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# GROUNDWATER EXPLORATION USING 2D RESISTIVITY IMAGING AT NUHU BAMALLI POLYTECHNIC, ZARIA, KADUNA STATE, NIGERIA

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## ABSTRACT
The groundwater resource of Nuhu Bamalli Polytechnic Zaria was investigated using 2D resistivity imaging. The data was collected using ABEM Terrameter SAS 4000 with an electrode selector along 35 profiles running orthogonally employing a dipole-dipole array with an equally spaced electrode of 5m. The apparent resistivity obtained from field was processed and interpreted using RES2DINV software to produce two two-dimensional images of the study area. The result of the inverted 2D resistivity imaging revealed that the site is predominantly of low resistivity values at the near surface, with sparsely high resistivity values at some places. The low resistivity values that range from 9 ohm-m to 142 ohm-m typify high clay content. The overburden thickness was found to be between 3m to 12 m depth with outcrops along profiles 10 and 21. The basement has a varying degree of weathering, and areas of withered/fractured zone were well pronounced along 11 profiles (profiles 2, 4, 7, 8, 10, 20, 21, 22, 26, 27, 31) at different depths. These areas of the withered/fractures zone could serve as a water-bearing zone (aquifer) in the study area.

**Keywords**: Overburden, Fractures, Orthogonal, Resistivity, and Basement

## INTRODUCTION
Water is essential for humans, animals, and plants. One of the main sources of fresh water is located beneath the Earth's surface as groundwater. As the water demand has risen, there has been a greater focus on tapping into underground water resources. This has led to advancements in geophysical techniques for studying the presence and flow of groundwater, the development of more efficient equipment for extracting it, and the creation of strategies for managing this vital resource. Groundwater is typically defined as water that exists beneath the Earth's subsurface, found within a basement complex rock or in saturated geological formations such as sand, gravel, and pore spaces (Ojoawo & Adagunod, 2023 and Serov & Kuginis, 2017)
The present water inadequacy experienced by inhabitant of Nuhu Bamalli Polytechnic (UPE) and its environs might be due to the rapid growth and development of the school, both in terms of academic infrastructures and social infrastructures. Also there is increasing rate of borehole failure in the study area couple with the fast increase in population which lead to high demand of water necessitated the need for this research. The area where hand-dug well and borehole are drilled through sandy soil and fracture zone have sustainable aquifers for groundwater exploitation, while borehole that are constructed through clayey formation usually fail (Afuwai., *et al*.,2015).
Geophysical techniques are widely used today for a variety of purposes, with 2D resistivity imaging being particularly common for water quality assessment and evaluation. This is likely due to its simplicity and the availability of software tools for modeling.( Costall et al., 2018 and Stanly et al.,2021). This research work is set to evaluate the groundwater potential of Nuhu Bamalli Polytechnic, Zaria, by applying 2D resistivity method so as to provide information on water bearing zone within the study area for easy management. The research has evaluated the potential area for groundwater and further researches should be carryout within the study area using different methods.

## LOCATION OF THE STUDY AREA
The study area is Nuhu Bamalli Polytechnic Zaria, main campus (UPE) it is located along Kaduna-Zaria Road. It lies between latitude 11.04059$^0$N to N11.04146$^0$N and longitude 7.67327$^o$E to 7.6329$^o$E and is about 3.0km west of the ancient Zaria city. It is the main campus of the famous Nuhu Bamalli Polytechnic, Zaria that sheltered the administrative block of the Institution, the ICT Centre, the Physical Planning Department, the Academic Planning, the School of Engineering, the School of Environmental Studies, the School of Applied Sciences, the School of Vocational and Technical Education and the Residential Staff Quarters (Fig.1)

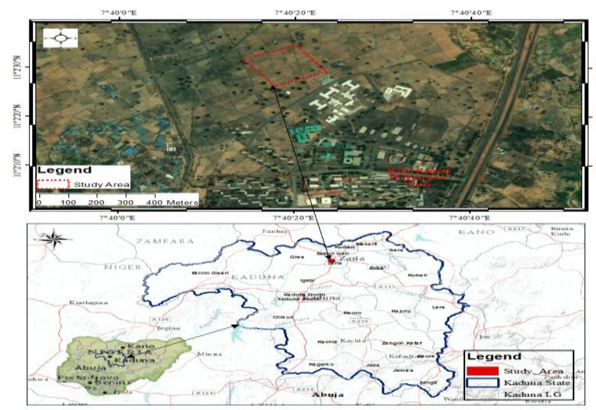


**Figure 1** map of the study area (Google Earth, 2024)

## GEOLOGY OF THE STUDY AREA
Figure.2 bellow shows the geology map of the study area. The study area belongs to the North-Western Nigerian Basement Complex, a region shaped by numerous episodes of magmatic

activity, metamorphic processes, and deformation throughout its long history. The most prominent rock type is porphyritic granite, with outcrops visible across the area (NGSA, 2019)

