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APPLICATION OF ELECTRICAL RESISTIVITY IMAGING AND INDUCED POLARIZATION METHODS FOR GROUNDWATER EXPLORATION AT AHMADU BELLO UNIVERSITY PHASE II, ZARIA, NIGERIA.

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ABSTRACT

Two-dimensional resistivity and induced polarization surveys have successfully been used to characterize the subsurface earth materials for groundwater exploration at Ahmadu Bello University Phase II, Zaria, Nigeria. Two imaging profile lines were established, with each profile length of 200 m. The electrical resistivity and induced polarization measurement on each profile lines were achieved using Wenner electrode array configuration. The data obtained from the survey were processed and interpreted using Res2Dinv software. The results of the 2D imaging profiles of resistivity and chargeability were calibrated using borehole data of the study area. The profiles revealed two to three layers, which comprises of brownish lateritic sandy clay, light brown clayey sand and greyish hard weathered rock. The possible location of fractured zones for groundwater exploration was mapped out from the imaging profiles. The zones have the resistivity and chargeability value of range between 0 – 62.8 Ωm and0.0001-0.167 ms respectively with a thickness of 9 m. Based on the results obtained from this study, it shows that groundwater exploration is feasible in the study area and drilling for the exploration of water should be targeted towards the fracture zone because it is hydro-geologically good in basement complex rock. In general, resistivity and chargeability values alongside borehole data have been used to provide better interpretation for groundwater exploration in the basement complex.

Keywords: Two-dimensional resistivity, induced polarization, groundwater, fractured zones and hydro-geological.

INTRODUCTION

In a developing country such as Nigeria, groundwater is a crucial resource used as an alternative source for drinking water (Mathiazhagan *et. al.*, 2015) and also a viable source for meeting domestic water needs such as washing, cooking, and bathing, this can be attributed to the fact that it is economical, safer, available, and is generally uncontaminated as compared to surface water (Sajeena *et. al.*, 2014).

An increase in student's intake yearly on the campuses of Ahmadu Bello University (A.B.U) has led to an increase in the number of Student's hostel which has led to the creation of A.B.U Phase II. As a result, the demand for potable water for domestic use by the student has highly increased. In order to meet up these demands of water by the students, an investigation for the groundwater potential and quantity is needed to be carried out in the new site.

Geophysical methods are widely used to investigate groundwater potential and this is because they usually provide accurate information about the subsurface conditions, such as type and depth of materials, depth to bedrock, depth of weathered or fractured zone, depth to groundwater, and salt content of groundwater. According to Goldman & Neubauer (1994), the most popular and suitable technique that is commonly used among all the geophysical methods for groundwater exploration is electrical techniques. Electrical techniques such as electrical resistivity method and induced polarization have been in used for groundwater exploration for decades (Sajeena *et. al.*, 2014). This is as a result of the fact that it is cost-effective, easy for operation, it also gives rapid and accurate results. Electrical resistivity tomography is used to determine the distribution of subsurface resistivity, which can vary with water content and lithology of the area of study. The distribution of subsurface resistivity can be interpreted from a hydrological point of view (Dahlin, 1996). The Induced Polarization (IP) effect is a measure of the soil ability to be polarized when it is under the influence of an electric field; in other words, it means that during the polarization the energy is stored reversibly in the soil (Marshall and Madden, 1959; Amana et al., 2016). Induced polarization can be used to distinguished different lithology composition and groundwater salinity. Hence, a combination of geophysical methods can give a better result in mapping subsurface composition and also enhance data interpretation (Yusof et al., 2016). In this research work, electrical resistivity tomography and induced polarization were used to characterize the soil for groundwater exploration within the study area. Thus, the objectives of this work are to image the distribution of the subsurface resistivity and chargeability in the study area and also to identify the location and depth of the zone probable for groundwater exploration from the imaging.

