Research Article *http://dx.doi.org/10.4314/mejs.v16i2.3* ***Open Access***

Configuration Reversal Effect on Earth Resistivity Measurements in Parts of Birnin Kebbi, Northwestern Nigeria

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ABSTRACT

An approach involving forward and reverse effects on earth resistivity measurements was carried out in some selected sites in the Birnin Kebbi area of Gwandu Formation Northwestern Nigeria. The primary objective of this research work was to investigate the relationship between the principle of reversibility of current, the potential difference in measuring earth's resistivity, and determining the depth of penetration for various probes. Because of shallow, deep, and very deep penetration used to measure resistivity in both locations, a Schlumberger array with half of the maximum current electrode spacing (AB/2) of 70 m was used to measure a total of sixteen (16) depth-sounding data in a randomly distributed manner. An Excel chart of (x, y) scattered data was used to automatically interpret the apparent resistivity data after the field was examined and interpreted using IPI2win. To compare the apparent soil resistivity of two switches and how it's impacted by the depth of the soil moisture contents, a series of measurements were made as part of this study. The collected results demonstrate how soil resistivity varies with depth and spacing, which guides the development of earthen protection plans for the worst-case scenarios. Based on the kind of soil and moisture content, it was found that resistivity varies. Reverse resistivity switch is higher than forward switch resistivity. According to the suggested design, there are 4 to 6 different forward switch circumstances that call for different numbers of earth electrodes.

Keywords: Apparent resistivity, Birnin Kebbi, Forward-reverse switch, Moisture contents, Pole reversal effect.

1. INTRODUCTION

The focus of electrical resistivity techniques is how the ground reacts to an electrical current flowing through it. These techniques involve passing an electrical current through the ground and two potential electrodes, which allowed the recording of the resulting potential difference between them and provided a way to gauge the electrical impedance (ratio of potential to

Submitted : 18th September 2022 Accepted : 10th October 2023 Published : 13th September 2024

current) and the electrode array's geometry. In order to seek for anomalous areas, the apparent resistivity data are shown as 1-D soundings, 1-D profiles, or 2-D cross-sections depending on the survey geometry (Adamu, 2019; Adamu et al., 2019a; Adamu et al., 2019b; Adamu et al., 2020; Adeoli et al., 2010; Telford et al., 1976). Resistivity is the opposite of conductivity, measurements of resistivity are connected to different depths depending on how far apart the current and potential electrodes are placed during the survey, and they can be interpreted in terms of a lithologic and/or geohydrologic model of the subsurface. The reason why the measured resistivity values are plotted at a single depth point for each potential electrode pair-instead of being averages across the entire current channel length is the data are defined as apparent resistivity. Cross-section data is a spatial representation of the real, complicated current flow patterns (Afuwai, 2013a; Afuwai, 2013b; Afuwai, 2014; Anomohanran, 2013; Adamu, 2019; Adamu et al., 2019a; Adamu et al., 2019b; Telford et al., 1976; Baker, 1981; Ibrahim et al., 2012; Telford et al., 1976; Onu, 2003; Orellana et al., 1966). Geoelectric data can be interpreted using computer modeling with the right software, leading to more precise three-dimensional earth models. The semi-consolidated gravel, sand, clay, and some limestones are interbedded beneath a sequence of sedimentary basins that make up the Nigerian sector of the Iullemmeden sedimentary basins, which are located in the Niger Republic. This succession spans the Cretaceous to the Quaternary and reaches a gross thickness of about 35 meters. The Sagaldu and Indian water terrestrial deposits are the oldest rocks in the sedimentary succession. The depositional environment once more changed to a terrestrial state, and beds of sand and heavy clay that make up the Sagaldu and Indian water were deposited. In the Kebbi State, the Cretaceous and Tertiary Formation typically strike in a northeastern direction and descend around 20 m per mile to the northwest. Although all these rivers become thinner as they move south along the outcrop and the Sagaldu groups fully pinch out, these rivers also typically become thicker down dip. A thin, unconsolidated layer of quaternary-aged alluvial sand, silt, and gravel underlies the Fadama of Kebbi and its significant tributaries. In most permeable components of the Cretaceous-Tertiary sedimentary succession, groundwater is found, both restricted as artesian water and unconfined just beneath the water table. At least three significant aquifers have semi-consolidated sand or gravel that contains confined water down dip and at deep. All three aquifers' outcrop areas have water table conditions. A small but significant perched ground-water body can be found in the limestone of the Dukku's outcrop area. In the quaternary alluvial fill of the Fadamas of the river Kebbi and its significant tributaries, unrestricted groundwater is also present. A consolidated rock, such as sandstone and granite, similarly differs in porosity and fluid content from an unconsolidated rock in terms of voids and fluid content. The electrical properties of earth materials, both consolidated and unconsolidated, also vary widely. The conductivity or its reciprocal resistivity is impacted by their discrepancies. Electrical exploration for depths of unconsolidated materials is typically of a greater order than differences within the two categories. In general, the detection of the surface effect created by the flow of electrical characteristics inside the earth serves as the foundation for electrical resistivity measurements used in geophysical prospecting (Olawuyi, 2012; Dobrin and Savit, 1988; Telford et al., 1976). Given the various subsurface lithology variations in resistivity distribution occurrence in the soil, it is crucial to comprehend and develop an empirical relationship between the forward and reverse switch of earth's resistivity measurements. The kind of electric current used is direct current from a dry cell. As a result, dry cell-supplied direct current (D.C.) serves as the foundation for the analysis and interpretation of geoelectric data. The concept of "apparent resistivity" describes the resistivity that is determined by measuring an induced current and potential difference. The ground must be uniform to perform this measurement. The earth's resistance is governed by lithological and geological inhomogeneities. To calculate the vertical variation in formation resistivity, a graph of apparent resistivity against current electron spacing is used (Anomohanran, 2013; Whiteman et al., 2003). The use of azimuthal square-array (Loke and Barker, 1996) resistivity sounding provides a method for measuring in-situ anisotropy and the directional nature of vertically dipping fracture systems, while Schlumberger resistivity sounding is well known for determining resistivity variation with depth to the aquifer. Knowing the resistivity of the soil is also necessary to obtain the resistivity variations of different subsurface lithologies (i.e., resistivity, thickness, and depth) using VES sounding curves. The main goal of this research project was to investigate and establish the relationship between forward and reverse switch based on the principle of reversibility of current on earth's resistivity measurement in Birnin Kebbi metropolis to ascertain the apparent resistivity and depth of penetration of sounding master curves.

