Subsurface Characterisation Using the Electrical Resistivity Method: A Case Study of Itohan Girls Grammar School, Benin City, Nigeria

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Abstract. To map the subsurface for borehole development, a 2D electrical resistivity inversion survey was conducted at Itohan Girls Grammar School, located on Sapele Road in Benin City. The researchers used the ABEM Terrameter SAS 2000 to perform Wenner and Schlumberger configurations over different areas. The inter-electrode spacings were 10 m, 20 m, 30 m, and 40 m, while the AB/2 values were 300 m for VES 1 in the NW–SE direction, 392m for VES 2 in the SE–NW direction, and for VES 3 in the N–S direction, with a traverse length of 600 m. Using DIPRO software, a pseudosection of the apparent resistivity values acquired along a 140 m (W–E) traverse was created to process the data. Thereafter, the researchers performed computer iterations. They generated a columnar geosection for the three VES datasets. VES 1, VES 2, and VES 3 revealed resistivity values of 283.4 Ωm, 153.0 Ωm, and 145.6 Ωm, respectively, indicating sandy clay formations with soil thicknesses of 3.5 m, 5.3 m, and 1.3 m, respectively. The second layers of VES 1 and VES 2 correspond to the third layer of VES 3, showing high resistivity values of 2601.6 Ωm, 1528.0 Ωm, and 4600 Ωm, respectively. These resistivity values depict lateritic sand formations with thicknesses of 23.6m, 29.6m, and 11.7m, respectively. The second layer of VES 3 has a resistivity of 87.0 Ωm, indicating a clayey sand formation with a thickness of 1.6m. VES 1 has a sandy clay formation as its basement, with a resistivity of 475.3 Ωm. The basement layers of VES 2 and VES 3 have resistivity values of 18,640.0 Ωm and 100,000.0 Ωm, respectively, indicating sandstone as the bedrock. The 2D resistivity structure revealed four distinct soil formations along the traverse from west to east, extending to depths of about 50 meters. These correspond to the geoelectric layers identified by the vertical electrical soundings conducted in the area. The results suggest that the area is suitable for large, shallow engineering structures and borehole drilling.

Keywords: Geoelectric layers; Investigation; Resistivity soundings; traverse.

INTRODUCTION

By examining Earth's physical characteristics, a geophysical investigation can provide valuable information about the material conditions beneath the surface [1]. This approach has numerous practical applications. The measurements, taken at or near the Earth's surface, are influenced by the internal distribution of physical properties. Consequently, researchers can analyse the physical characteristics of the Earth's interior to determine their lateral and vertical variations, which reflect the underlying subsurface geology. Subsurface characteristics vary from one location to another with the same geologic history. Even after a reconnaissance survey, the researchers need to thoroughly examine the outcome. Researchers should never generalise results from a mere inspection of geoelectric layers at a site, because results will always vary when they perform a similar investigation in areas with the same geologic history. However, similarities in the characterisation will help buttress the interpretation of the distinct geologic attributes. A proper understanding of the nature of the subsurface is extremely vital before any building is erected, to prevent property collapse and fatalities, and to promote the ecosystem. There is a need to understand the subsurface before road construction commences, as this will help avoid Road failures and control them by strengthening the soil. Subsurface characterisation contributes significantly to determining areas of the soil suitable for borehole drilling by providing an estimate of the water table depth.

Alternative methods for studying subsurface geology, such as drilling and pitting, are often expensive and provide data limited to specific locations [2]. In this fieldwork, the 2D Electrical Resistivity Method was employed to characterise the subsurface conditions. The Wenner and Schlumberger configurations were used to map the subsurface's electrical properties.

Resistivity surveys measure variations in subsurface electrical resistivity by applying electric current across arrays of surface electrodes [3]. Factors such as porosity, fluid saturation, the resistivity of the solid matrix and pore fluid, and material texture all influence electrical resistivity [4]. The collected data are processed to generate graphic depth sections that represent the thickness and resistivity of the subsurface electrical layers. The researchers used the Schlumberger and Wenner array configurations to delineate the subsurface geology of Itohan Girls Grammar School, Sapele Road, Benin City.