Location, Geology and Hydrogeology of the Study Area

The area of investigation falls within Ahamdu Bello University Phase II, Zaria, which is located in Sabon-Gari Local Government Area (L.G.A.) of Kaduna State, Nigeria. The study area has a tropical-continental climate with a distinct wet and dry season. The dry season usually occurs within the period of November to April and rainfall is usually experienced from May to end of October. The area is bounded between longitudes of 7° 37' 58.80''E to 7° 39' 4.42''E and latitudes 11° 7' 51.81''N to 11° 8' 30.13''Non the Nigeria National grid (see Fig. 1a). The study area is underlain by the porphyritic granite which is part of Nigeria basement complex of northern Nigeria (Fig. 1b). The rock units within the basement complex consist of schists, granites, and gneisses. The gneisses are found as small belts within the granite intrusions and are also found east and west of the batholiths. The gneiss continues eastwards to some extent and is occasionally broken up by the Older Granite and form a gradational boundary with the schist belt in the west (Wright and McCurry, 1970). Groundwater potential in crystalline basement rocks depends partly on the thickness of overburden regolith and the extent of fracturing within the rocks. In the study area, the drainage pattern is dendritic and surface water are well exploited. Water table occurs below 700m, which flows in the NW-SE direction. However, surface run-off significantly drains into the Kubanni Dam (see Fig. 2a and 2b).

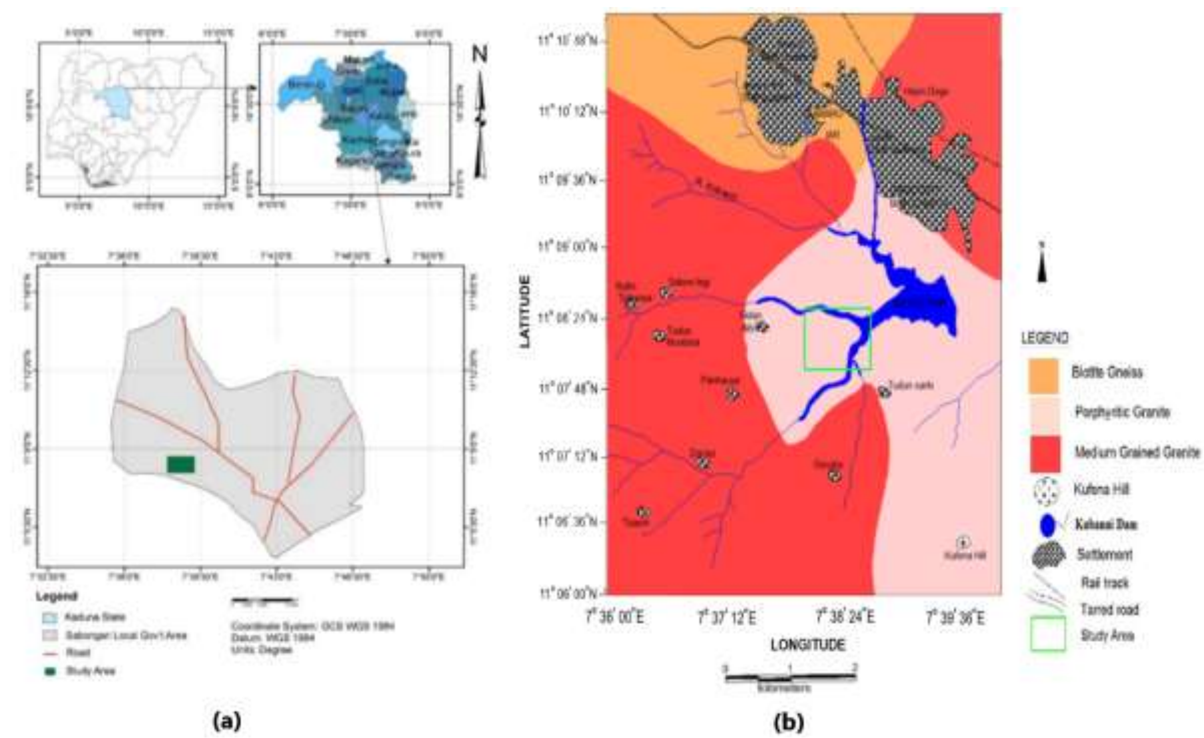

Fig. 1: (a) Location map of the area. (b) Geological map of the study area (Modified after Garba *et. al.*, 2014)