2. STUDY AREA

2.1. Location and Topography

The Birnin Kebbi Metropolis "Kalgo and Dakingari Quarters" in Kebbi State NW Nigeria, served as the sampling location. The research area, which has a mean regular altitude of 218 m of above mean level, is located between Longitudes 4° 15' 21" E to 4° 15' 89.8" E and Latitudes 12° 28' 55.7" N to 12° 28' 54.3" N. (Fig 1). There are good connections between them by motorized road and pedestrian paths. These roads connect some of the survey traverse and are primarily utilized by rural residents to access their homes and settlements. The relief of plain undulations that have been impacted by weathering and erosion is what distinguishes the study region. The area possesses prominent escarpment features, including flat hilltops, the Gwandu formation, and other ridges, whereas the river courses are situated in low-elevation areas (Kogbe, 1989). Typically, during the dry season, rivers and stream dry up. Due to the local geography, the rivers have many tributaries at different locations.

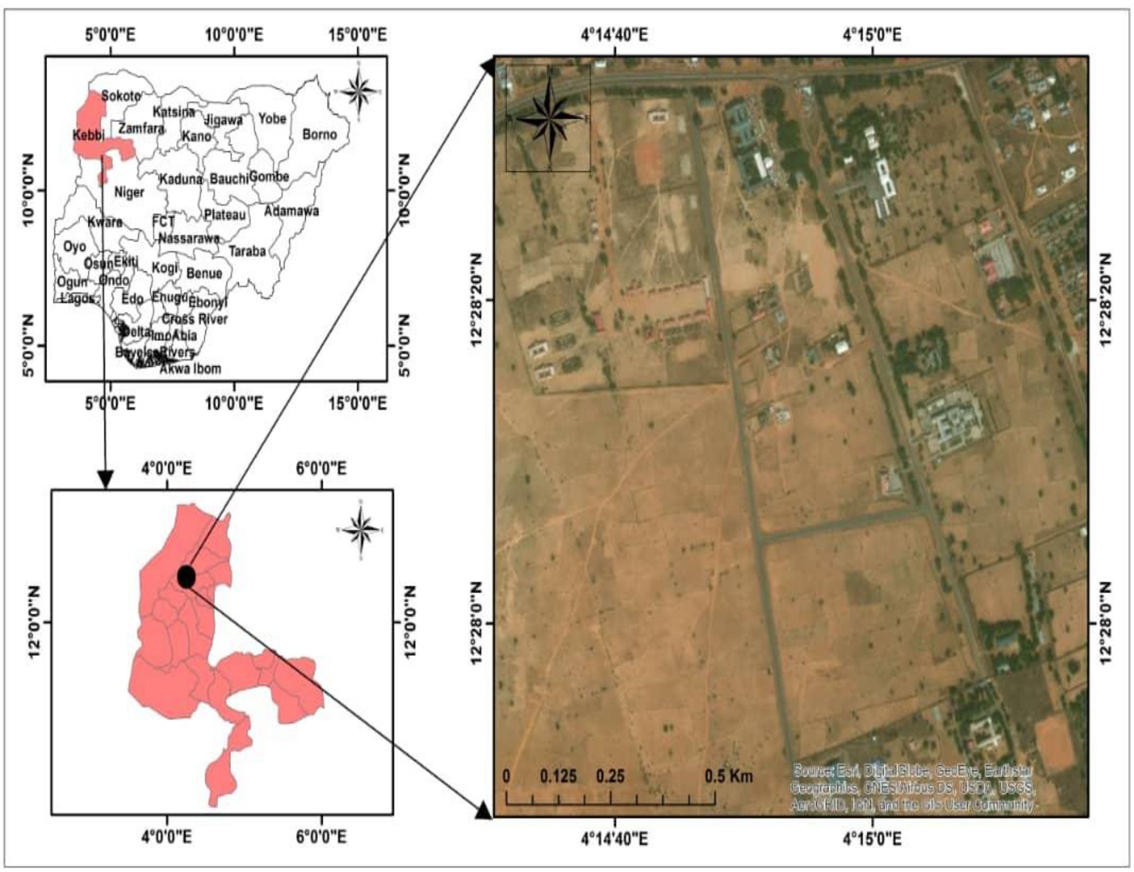

Figure 1. Location map illustrating the research area (Adopted from Google Earth, 2021).

2.2. Geological Setting

The area is generally underlain by sedimentary rocks of the Gwandu formation. It contains several prominent ridges and groups of flat-topped, steep-side hills capped by ironstone. Other hills covered with ironstone debris occur in all stages of disintegration, rising out of the sandy plain over which the products of erosion have been distributed. Rock exposures are rare on the plain, but numerous on the hillsides, however, they are small and obscured by rain-wash and ironstone screen (Fig 2). The non-marine origin of the Gwandu formation is certain, and the sediments can be correctly attributed to a continental environment, or more precisely to a lacustrine environment (Kogbe, 1989).

