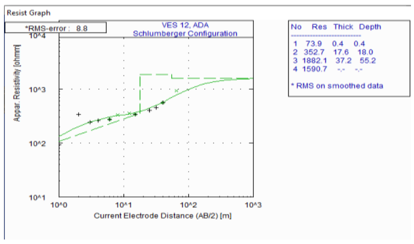

Figure 8l: Showing the Sounding Curve along VES 12

The results of the VES curves were used to create six 2D geoelectric sections around the dumpsite environment as shown in Figure 9a-f. These sections were generated along a straight part as convenient by employing the resistivity and depth valuesto depict the vertical and lateral variations in the layer resistivities.

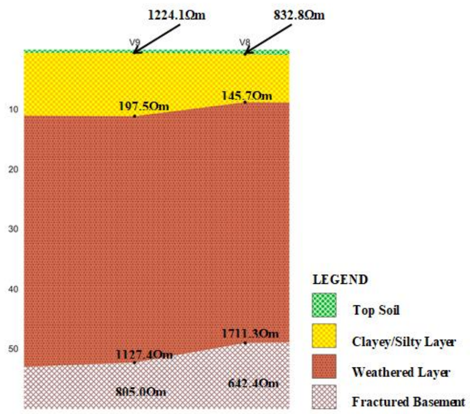

Figure 9a: Geoelectric section VES 9 and 8

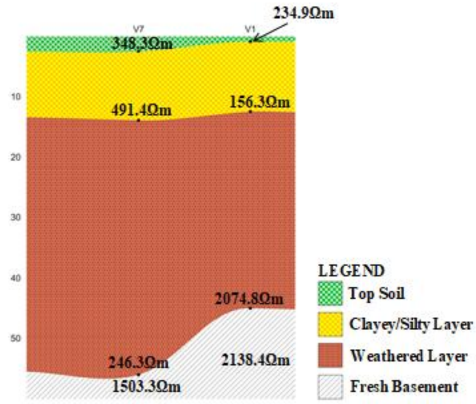

Figure 9d: Geoelectric section VES 7 and 1

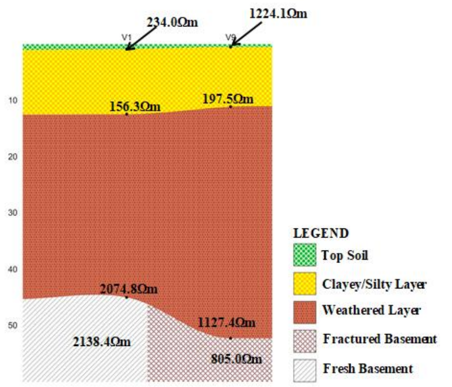

Figure 9b: Geoelectric section VES 1 and 9

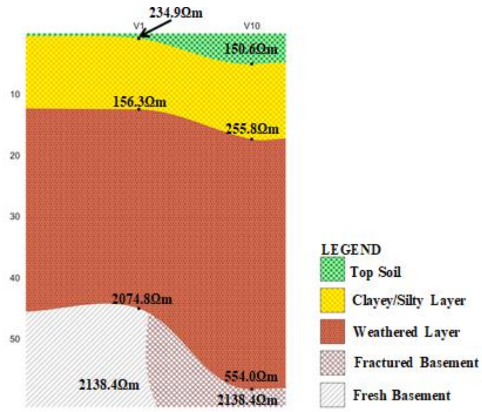

Figure 9e: Geoelectric section VES 1 and 10

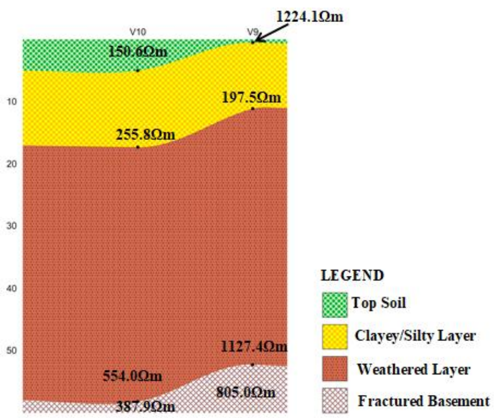

Figure 9c: Geoelectric section VES 10 and 9

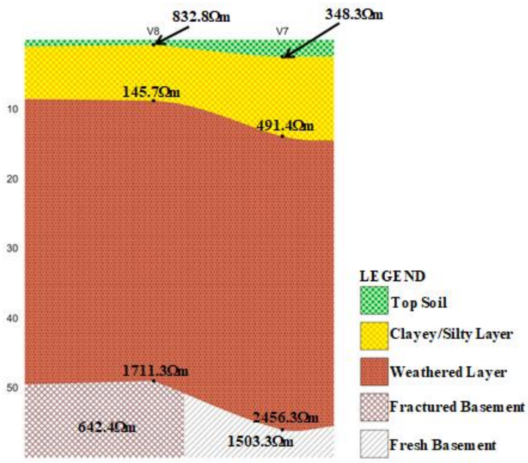

Figure 9f: Geoelectric section VES 8 and 7

The geoelectric sections reveal four lithological variations such as top soil, clayey/silty layer, weathered layer, fractured and fresh basement. In addition, [35-38], reported that one of the benefits of 2D geoelectric sections is that they allow perceiving the differences in overburden thickness and the character of each stratum. The 2D geoelectric section revealed that the topsoil is composed of sandy clay while the second layer is the clayey/silty layer. The obtained resistivity values of 10-800 Ωm from topsoil are due to the presence of alluvium or charged surfaces (feature of clay) [39] and connected boundary layers of ions that are interacting with one another. As evidence at VES 8, 9 and 10, due to weathered and fractured basement, the possible impact of the open dumpsite on the groundwater can be envisaged, since the weathered layer accumulates the contaminant and infiltrate through the fractured basement down to the groundwater.

4. Conclusions and Recommendation

Interpretation from the results obtained from the integrated geophysical assessment carried out in and around the main dumpsite of the ancient and densely populated Adaland, Southwestern Nigeria revealed the high possibleimpact of dumpsite on groundwaterquality within a portion of the study area.The two surface geophysical methods used in this work to achieve this goal were the very low frequency electromagnetic (VLF-EM) method, and 2D vertical electrical resistivity profiling method.These methods collected geophysical data, which was then processed and analyzed to depict the underlying geological properties of the environment under study. However, the two geophysical approaches identified several geological features, and the complete interpretation concludes that the impact of the dumpsite on the groundwater qualityis caused by inadequate clay materials, near-surface features such as fractures/faults, and lateral in-homogeneity. Therefore, the results of this research work can be utilized as a guide to any hydrogeological exploration and it is critical to conduct a detailed geophysical investigation, particularly in the virgin and neighbouring areas of the study area before embarking on groundwater exploitation.

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