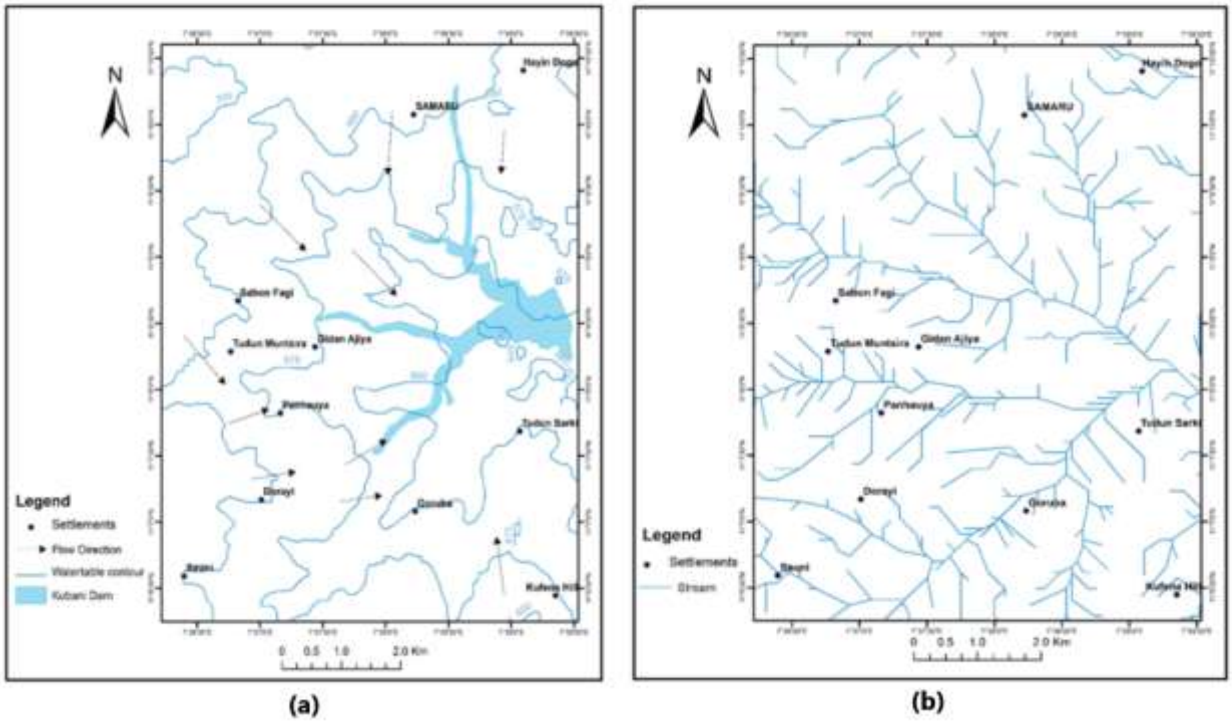

Fig. 2: (a) Ground water flow map of kubanni and its environs. (b) Drainage map of kubanni and its environs.

MATERIALS AND METHOD

Theory of Electrical Resistivity and Induced Polarization

Resistivity method is governed by Ohm's law which states that the current (I) passing through a conductor (such as earth's materials) between two points is directly proportional to the potential difference (ΔU) across these points.

Mathematically, it can be expressed as:

$$R = \frac{\Delta U}{I} \tag{1}$$

Where R is the resistance of the earth's materials. The values of R can be obtained from equation 1 by measuring the potential difference (ΔU) and current (I) at the surface of the earth.

For two-point current electrodes C_1 and C_2 on the earth's surface, the potential difference (ΔU), between potential electrodes P_1 and P_2 as shown in Fig. 3, is given as:

$$\Delta U = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right) \tag{2}$$

$$\rho = \frac{\Delta U}{I} k_f = R k_f \tag{3}$$

where,

$$K_f = \frac{2\pi}{\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)} \tag{4}$$

is known as the geometric factor and depends on the electrode configuration and $\boldsymbol{r_1}$, $\boldsymbol{r_2}$, $\boldsymbol{r_3}$ and $\boldsymbol{r_4}$ are the inter-electrode distances. The electrode configuration used was Wenner, whose K_f is $2\pi r$. Thus, the resistivity of the subsurface materials can be obtained by applying an electrical current to the ground through a pair of electrodes C_1 and C_2, and the second pair of electrodes are then used to measure the resulting potential difference P_1 and P_2. The greater the distances between the electrode pair, the greater the depth of investigation.