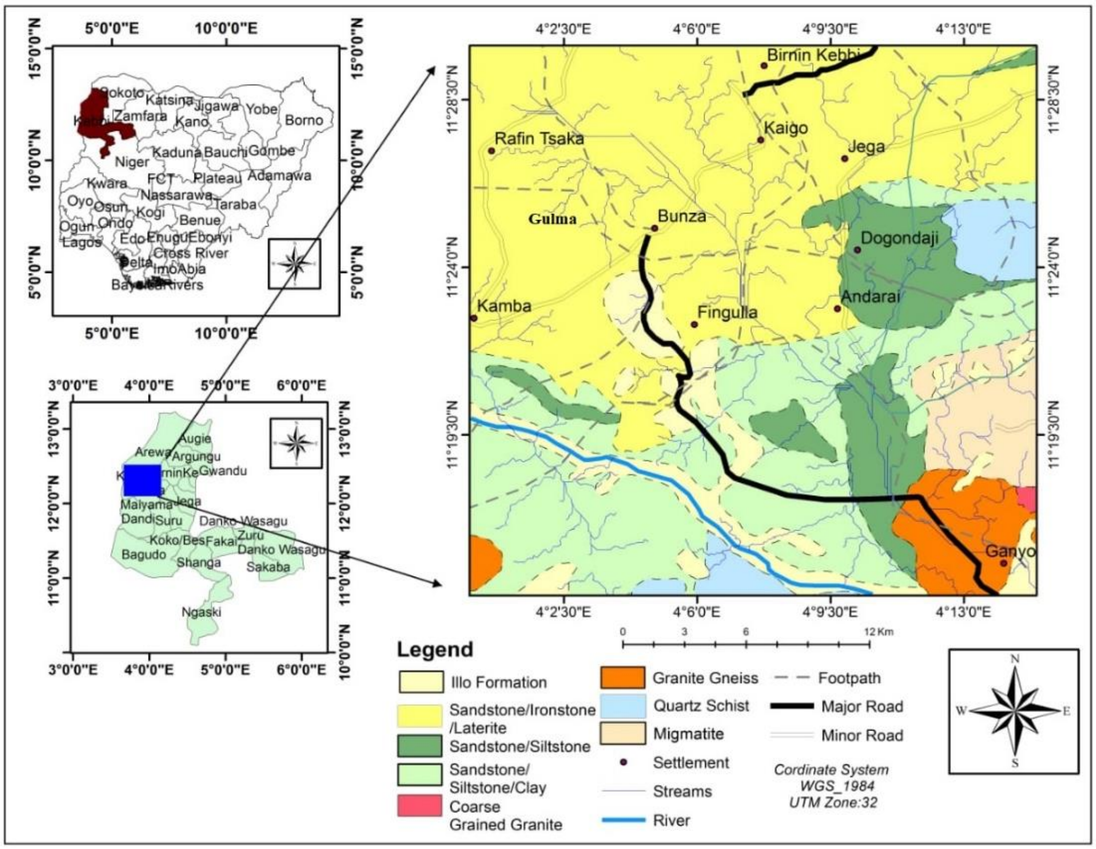

Figure 2. Geological Map of the Study Area (Modified After Kogbe, 1989).

The best outcrops of the Gwandu formation occur around Birnin Kebbi and Argungu. The sediments consist of massive white clays interbedded with coarse and medium-grained red sandstones and mudstones with occasional peat bands. The type-section proposed for the formation by Kogbe (1989) shows the typical lithologic characteristic of the formation. Beneath the lateritic capping is a hard ferruginous sandstone layer which is easily eroded into network of gullies. These are underlain by red sandy clays and white massive mudstones, which are invariably, stained pale brown or pink. The mudstone with sandstone intercalations extends monotonously throughout the sections. Similar sections of the Gwandu Formation occur on the slopes of the Gwandu outliers within the Kalambaina Formation on the outskirts of Sokoto Township near the cement factory. The sands at the surface are quite red in colour, often showing colour banding and poor stratification. The mudstones often show a nodular structure with nodules suggestive of local turbulence in the depositional environment. By correlation with palynomorphs from tropical Tertiary deposits earlier mentioned, the age of the Gwandu Formation was tentatively put as Eocene-Miocene (Kogbe, 1989).

3. METHODOLOGY

3.1. Field Layout and Instrumentation

Schlumberger Vertical Electrical Sounding (VES) based on forward and reverse switches was used in this work to investigate electrical resistivity over a 400 m^2 area. The model employed was the ABEM SAS 300C model. Data collection tools utilized in the field included four insulated wire conductors, a hammer, four electrodes, measuring tape, and a wire striper. Plate I show the experimental setup utilized to conduct the measurements (Loke and Baker, 1996),

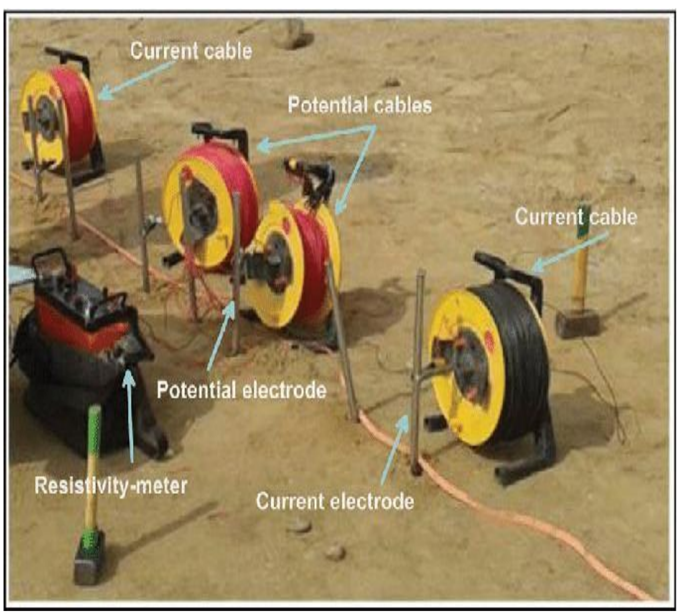

Plate I. ABEM-TERRAMETER-SAS-300C model with Accessories during the Field Work.

3.2. Field Procedure and Data Collection

The field work was carried out within Birnin Kebbi metropolis (Fig 3). Electrodes were placed in the straight line at equally spaced, hence were placed at different soil depth for each measurement. The soil depth ranged from 1.5 m to 2.0 m depending on the electrodes spacing. The wire cables were connected to the meter and electrodes steel. Thus, electrodes were driven to the earth to establish electrical contacts. C_1 and C_2 are two outer electrodes that are connected to the meter to inject constant current to the ground, the current flows through the earth (resistive material) develop a potential difference or voltage P_1 and P_2 are inner electrodes measures voltage drop. Therefore, the electrodes were successfully reversing by taking the potential outer electrodes and injecting the current electrodes inner which is called the reversibility of electrodes.