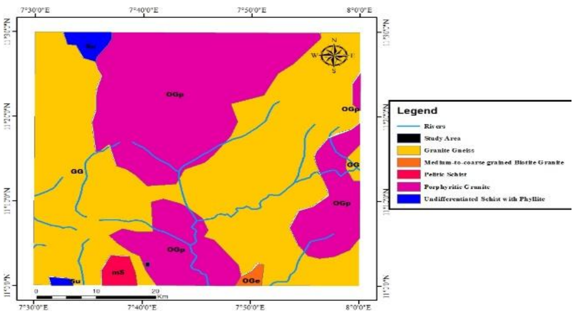


**Figure 2** geology map of the study area (NGSA, 2019)

**MATERIALS AND METHODS**

The LUND Imaging System is a multi-electrode system for cost effective and high resolution 2D and 3D resistivity surveys. It is an automatic electric imaging system suited for automatic resistivity profiling and drilling. The LUND Resistivity imaging System consists of a basic unit, a standard resistivity meter (ABEM Terrameter SAS 4000), a (4x64) multi-channel relay matrix switch unit called Electrode Selector ES 464. The system also has four multi-conductor electrode cables wound on reels each with 21 take outs, stainless steel electrodes and cable jumpers and various connectors. The ABEM Lund imaging System is shown in Plate 1 bellow. Other materials used in this research work includes the following Global positioning system (GPS), measuring type and hammer

**Plate 1**. ABEM Terrameter SAS 4000

**DATA COLLECTION**

The data was collected along 35 profiles orthogonally with 20 profiles (01 to 20) in the orientation of NE to SW while the remaining 15 profiles (21 to 35) were oriented in the SE to NE direction as shown in Fig. 3. The multiple Azimuths choice is the common orientation used to cover orthogonal direction to reveal the directional variation in resistivity (Udosen & George, 2018).The distance between the profiles is 10m and data were collected employing dipole-dipole array with an equal electrode spacing of 5m. The subsurface resistivity measurement was carried out by laying out the cables and electrodes along the chosen profiles while the coordinates of each of the profile were recorded. The ABEM SAS400 Terrameter , battery and the Electrode Selector (ES464) were placed at the centre of the layout. The two cables from the reels were connected to the ES464 and SAS4000 serial port was also connected to the ES464 by the means of a connector. The total number of41 electrodes were all connected to all the take-outs at the interval spacing of 5 m on the electrode cables using cable jumpers. The SAS 4000 was switched on, which automatically switch on the ES464 and the system set-up displayed on the screen. The instrument was set to resistivity mode and LUND Imaging. The measurement recorded by the instrument is the apparent resistivity of the subsurface soil and is shown on the screen as the measurement continued. When the measurements on each layout were finished, the program was stopped and the Terrameter switched off. All the equipment is then moved to a new profile and the entire process is then repeated until all the profiles were completed.

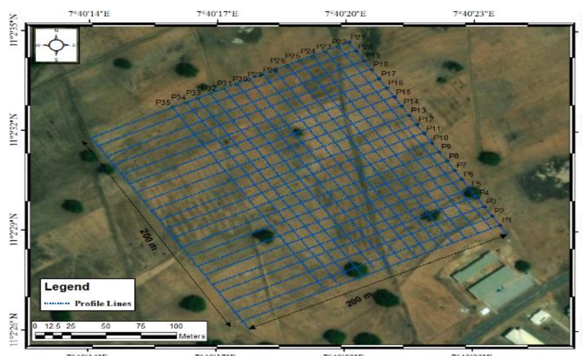


**Figure 3**.Data Acquisition Map of the Study Area

**RESULTS AND DISCUSSION**

The interpretation of the resistivity model into the geological model requires the knowledge of the typical resistivity values for the different types of earth materials and geology of the surveyed area (Raji & Adedoyin, 2020).The borehole log and Table 1 adopted are used as guide in the interpretation of this research work. The acquired apparent resistivity data were processed and inverted using the RES2DINV Software and smoothness constrain was applied to ensure resulting model shows smooth variations in the resistivity values