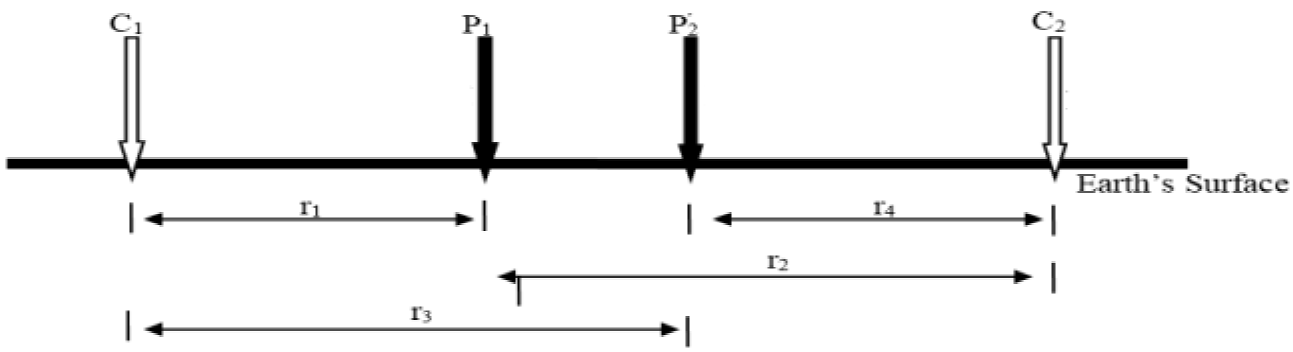

Figure 3: Current and potential electrodes in standard configuration

The induced polarization response is a delay of a voltage response $V_p(t)$ to an injected current into the earth surface, both when attaining a voltage (charging) and on a return to the background level when the current has been shut off (decay). The amplitude of $V_{ip}(t)$ as shown in Fig. 4 is related to the polarizability of the earth materials (Sumner, 1976; Antonio *et al.,* 1999). The ability to polarize constitutes the induce polarization susceptibility of the earth materials.

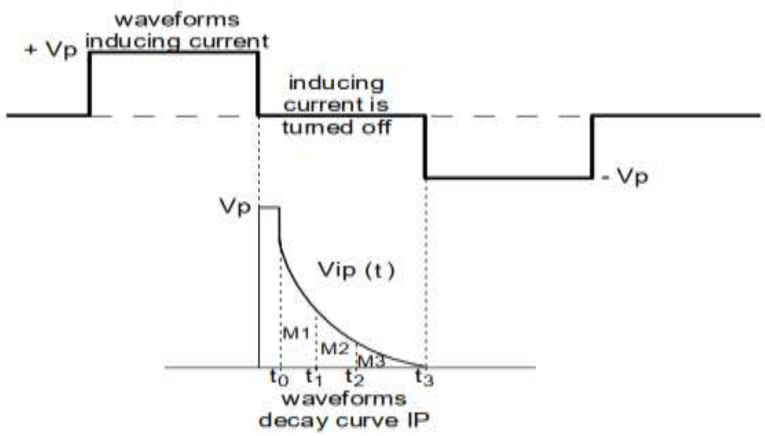

Fig. 4: Discharge curve of a time-domain induced polarization

The curve ΔV_{ip} can therefore be called the induced polarization decay curve. In time domain induced polarization, the decay curve is the object of study. The parameter measure in time domain induced polarization is called the chargeability, which is expressed in milliseconds (msec). Mathematically, Chargeability (M) is

$$M = \frac{1}{V_{ip}}\int_{t_1}^{t_2} V_p(t)\, dt \qquad (4)$$

The measurement of the chargeability of earth's materials is achieved with the aid of electrodes on the surface of the earth as shown in Fig. 3 using Wenner configuration.