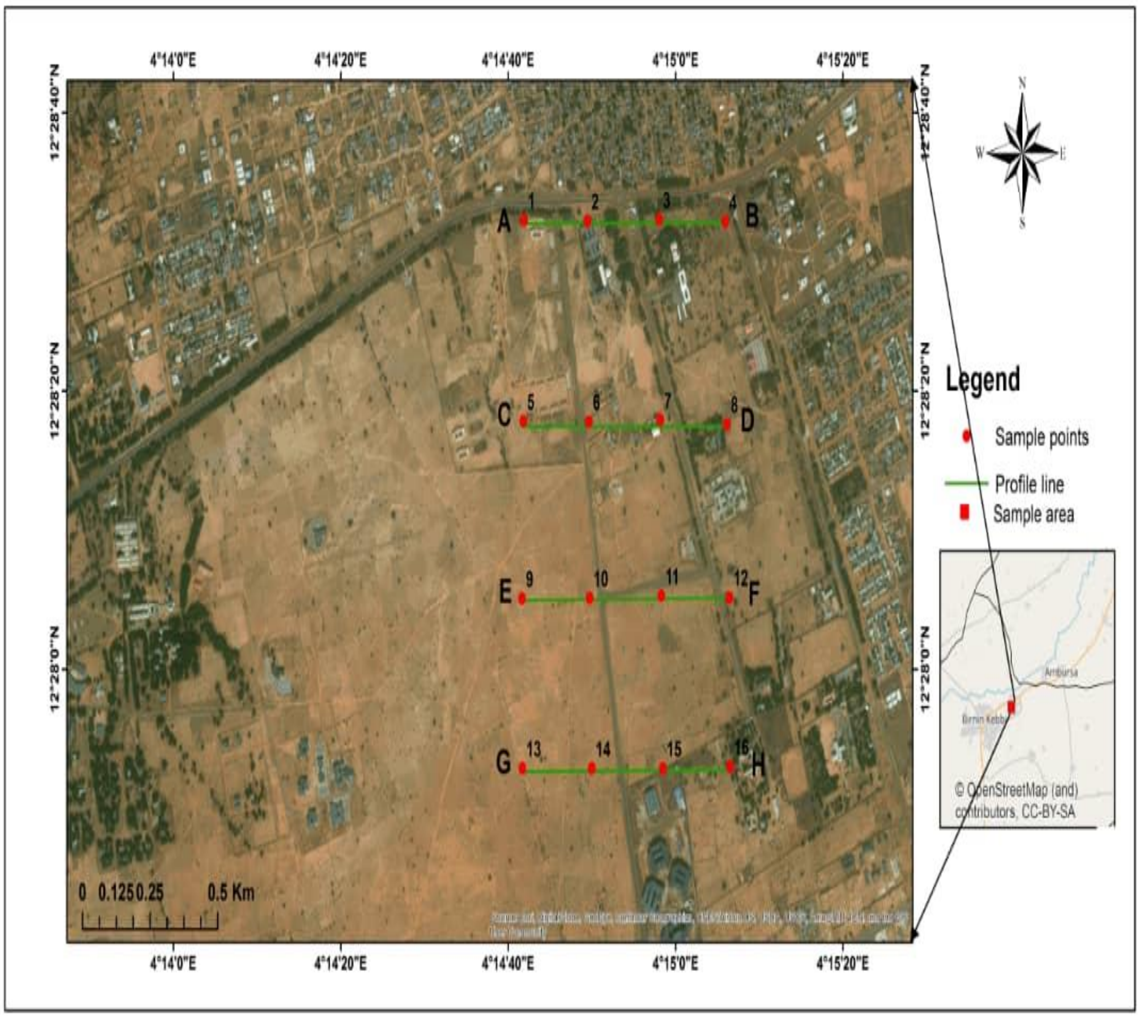

Figure 3. Established Profile on Google Earth Map (Digital Globe, 2018).

Thus, the resistivity of the subsurface differs perpendicularly with depth and laterally with distance. Mutually these variations give valuable information about the subsurface structures (Coker et al., 2008; Dobrin and Savit, 1988; Telford et al., 1976). It is therefore necessary to look at these disparities. In this case study the vertical electrical sounding was carried out to investigate the resistivity based on forward and reverse switch respectively.

3.2.1. Vertical Electrical Sounding Data Acquisition

For this exploration, electrodes separation varies from 0.5 to 200 meters safeguarding a reasonable depth of probe over 60 - 100 meters considering the depth of penetration which ranges between 1/3 and ¼ of the total current electrode separation (Gholam and Nad, 2005). VES services collinear arrays designed to output a 1-D vertical apparent resistivity versus depth model of the subsurface at a specific observation point. In this method, a series of potential differences are acquired at sequentially more electrodes spacing while maintaining a fixed central reference point. The induced current passes through progressively deeper layers at more electrodes spacing. The potential difference measurements are directly proportional to the charges in the deeper subsurface. Apparent resistivity values calculated from measured 12 potential differences can be interpreted in terms of (overburden thickness, the depths and thickness of subsurface strata) (Adamu, 2019; Omosuyi, 2010). The VES was conducted using a setup of Schlumberger electrodes spaced 3 meters apart. 16 VES stations in total were randomly positioned along a predetermined profile (Fig 3). VES data for two switches (forward and reverse) were processed using the IPI2Win software, and the findings were used to highlight different subsurface layers.

3.3. Schlumberger Array Comparison of the Forward and Reverse Switches

The Schlumberger array is the most popular array for resistivity prospecting. The following are the main distinctions between these arrays:

(a) Schlumberger array forward switch Arrangement

The potential electrodes in this array are placed significantly closer together than the current electrodes are (Fig 4). The apparent resistivity is given as follows an approximate measurement of the electric field:

$$\rho a = \pi \left\{ \frac{l^2}{2b} - \frac{b}{2} \right\} \frac{DV}{I}$$

Where, l denotes the separation between the outermost current electrodes (C_1 & C_2) and the sounding point, and b denotes the separation between the innermost potential electrodes (P_1

& P_2, see Fig 4). In this way, the current electrode spacing is increased symmetrically around the spread's center while the potential electrodes are fixed. The distance between the potential electrodes (MN), which is modest compared to the spacing between the current electrodes (AB), is the constraint under which Schlumberger soundings are performed, i.e., MN AB/2.

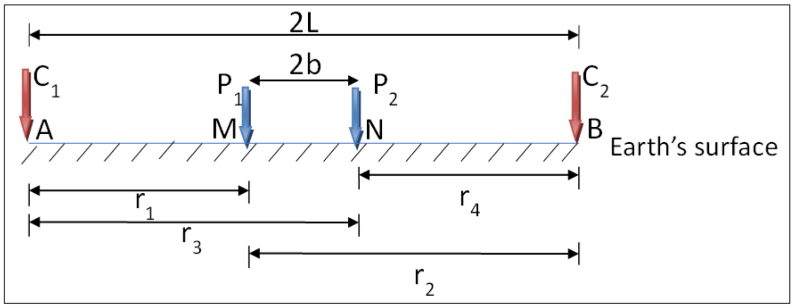

Figure 4. Schlumberger Electrodes Configuration for Forward Switch.

(b) Schlumberger array reverse switch configuration

In this array, the current electrodes (AB/2) are positioned inside the array while the potential electrodes (MN/2) are outside and are always kept equal or small at pre-selected readings (Fig 5) (Zohdy, 1974; 1965).