**Borehole Log of the Study Area**

Fig. 4 below show the borehole log near the study area (obtaitained from Al-Nas borehole drilling company Zaria , 2009). The top soil comprises clay, sandy and silt with resistivities values ranging from 10 ohm-m to 148 ohm-m covering depth from 0 to 5m depth.The second layer comprises gravel and pebble with resistivities values ranging from 250 ohm-m to 480 ohm-m and depth range from 6 to 15 , the fracture is made up of gneiss with resistivities values range from 500 ohm-m to 850 ohm-m within the depth range of 16 to 35m and the fresh basement is made up schist with resistivity values > 1000 ohm-m at a depth > 35m

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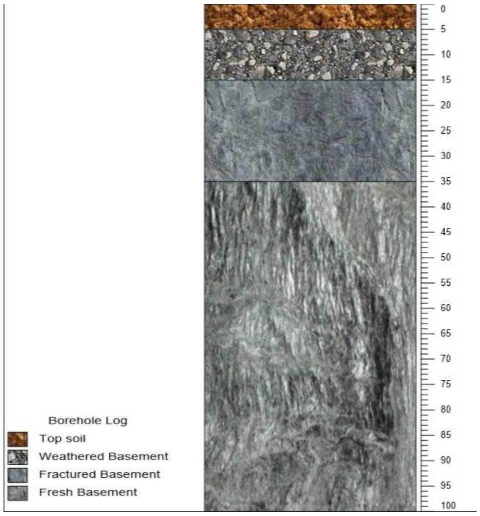


**Figure 4** borehole log of the study are

**Table 1:** Typical Electrical Resistivity of the earth's materials (Park et-al., 2017)

| Materials | Electrical Resistivity(Ωm) |
|---|---|
| Granite | 300-1,300,000 |
| Sandstone | 1-740,000,000 |
| Clay | 1-100 |
| Topsoil | 250-1700 |
| Gravel | 100-1400 |
| Alluvium and Sand | 10-800 |
| Dry Sandy Soil | 80-1050 |
| Sandy Clay/Clayey sand | 30-215 |
| Sand and Gravel | 30-225 |

**Interpretation of Profile 02**

Fig.6 shows the inverse model resistivity section of profile 02 which has a length of 200m in the direction of NE to SW. The data were collected using dipole-dipole array configuration with an equal spacing of 5m between the electrodes spacing. The result of this profile show a near surface low resistivity values ranging from 53 ohm-m to 147 ohm-m at a distance of 25m and also along profile distance of 55m to 120m with a maximum depth of about 5m. These low resistivity values penetrated deeper at profile locations of 120m to a depth > 28m which were all planked by high resistivity values on both sides. The resistivity values along this zone revealed a vertical geological structure (possibly a fracture zone) that extended beyond the depth of investigation. This Low resistivity zone can also suggest high porosity, as greater water saturation typically indicates better porosity ( Aluko and Igwe, 2017). The resistivity values that range from 1086 ohm-m to 1792 ohm-m revealed the presence of fresh basement rock.

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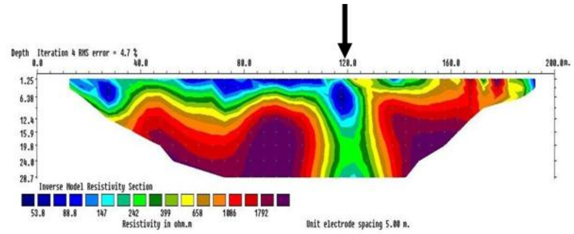


**Figure 6** 2D inverse model of profile 02

**Interpretation of Profile 04**

Fig.7 is the result of 2D resistivity model along profile 04. This profile is also oriented in the NE to SW direction and has a maximum length of 200m. The figure shows a trend of increasing resistivity value at near surface. With resistivity values varying between 37 ohm-m to 130 ohm-m which penetrated to a maximum depression depth of about 12.5m at a profile position between 90 to 120m. The Depression appears as a lower resistivity zone. Such low resistivity values may indicate the presence of saturated materials, which could suggest groundwater accumulation within this depression. The shape of the depression and the presence of lower resistivity zones above it may suggest that this area could act as a groundwater reservoir or a preferential pathway for water flow. There is also presence of high resistivity section between 5m to 29m depth with resistivity values ranging from 1543 ohm-m to 2865 ohm-m, which are in agreement with the existing borehole log of the study area as shown in fig 7.This zone is defined as fresh basement rock.