Study Area Location. This research is located at Itohan Girls Grammar School, close to a dual-carriageway expressway leading to Sapele and Warri, Delta State, and adjacent to the Edo State Urban Water Board. Asologun Street powerline road is actually behind the school (figure 1), with GPS coordinates of lat. 697348.5 m, long. 791199.2 m to lat. 697570 m, long. 791525.1 m were the sites for this inquiry.

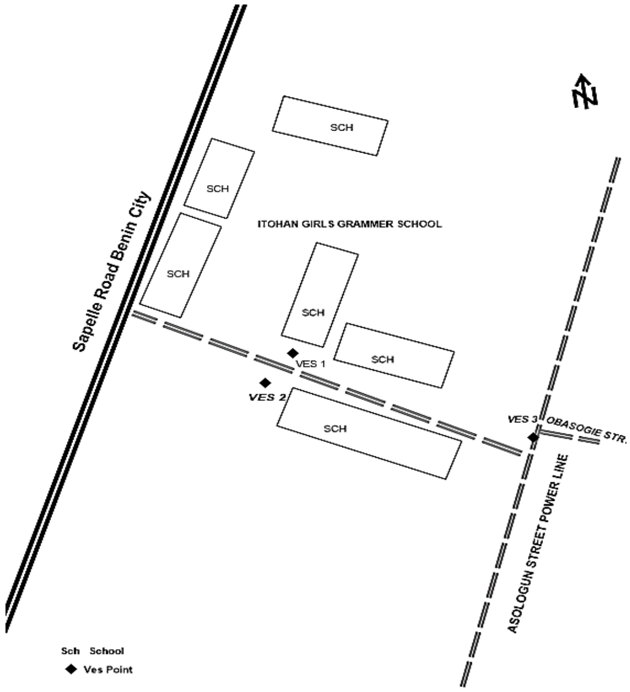


Figure 1 – Site Description

Geology of the Study Area. Benin lies within the southern geological basin. The researchers typically characterise the area's geology by a reddish topsoil composed of laterite or ferruginized clay sand [5]. The reddish Earth beneath, consisting of sands, ferruginized sandstone, and sandy clays that define the paleo-coastal environment of the Palaeocene–Pleistocene age, is referred to in this study as the Benin Sand. The formation is characterised by lateritic, coarse, red to reddish-brown, moderately indurated sands and clays [6]. Geologists frequently use reticulate mud cracks as indicators of this unit. It also includes more friable, pinkish to yellowish-white sands, clayey soils, and gravelly–pebbly sands found beneath the surface [7]. Discontinuous clay layers occurring at various depths characterise the weakly bedded sedimentary sequences [8]. The formation is estimated to be approximately 800 meters thick beneath Benin City and about 1,830 meters thick toward the coastal regions. Exposures of this formation can be observed in road cuttings, sand quarry sites, and erosion-prone areas. The Benin Formation covers nearly 95% of the entire region [8]. The whole area has a reddish topsoil, as shown in Figure 2. The soils are loose when dried and stick together when wet or when compacted after a long time. In the study area, water was observed settling on the topsoil surface after rainfall, as shown in Figure2.

Figure 2 – Itohan Girls' Grammar School

Supplies and Techniques. Geophysical techniques such as resistivity mapping and sounding are used to create non-destructive images of the subsurface resistivity [9]. Using collinear arrays, electrical profiling, also referred to as constant separation traversing (CST), measures lateral resistivity variations in the shallow subsurface at a relatively constant depth of investigation. Therefore, when measurements are taken along a profile at different values of n, the Wenner method produces a combined-sounding dataset. To carry out this investigation, materials such as the GPS, compass, Terameter, reel & wire, two current electrodes and two potential electrodes, measuring tapes, and several pegs were all supplied.