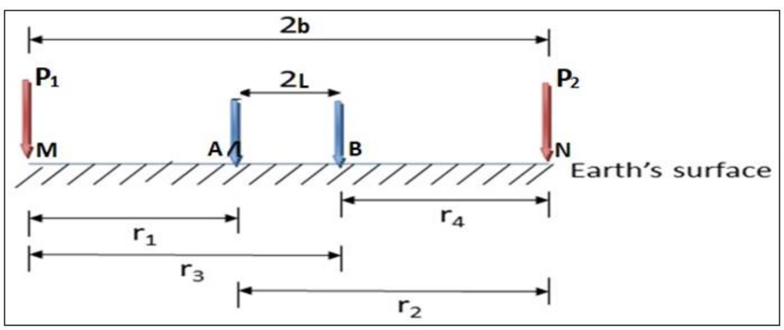

Figure 5. Schlumberger Electrodes Configuration for Reverse Switch.

The two disparities now make the following facts immediately apparent. The VES master curves (i) show a slightly deeper probing level. On measurements and findings from the forward array switch, the maximum and minimum values of apparent resistivity are slightly more pronounced (shorter/longer electrode spacing) than on measurements from the reverse array switch. By standardizing the electrode spacing for the two array switches, whose apparent resistivity (a) ohm should be shown as a function of AB/2 (m), a meaningful comparison between two types of sounding measurements can be done. (ii) Reverse sounding measurements are more susceptible to the lateral effects of near-surface geology than are forward sounding observations. Additionally, the two measurements make it easier to see how lateral resistivity differences affect the results. (iii) When the two metal electrodes are driven into the ground, a drifting or unstable potential difference is produced.

3.4. Computed Resistivity Enhancement

The computed soil resistivity on configuration reversal effect on earth resistivity measurements displays the probable variations by means of sounding depth in some parts of Birnin Kebbi and its environs. The computed readings were processed and analyzed based on spatial distribution of histogram plots by means of statistical excel application package (Sindisiwe et al., 2018). All the study parameters from forward- reverse switch is processed and interpreted in order established the variations in resistivity below the earth subsurface.

4. RESULTS AND DISCUSSION

4.1. Interpretation of Resistivity Data

Due to the wide variations in resistivity that geological materials exhibit and the difficulty in developing theoretical expressions for apparent resistivity's of all but the simplest geometries, it is frequently challenging to provide an exhaustive quantitative interpretation of apparent resistivity (Bhattacharya, 1992). There are a variety of techniques for analyzing apparent data, including the empirical Moore Cumulative Resistivity Method (Mooney, 1954; Moore, 1945) and Barnes Layer Method (Beck, 1991) as well as Analysis Methods, which involved curve matching, computer-based analysis, and other techniques. Even though, both Zohdy (1965); and Adamu (2019) advocate using computers in the research. Technological advancements have led to the development of software that helps to remove uncertainty that may exist when interpreting apparent resistivity data. But to use computer-derived solutions for field measurements, it is necessary to have a thorough understanding of the resistivity principles as well as practical experience as is feasible due to the issue of equivalence and suppression as well as the numerous factors that affect curve details (Bhattacharya, 1992). For the purpose of this investigation, IP2Win is utilized to translate vertical electrical soundings for the forward and reverse switch.

4.1.1. Electrical Resistivity Sounding Interpretation

The resistance measured in the field was used to calculate the apparent resistivity value at each sounding location, which was then displayed as sounding curves. The sixteen VES curves' results along the chosen profiles were utilized to forecast how the resistivity would change for a forward and reverse switch. In figures 6a, b, c & d, the number of layers varies between three and four. Based on the results measured at forward and reverse Switch distance, it gives a clear indication that the resistivity varies depending on the type of soil encountered below the subsurface. This is caused by the fact that various soils have variable moisture contents (Ibrahim et al., 2012). In conditions of forward switch, resistivity decreases as spacing rises, but it increases in cases of reverse switch. This demonstrates that a layer with higher resistivity is layered on top of the lower layer. The research area's geoelectric parameters have been calculated using the computer inversion tool IPI2WIN. Resistivity layer, log resistivity graph, and resistivity depth table are the results of the sounding process.