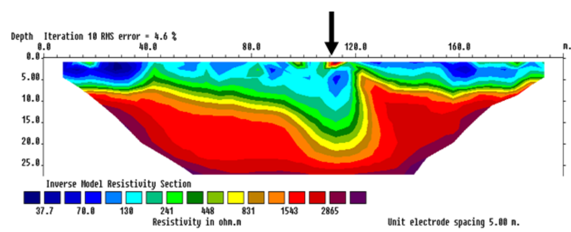


**Figure 7** 2D inverse model of profile 04

**Interpretation of Profile 07**

The resistivity model along this profile in Fig.8 shows that the resistivity values varying between 53 ohm-m to 8825 ohm-m. The model show that the near surface geology is characterizes by high and low resistivity values. The low resistivity values at the top soil are uniformly distributed from top to a maximum depth of 12.4m. This low resistivity values in the top soil indicates a sign of clay formation. The 2D resistivity model along this profile revealed the presence of an outcrop at profile positions of 40m to 50m and at the extreme end of the profile. Underlying the top layer there is formation of thin layer (weathered basement layer) with resistivity values range from 229 ohm-m to 475 ohm-m with maximum thickness and depth at 75m.The area with maximum depression zone at a horizontal distance of 75 and 115m defined the water bearing zone (aquifer). Bellow weathered layer the resistivity values increase with increasing in depth and with varying degree of weathering from 9m up to a depth of 25m. This resistivity values that varied between 2048 ohm-m to 8825 ohm-m is interpreted as fresh basement rock.

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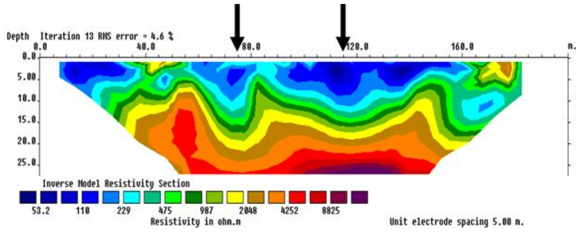


**Figure 8** 2D inverse model of profile 7

**Interpretation of Profile 08**
The inverse mode resistivity along this profile (Fig.9) reveals low resistivity top soil varying from 45ohm-m to 142 ohm-m. The top layer may be an intercalation of clay, sandy and silt which is in agreement with the borehole log near the study area (Fig. 4). The 2D resistivity inverse model revealed suspected fracture zone at 115 m on the profile distance. This vertical geological structure (fracture) become narrower with increase in depth which indicate that the fracture is closing with increase in depth, this is because structural depression or basin feature that has subsequently been affected by tectonic forces, causing a narrowing into a fracture zone at greater depths (Nabavi et al.,2020 ). The transition to a narrow, linear vertical anomaly suggests a fracture and such a structure often act as conduits for groundwater flow and storage ( Kouider et al., 2023).Also there is occurrence of high resistivity values ranging from 2114 ohm-m to 24547 ohm-m between 6m to depth greater than 25m depth. This high resistive zone is typical basement rocks found in basements terrain.

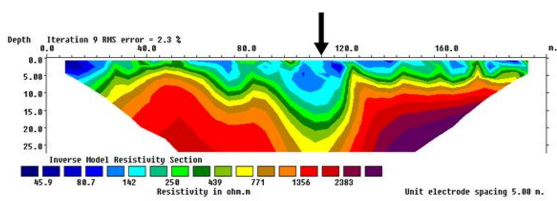


**Figure 9** 2D inverse model of profile of profile 8

**Interpretation of Profile 10**
Fig.10 shows the inverse resistivity model of profile 10 measured with 5m electrode spacing measurement along NE to SW direction. At profile distances of 60m to 90m and 110m to 190mm, there is a distribution of low resistivity (42 ohm-m to 139 ohm-m) with a maximum thickness of 8m at a lateral distance of 75m.This zone formed a combination of clay, sandy and silt which is also correlate with the borehole log found at the study area. Anomaly delineated is interpreted as Fractures at a horizontal distance of 115m which found between the granite bedrock that has high resistivity values varied between 1494 ohm-m to 2706 ohm-m, suggesting that water seeps through the fractured bedrock and accumulates there. Therefore this fracture zone located at the identified position is good for groundwater potential exploitation. The high resistivity that is starting from 6m to a depth >25m represent the fresh basement rock.