Schlumberger Configuration. In the Schlumberger array (Figure 3), the potential electrodes (M and N) are positioned at a fixed spacing (b), which is typically no more than one-fifth of the half-spacing (a) between the current electrodes (A and B). The operator progressively increases the distance between the current electrodes during the measurement process. When the measured voltage between M and N drops to extremely low values due to the potential gradient gradually decreasing with increasing current-electrode separation, the potential electrodes are farther apart (spacing b), and correspondingly increased. The measurements continue in this manner until the vertical electrical sounding (VES) is completed [10]. Electric current is channelled to the ground via two current electrodes inserted into the ground, and the response from the Earth is received via two potential electrodes inserted at a fixed distance from the current electrodes on the ground. Resistivity readings on the Terameter are recorded and used to estimate the apparent resistivity at various investigation points as the current electrode distance is increased successively to a fixed potential distance, achieving the target of interest. This array method helps explore the subsurface vertically downward, which is very important in geoelectric delineation.

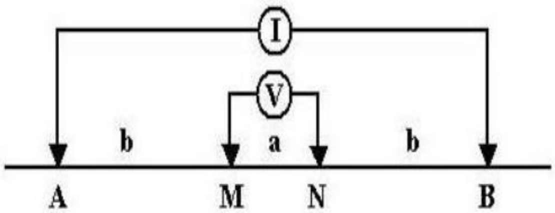
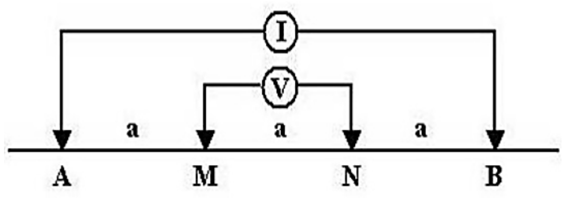


Figure 3 – Schlumberger Array Configuration [11]

Wenner Configuration. Wenner described a simple and effective method for measuring Earth's resistivity using four metallic electrodes, as illustrated in Figure 3. In this configuration, the researchers arrange the electrodes in a linear array, pass an electric current through the outer electrodes, and measure the potential difference between the inner electrodes. The apparent resistivity (ρ) of the subsurface is then calculated using the formula presented in Figure 4. During field operation, the same distance exists between the current and potential electrodes, which is increased successively after recording Earth's resistance with the Terameter at each distance. This method provides horizontal graphic details of the subsurface after effective data processing.



$$\rho_A = 2\pi\, a \frac{V}{I}$$

Figure 4 – Wenner Array Configuration [11]

where "a" is the measured distance between the subsequent metal electrodes and 2π, a constant, and V is the potential difference in volts obtained at a measured distance between the two inner metallic electrodes when current I, which is measured in amperes, is passed into the Earth. Given that V/I = R, the resistance (measured in ohms), the formula can be written as follows: ρ = 2 Π a R in (Ωm) A&B represent current electrodes, while M&N are the potential electrodes in Figure 4.

Data Acquisition and Presentation. The research team used the ABEM Terrameter SAS 1000, along with electrodes, wire reels, and a cell, to conduct a geophysical investigation of subsurface characterisation in the study area. To obtain horizontal soundings within the research region, the Wenner array configuration was employed in the field. The electrodes were spaced at 10 m, 20 m, 30 m, and 40 m intervals along a 140 m traverse. The survey data were processed using DIIPRO software, which generated a pseudosection of the apparent resistivity values. Subsequently, computer iterations were performed using the Schlumberger configuration. The research team conducted a survey consisting of four profiles distributed across the study area [12]. They used maximum electrode separations (AB/2) of 300 m, 392 m, and 600 m for VES 1, VES 2, and VES 3, respectively. They conducted VES 1 and VES 2 along traverses in the NW–SE and SE–NW directions, respectively, and carried out VES 3 in the N–S direction. The researchers focused on the geoelectric attributes of the obtained sounding results, recognising that the resistivity and thickness of the geoelectric layers play a vital role in characterising the subsurface geology at Itohan Girls Grammar School, Sapele Road, Benin City.

RESULTS AND DISCUSSION

The obtained Geophysical results from the investigation should correlate with the geology of the Benin Sand formation after examination. The acquired VES and Wenner data were presented as sounding curves, columnar sections, and 2D resistivity imaging. The researchers identified two curve types: VES 1 exhibited a K-type curve (Figure 5a), while VES 2 and VES 3 displayed A-type curves (Figures 5b and 5c). The researchers delineated four geoelectric layers within Itohan Girls Grammar School: topsoil, weathered layer, lateritic layer, and bedrock. The resistivity and thickness values of the delineated geoelectric layers reveal variations in subsurface characteristics across different sounding points [12, 13, 14].