Data Acquisition and Processing

Electrical resistivity imaging and Induced polarization survey were carried out on the same profile line with the aid of ABEM Terrameter SAS 4000. The direction of the two profile lines is shown in Fig. 5 with each length of 200 m.

Fig. 5: Google Earth map showing the orientation of profile lines.

The data were automatically recorded using the Wenner array with 41 electrodes spread along the profile line at an inter-electrode spacing of 5m. The reason for this choice of an array was that it is good in resolving vertical changes (that is horizontal structures). Thus, it is the most preferred array for mapping horizontal structures like fault and fracture zone. These zones are good and potential zones for groundwater exploration. The data obtained were processed and interpreted using Res2Dinv software (Loke, 2000) which then produces continuous images of variation in the subsurface properties. Additional information such as borehole log of the study area as shown in Fig. 6 was used to correlate with the inversion model obtained from Res2Dinv software which serves as a calibration tool. This can assist in the interpretation of the resistivity models obtained by making it more reliable and also reduces ambiguity in interpretation.

Figure 6: Geological borehole log used for calibration of the models

Results and Discussion

The results of the electrical resistivity and induced polarization models are displayed as a cross-section of the true resistivity and chargeability distribution of the subsurface with depth along with each profile (Figure 7 and 8).

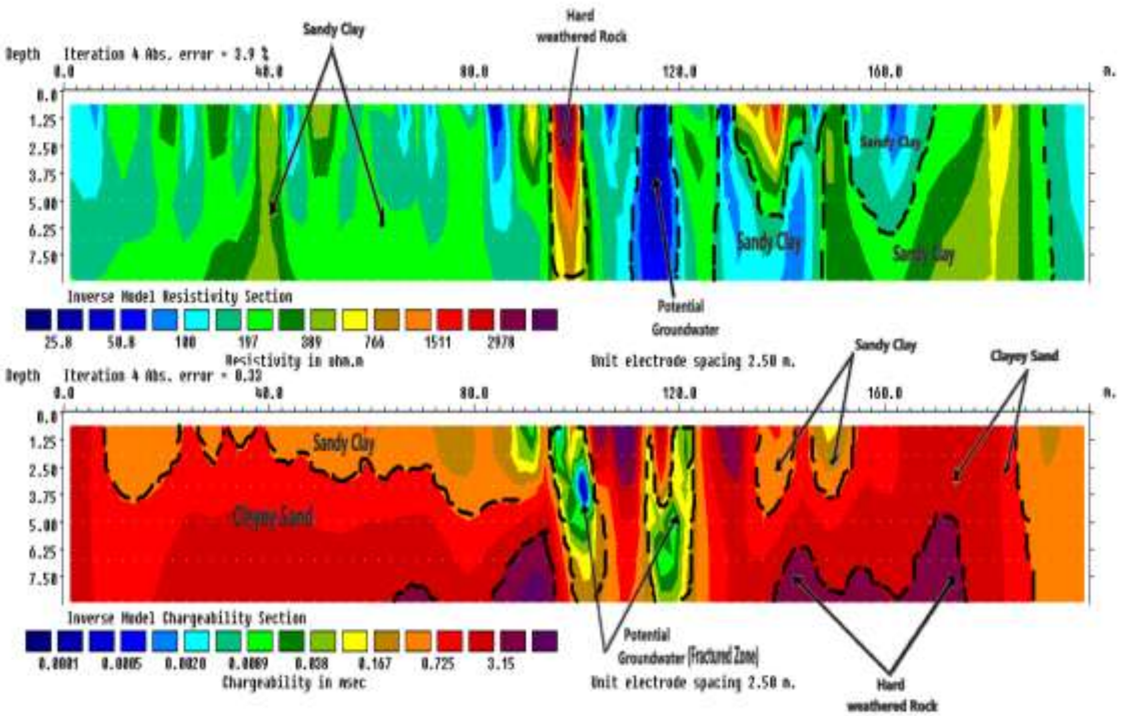

Fig. 7: 2D electrical resistivity and induced polarization models for profile 1

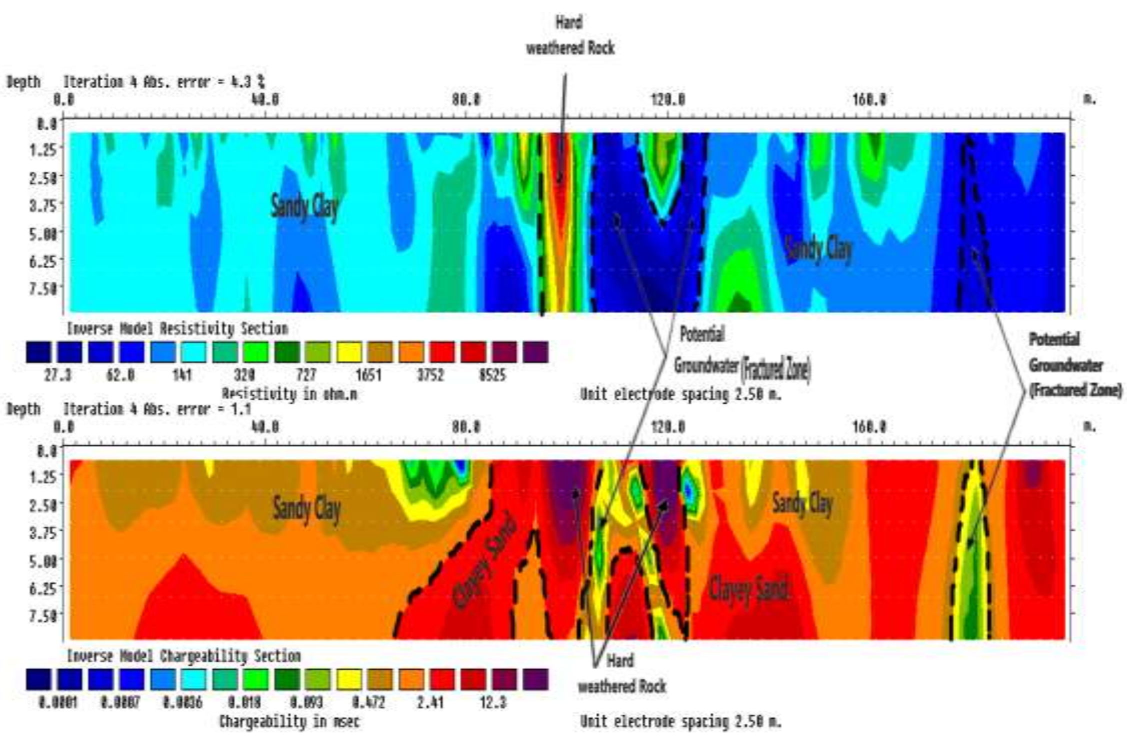

Fig. 8: 2D electrical resistivity and induced polarization models for profile 2

The inverted models in Fig. 7 have RMS errors of 3.9% and 0.33% while in Fig. 8, the models have RMS errors of 4.3% and 1.1% for resistivity and chargeability respectively. The depth of investigation beneath the subsurface soil for the 2D imaging profile is 9 m. The resistivity and chargeability data were interpreted with reference to established chargeability and resistivity of various earth materials (see Table 1 and Fig. 9).

Table 1: Chargeability of Various Materials (Murali and patangay, 2006; Ayolabi *et al.*, 2010)

Materials	Chargeability (MS)
Groundwater	0
Alluvium	1 - 4
Gravels	3 - 9
Precambrian Volcanics	8 - 20
Precambrian Gneisses	6 - 30
Schists	5 - 20
Sandstone	3 - 12
rightArgillites	3 - 10
Quartzite	5 - 12