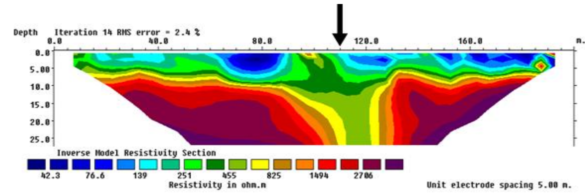


**Figure 10** 2D inverse model of profile of profile 10

**Interpretation of Profile 20**
Fig. 11 shows the result of the processed 2D resistivity image data collected along profile 20. The resistivity model reveals a top layer with a high and low resistivity values. The low resistivity values toward the extreme end of the profile vary between 5 ohm-m to 50ohm-m. This layer may be made up of silt and clay p .The interpretations also indicate the present of an outcrop between profile distances of 40m to 45m and penetrated to depth of about 6m which are physically seen during the survey. The resistivity values of 1549 ohm-m to 3652 ohm-m observed at profile distance of 60 to 170m within a depth of 9m down to 28m correspond to the outcrop observed along this profile. The broader, horizontal portion of the anomaly as indicated in the 2D resistivity model is possibly an ancient stream buried by accumulated sediments (Obrocki et al., 2019).The linearity and being narrow, anomaly at 115 m define a fracture zone with resistivity values varied between 279 ohm-m to 657 ohm-m.

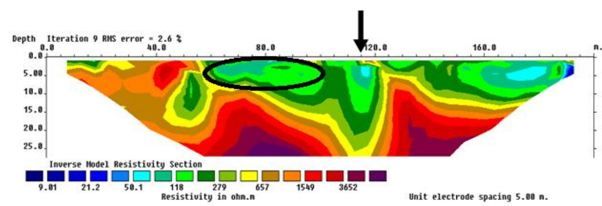


**Figure 11** 2D inverse model of profile of profile 20

**Interpretation of Profile 21**
Fig.12 Represents the result obtained from the measurement of 2D resistivity imaging using dipole-dipole array spread with 5.0m electrode spacing along profile 21 having 200m maximum length measured along SE to NE direction. The inverse resistivity model reveals a top layer of low, moderate and high resistivity values varying from 94 ohm-m to 2102 ohm-m. This layer is about 1.0m thick and may be an intercalation of clay, gravels and outcrop of granite rock. Underlying this zone is a zone of high resistivity values ranging from 1350 ohm-m to 2102 ohm-m at a depth of 2.5m to 30m is interpreted as fresh basement rock along the profile distance from 70m to 175m.The anomaly in the 2D resistivity models represent a fracture due to high porosity or fluid saturation (Hasan et al., 2019) at a profile distance of 65m and 115m with resistivity values ranging from 147 ohm-m to 557 ohm-m with a maximum depth of 26m.

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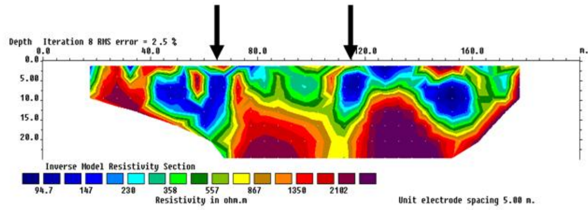


**Figure 12** 2D inverse model of profile of profile 21

**Interpretation of Profile 22**

Fig.13 show the inverse resistivity model along profile 22.This profile is also oriented in the SE to NE direction and has a maximum length of 200m. The 2D resistivity model shows a trend of distributed low resistivity values (47 ohm-m to 214ohm-m) at the near surface which are visible at profile positions of 40m to 180m that is occurring at depth of 1m to 18m with maximum depth of 18m at profile position of 75m. This low resistive zone is suspected to be clay material with high porosity or fluid saturation revealed the water bearing zone (aquifer).Underlying the top layer at depth of 1.25m to 28 m interpreted as fresh basement rocks with resistivity values greater than 9000 ohm-m