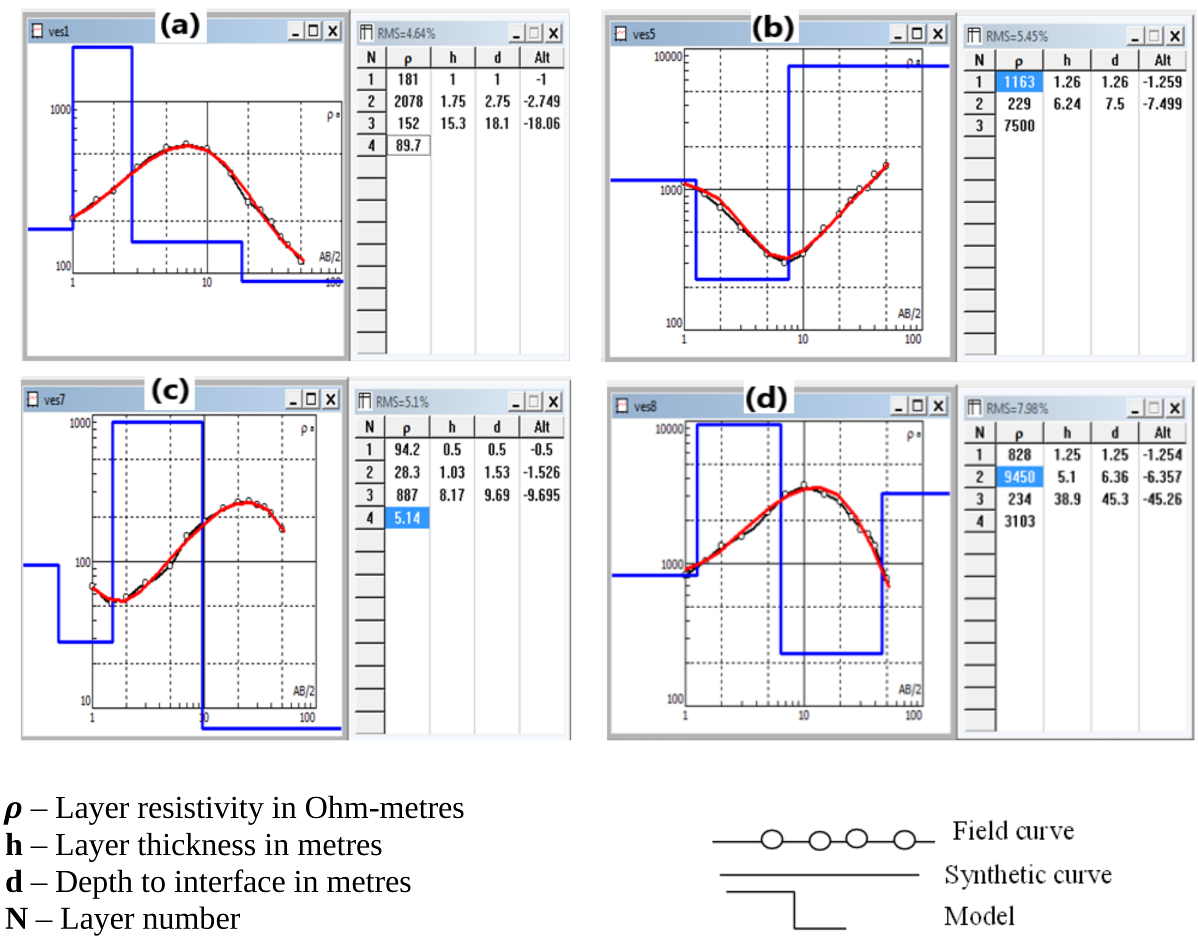

Figure 6. (a-d) an example of the model interpretation of resistivity sounding curves derived from forward and reverse switches.

4.1.2. Predictive Soil Resistivity Variation based on Forward and Reverse Switch

In the entire research area, the resistivity of the soil at various sounding depths shows the anticipated differences in forward-reverse switch arrangement. In this region, the forward-reverse switch conditions were spatially dispersed in the XY plane and stacked column as shown in figures 7a & b and 8a & b. These figures show the link between soil depth and resistivity changes from the soil. The soil's resistivity falls (forwardly) as the spacing is increased in the reverse switch. Determine which layer of resistivity is layered on top of the bottom layers.

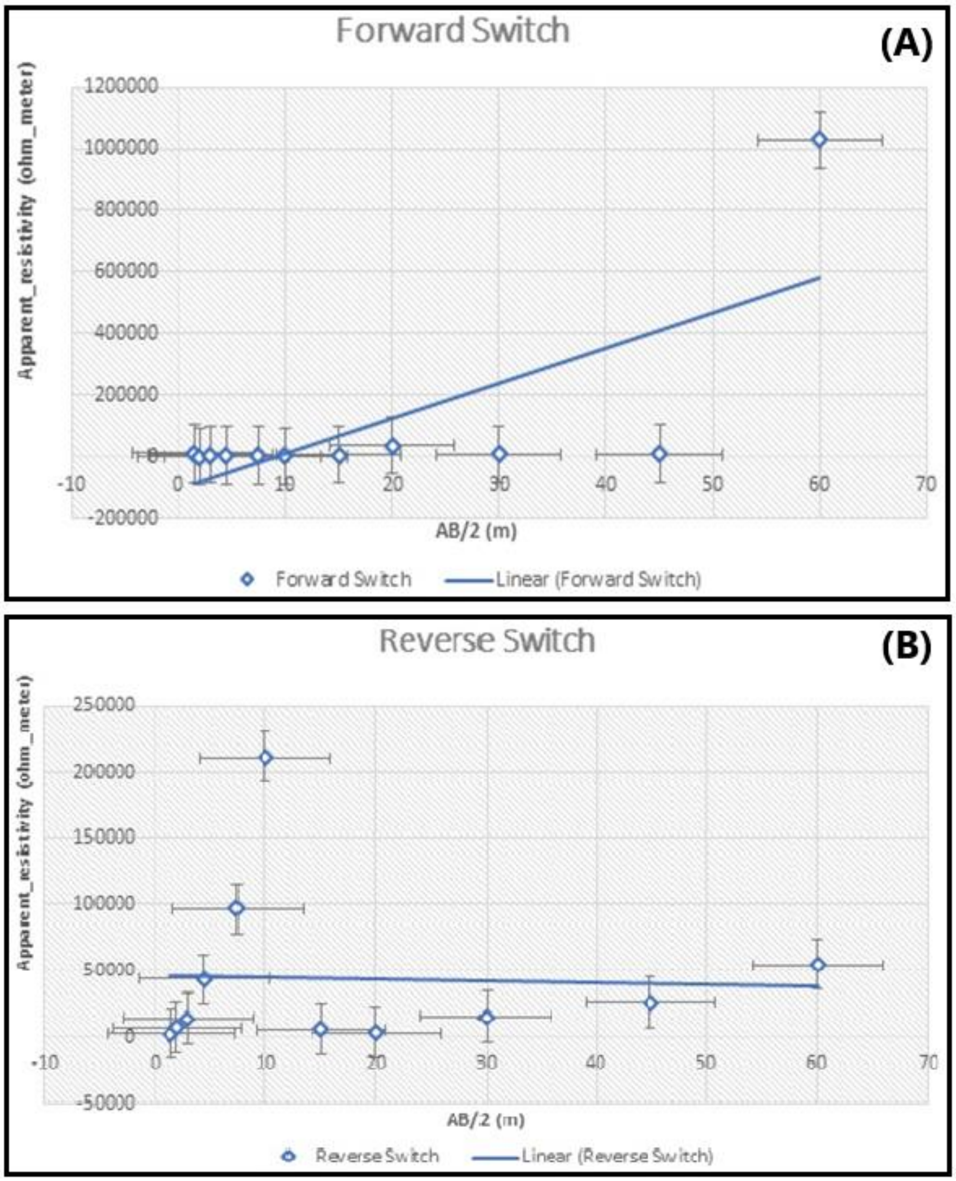

Figure 7. (a & b) displays a linear plot relations forward-reverse switch configuration.