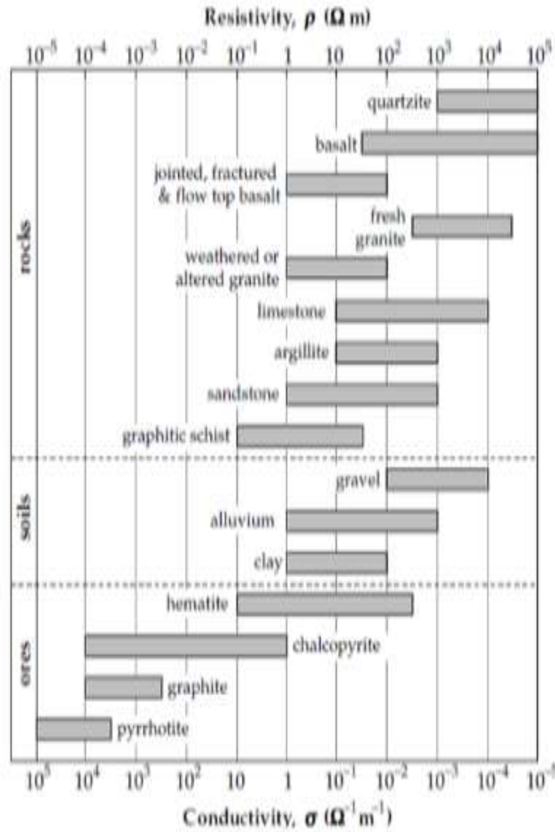

Figure 9: Ranges of electrical resistivity of some rocks, soils, and ores. (Ward, 1990).

The resistivity and chargeability values obtained from the 2D imaging profiles range from 10 Ωm to 9000 Ωm and 0 to 15 ms respectively. These range of values of resistivity and chargeability indicates the various type of subsurface materials present in the study area. With these values, it makes it easier to distinguish the zones which are feasible for groundwater exploration from the zones that are not feasible for the exploration. According to Ayolabi *et al.* 2010 and Ward, 1990, the chargeability and resistivity values as shown in Table 1 and Fig. 9 indicates the presence of groundwater. For the groundwater interpretation, it is suggested to distinguish fresh groundwater based on resistivity value range from 10 Ωm to 100 Ωm while chargeability value for water is 0 ms due to its poor ability to store electrical charges (Saiful *et al.*, 2018). In Profile 1 and 2, The layers for resistivity model are generally uneven as compared to the chargeability model which clearly depicts 3 layers and this might probably be as a result of the low range of chargeability values. The chargeability model of the profile is in agreement with the borehole data of the study area. The top layer of the models which is interpreted as brownish lateritic sandy clay has resistivity and chargeability value of 25 to 197 Ωm and 0.0001 to 0.472 ms respectively with an average depth of 3.75 m. Underlain the layer has high resistivity and chargeability value of 197 to 400 Ωm and 0.725 to 3.15 ms with an average thickness of 4 m. This layer was interpreted as lateritic clayey sand. The last layer of the chargeability model was interpreted as a hard-weathered rock with chargeability value of range between 3 -5 ms. In profile 1, at the lateral distance of 95 m and 120 m, also in profile 2, at the lateral distance of 105 to 115 m, it can be observed that the values of resistivity (0 – 62.8Ωm) and chargeability (0.0001-0.167 ms) is low. Moreover, at these lateral distances, there is a discontinuity in the layers and this might probably indicate the presence of a fracture zone. This zone is hydro-geologically good in basement complex area in terms of groundwater prospecting.

CONCLUSION

The geophysical techniques involving 2D electrical resistivity and induced polarization method have been used in this present work to characterized the soil for groundwater exploration within the study area. Two electrical profile lines were carried out at Ahmadu Bello University Phase II. The 2D model of the two profiles provides a clearer view of geological structures and lithological units which might probably be plausible for groundwater exploration. The models show a maximum of three lithological layers which includes; top layer (consist of brownish lateritic sandy clay), weathered layer (consist of lateritic clayey sand), and hard weathered rock with an average thickness of 3.75 m, 4 m, and 2 m respectively. In the models, there was a discontinuity in the layers and this was probably caused by the presence of the fracture zone. This zone has low resistivity and chargeability values and was encountered at a lateral distance of 95 m and 120 m with an average thickness of 4 m in profile one, and 105 m to 115 m with an average thickness of 9 m in profile two. Based on this result, groundwater exploration should be targeted towards the fractured zone of profile two because of the low resistivity and chargeability of the zone, high thickness value, and wide lateral distance covered, moreover this zone is hydro-geologically good in basement complex rock.

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