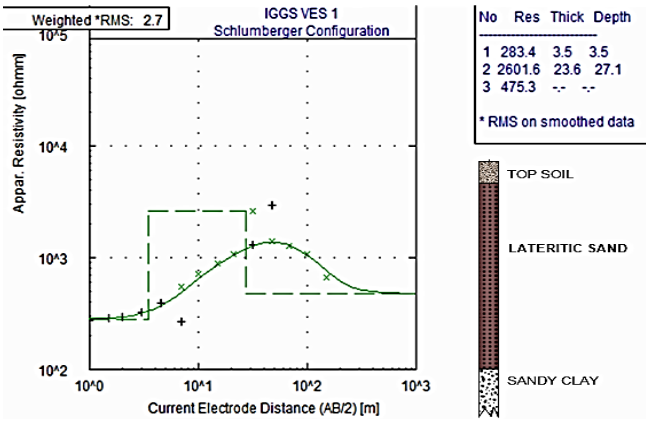


Figure 5a – Graphical Representation of VES 1 Data with Layer Model and Geologic Inference

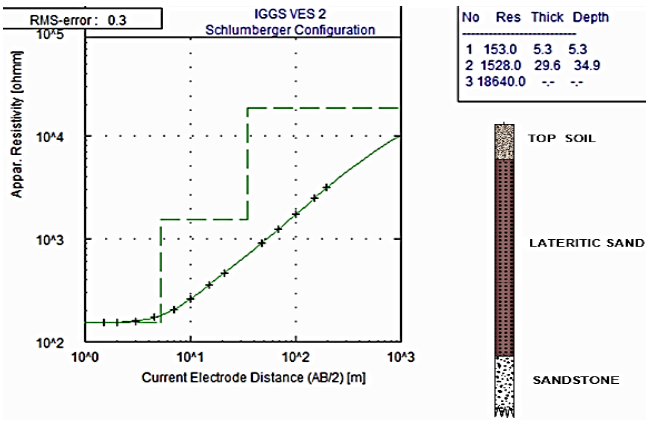


Figure 5b – Graphical representation of VES2 data with layer model and geologic inference

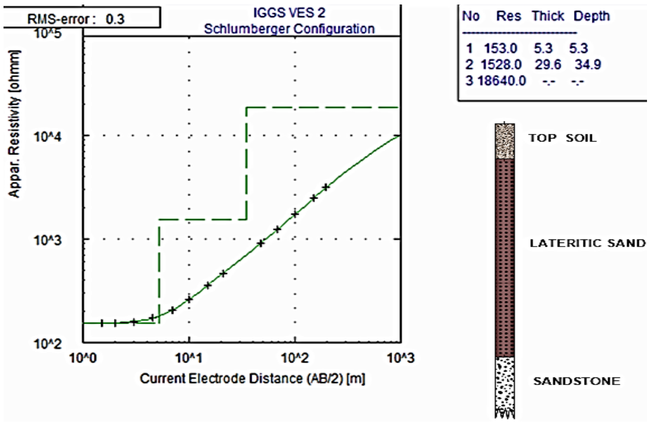


Figure 5c – Graphical Representation of VES 3 Data with Layer Model and Geologic Inference

Figure 5d below shows that the topsoil of VES 1, VES 2, and VES 3 revealed resistivity values of 283.4 Ωm, 153.0 Ωm, and 145.6 Ωm, respectively, indicating sandy clay formations with thicknesses of 3.5 m, 5.3 m, and 1.3 m, respectively. The second layers of VES 1 and VES 2 correspond to the third layer of VES 3, exhibiting high resistivity values of 2601.6 Ωm, 1528.0 Ωm, and 4600 Ωm, respectively.