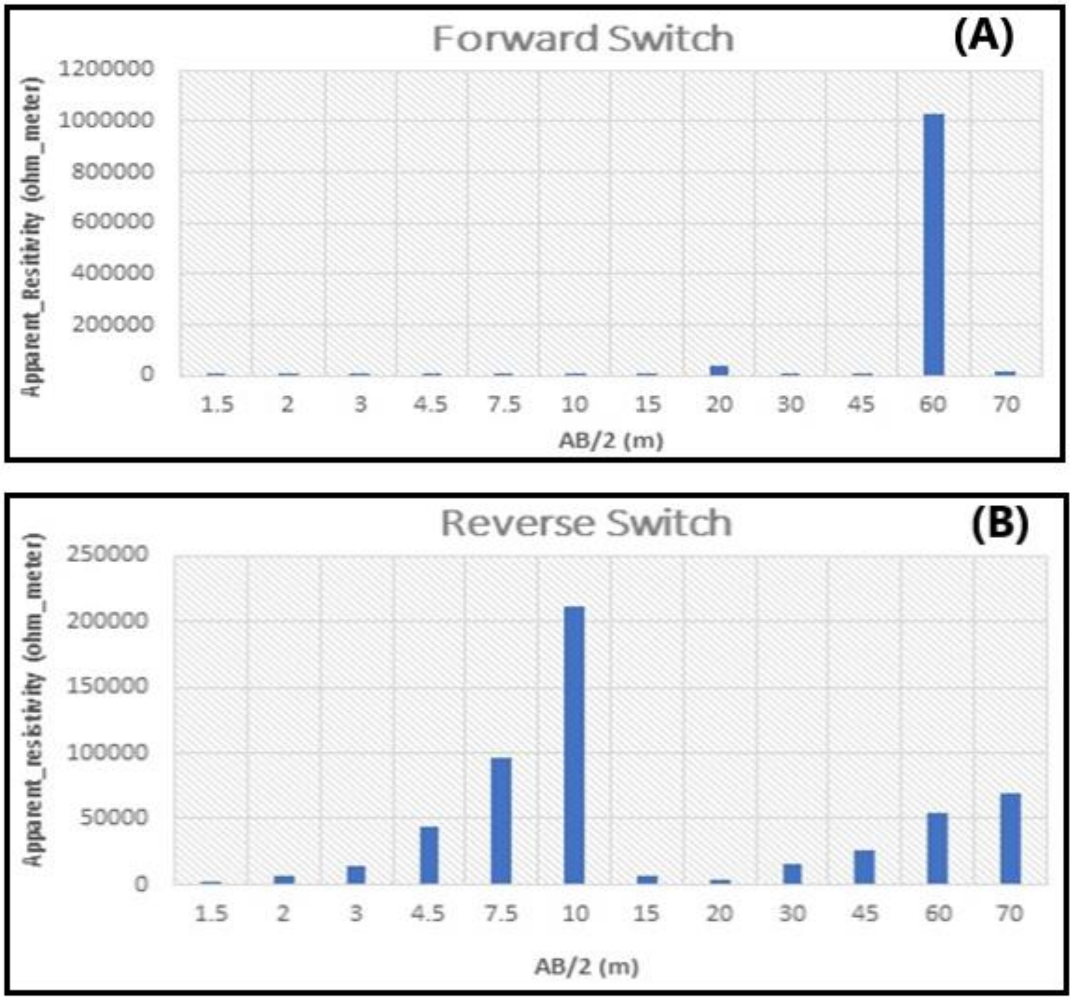

Figure 8. (a & b) displays a Stacked column relationship between forward-reverse switch configurations.

4.1.3. Predictive Soil Resistivity Variation based on Reverse and Forward Switch

Figures (9a & b) and (10a & b) depicts the relationship between soil resistivity and soil depth as well as soil resistance and soil depth respectively for this location under both reverse and forward conditions excel chart using XY Scatter line and Stacked Column as shown below. As spacing increases, the resistivity reduces in reverse switch and increases in forward switch. This indicates that the bottom layer which has low resistivity is overlaid by high resistivity upper layer.

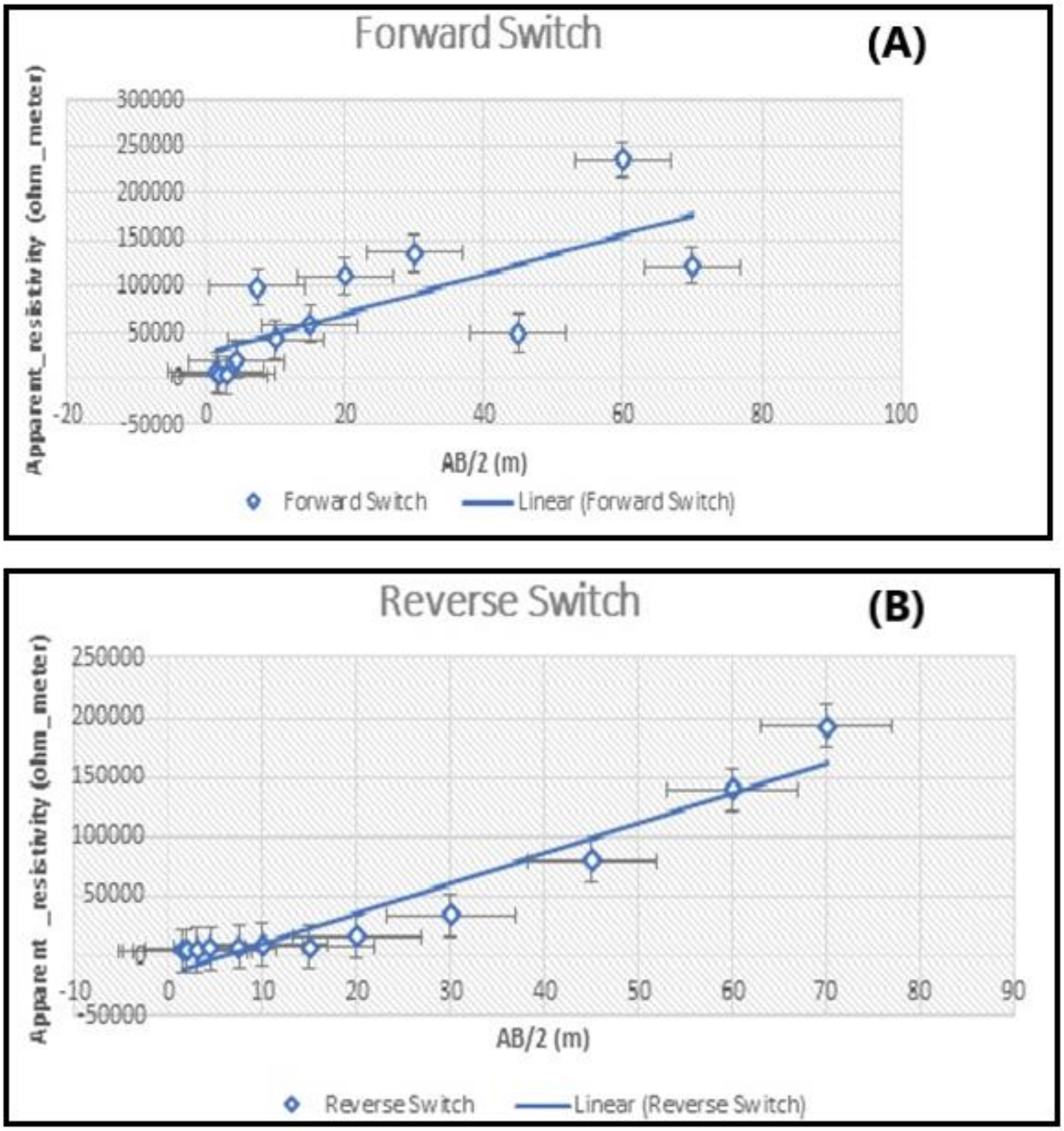

Figure 9. (a & b) shows a Linear plot Relationship between reverse and forwardSwitch distance.