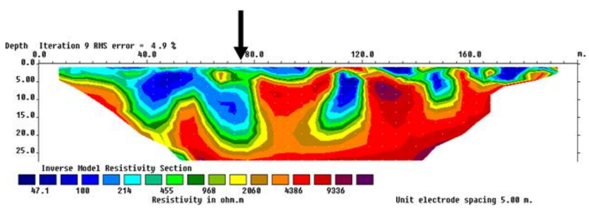


**Figure13** 2D inverse model of profile 22

**Interpretation of Profile 26**

Fig.14 shows the inverse resistivity model along profile 26. The resistivity model reveals a top layer with low resistivity values ranging from 54 ohm-m to 119 ohm-m extending to a depth of about 5m on the profile with uniform distribution of 30m to 95m in the profile position. This zone is typically consisting of clay, sand and silt. At the beginning of the profile there is a small region of extremely high resistivity value greater than 1000 ohm-m penetrated to about 6m depth interpreted as an outcrop. The 2D resistivity model delineates the presence of a vertical depression feature at 115m along the profile length. This geological feature can serve as a water bearing zone in the study area. Underlying the top layer from 6.38 m to a depth > 25 m is high resistivity zone with increasing degree of weathering. The resistivity values of this layer defined the fresh basement rocks with resistivity values ranging from 1838 ohm-m to 7501 ohm-m

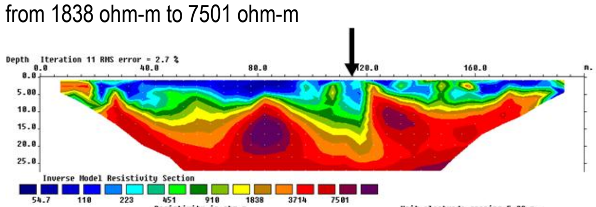


**Figure 14** 2D inverse model of profile 26

**Interpretation of Profile 27**

Fig. 15 shows the inverse resistivity model along profile 27. From profile distance of 10m to 195m is region of low resistivity values ranging from 50 ohm-m to 95 ohm-m with maximum depth of 8m at a profile position of 110m. These areas representing the top layer is interpreted as clay material. Underlying the top layer, the 2D resistivity model shows trends of continuous moderate resistivity values (337 ohm-m to 632 ohm-m) with a thin layer across the entire profile. This layer is suspected to be weathered basement with maximum depth of about 18m at a horizontal distance of 110m as shown with arrow bellow. A high resistivity zone underlying the moderately resistivity values which ranges from 2229 ohm-m to 4185 ohm-m and dominate the lower part of the profile within depth range of 4m to 25m is interpreted as the fresh basement rock.

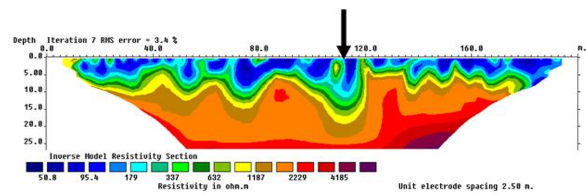


**Figure 15** D inverse model of profile 27

**Interpretation of Profile 31**

Fig.16 shows the result of the 2D inverse resistivity model of profile 31. The resistivity model reveals a top layer with low and moderate resistivity. The low resistivity of the top layer is uniformly distributed from profile distance of 110m to 195m and from 55m to 70m has values ranging from 35 ohm-m to 63 ohm-m. The moderate resistivity occupies at a profile position from 10m to 50m and at 80m.This layer is likely to be weathered basement which made up of sand and gravel material with resistivity values ranging from 204 ohm-m to 364 ohm-m. The weathered layer has maximum depth of 19m at a profile position of 75m and this position will serve as best position for installing a productive borehole along the profile. The zone with resistivity values ranging from 1166 ohm-m to 2085 ohm-m is the fresh basement rock.

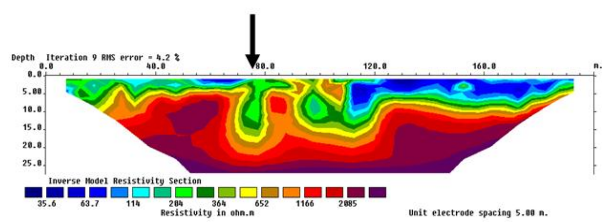


**Figure 16** 2D inverse model of profile 31

**Conclusion**

The 2D resistivity survey captured both horizontal and vertical changes in resistivity with depth, for identifying features like depressions and fractures that vary in both directions. Also the study shows linear and narrow vertical anomaly with high resistivity contrast interpreted as fractures and horizontal flat anomaly as depression. The Fracture basement underlying the weathered basement or depression in the bedrock, both in the in-line and cross-line profiles delineated in 11 profiles were recommended for setting a productive borehole at the study. It is recommended to employ additional geophysical exploration methods, such as

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seismic refraction tomography (SRT), Electromagnetic methods and magnetic techniques, to investigate the fracture zone and other subsurface geological structures in the study area. These methods could enhance groundwater exploitation in the region. Furthermore, the traditional electrical resistivity sounding technique can be used to validate and correlate the findings of the current study

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