These resistivity values indicate lateritic sand formations with thicknesses of 23.6 m, 29.6 m, and 11.7 m, respectively. The second layer of VES 3 has a resistivity of 87.0 Ωm, corresponding to a clayey sand formation with a thickness of 1.6 m. The basement of VES 1 consists of sandy clay with a resistivity of 475.3 Ωm. In comparison, the basements of VES 2 and VES 3 have resistivities of 18,640.0 Ωm and 100,000.0 Ωm, respectively, indicating sandstone as the bedrock.

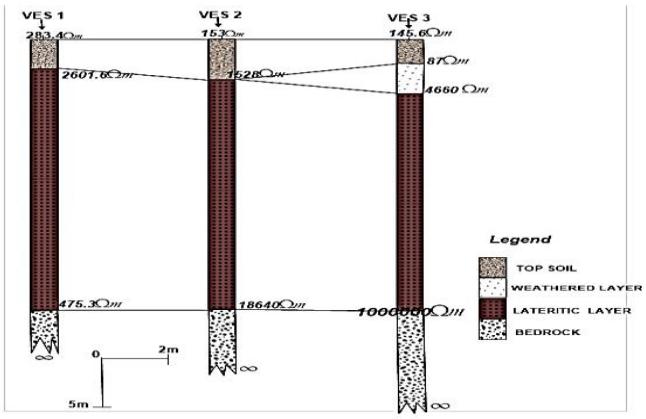


Figure 5d – Columnar Section of the VES Points

Four distinct soil formations were identified in the 2-D resistivity structure (Figure 5e) along the traverse from west to east, extending to approximately 50 meters in depth. At a depth of 10 m, the resistivity values of the 2-D resistivity structure ranged from 0.94 Ωm to 39.5 Ωm, indicating the high conductivity of the topsoil. These variations in electrical resistivity correspond to changes in mineralogical composition and water content. As the water content, degree of saturation, and dry density of lateritic soil increase, its conductivity also increases [15]. Lateritic soils exhibit several unfavourable characteristics, including uneven distribution, water sensitivity, shrinkage, and cracking [15]. Along the traverse, a consistent clayey/silty clay layer was observed between 10 m and 13.5 m below the surface. Between 13.5 m and 18 m, a significant sandy clay/sand formation was detected, with resistivity values ranging from 147 Ωm to 481 Ωm. The investigation identified a lateritic sand formation with resistivity values ranging from 482 Ωm to 1575 Ωm at depths of 18 to 25 m. Below 25 m, a sandstone formation with resistivity exceeding 1575 Ωm was identified, representing the deeper subsurface layer.

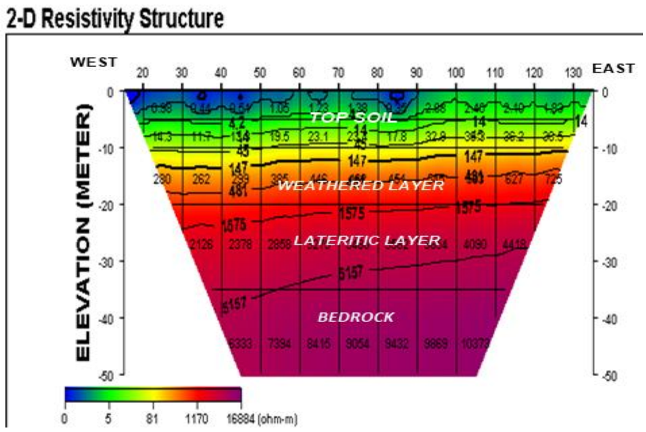


Figure 5e – 2D Resistivity Image

CONCLUSIONS

Geophysical investigation is vital when laying structures, facilities, rings, and pipes above and underground, as it provides a more straightforward guide for users to identify which subsurface areas support their interests. Our analysis describes the subsurface layers of Itohan Girls Grammar School by integrating the geoelectric characteristics from the electrical resistivity investigation with geologic information from the Benin Sand formation. The predominant soil types in the area include sandy clay, clayey sand, lateritic sand deposits, and a deeper sandstone formation. The findings indicate that the area can support hand-dug wells up to approximately 10 meters deep. Further investigation on the school premises will allow us to accurately determine the most suitable locations for borehole drilling. The subsurface conditions also suggest that the area is ideal for large and shallow engineering structures, owing to its relatively stable geological formations.

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