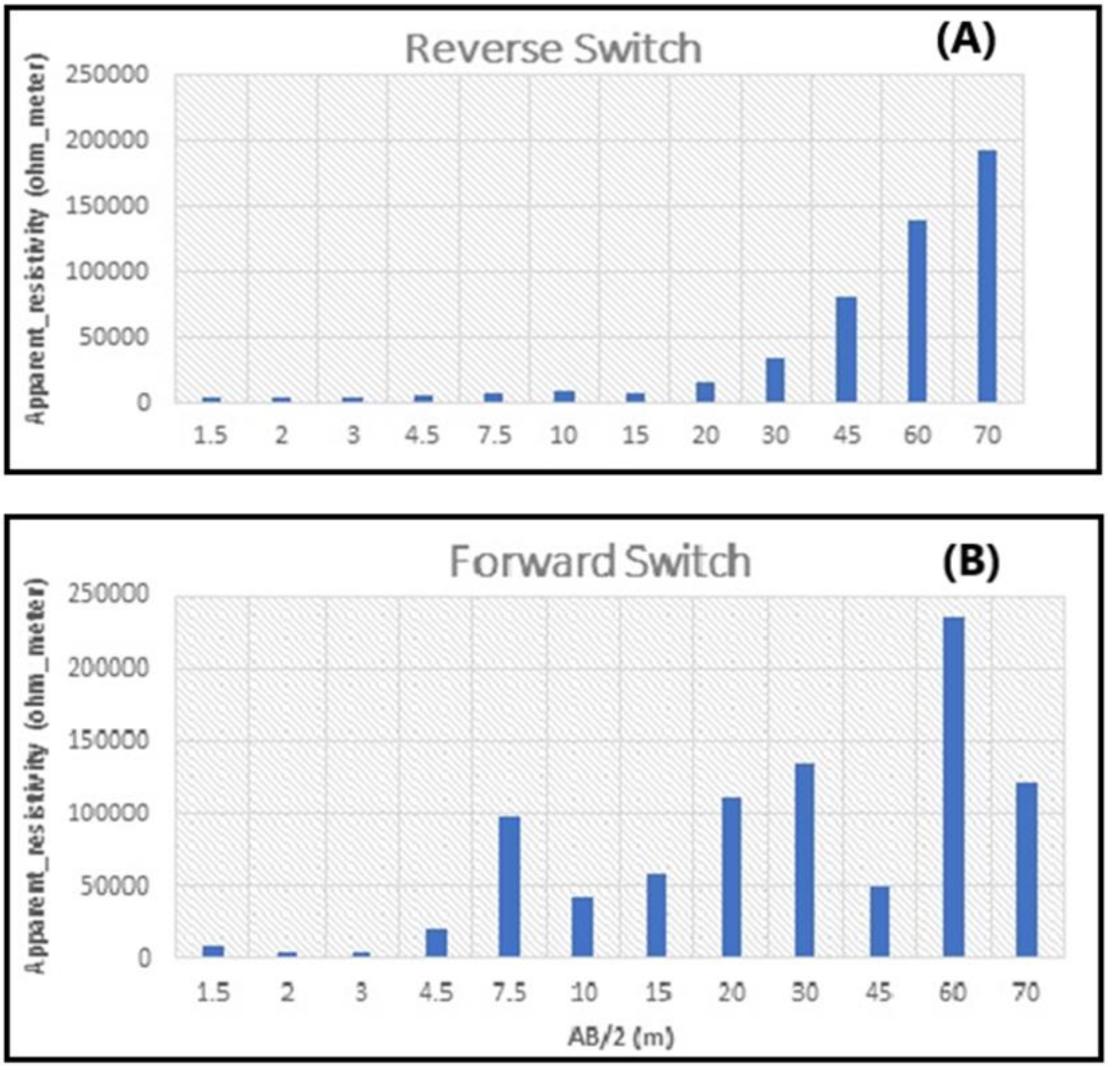

Figure 10. (a & b) shows a Stacked column Relationship between reverse and forward switch distance.

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, subsurface layer mapping throughout the Birnin Kebbi metropolis was accomplished using Schlumberger electrode resistivity techniques (forward and reverse switch). The research is regarded as an evaluation of the technique's effectiveness in Gwandu formation. The resistivity of different layers was assessed using the Vertical Electrical Sounding method. IPI2WIN software and an Excel chart that displays the variation of the condition for forward and reverse Switch were used to combine the results of the VES data's interpretation. Using the excel chart application package, the two location measurements were examined and depicted in numerous graphs. After investigating a different design, it is suggested that when the spacing between the electrodes grows, the resistivities decrease in forward switch but increase in reverse switch or decrease in forward switch and increase in reverse switch conditions. By lengthening the electrodes, this can be accomplished. Therefore, it can only be considered in situations where huge power sub-stations are being built. The findings also showed that there were three and four geo-resistivity units, with resistivity values typically ranging from 89 to 9450 Ωm and thicknesses between 1 and 45 m. The resistivity values (5–152 Ωm) of the saturated fractured shale unit are relatively low. In this regard, great consideration should be given to the selection of the acquisition parameters, processing stages, and interpretation techniques to ensure that the resistivity sounding curve models that are used to target successful subsurface lithologic conditions are of high quality. More extensive 1D and 2D electrical resistivity study, combined with seismic or magnetotelluric (MT) studies over the northern and southern parts of Kebbi State, should be carried out to provide a more complete picture of the lithologic layers there. This will help shed additional light on the situation below the surface.

6. ACKNOWLEDGEMENTS

We would like to express our gratitude to the Department of Applied Geophysics at Federal University Birnin Kebbi in Nigeria for lending us the equipment which was used to carry out the resistivity survey. The authors also acknowledge the valuable insightful comments provided by the two anonymous reviewers, which enabled the final draft of this work to be improved.

7. CONFLICT OF INTEREST

Authors have no conflict of interest.

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