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Geoelectrical characterization for siting an earth dam in a basement complex terrain

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Abstract

Geoelectrical surveys were conducted at a site across river Shasha, Edunabon, Southwestern Nigeria in order to determine its suitability for an earth dam. The investigation employed Schlumberger vertical electrical sounding (VES) and dipole-dipole horizontal profiling to delineate the subsurface strata, determine depth to the bedrock and overburden thickness, and identify subsurface geological structures which might compromise structural integrity along the dam and its vicinity**.** The study area is underlain by three geoelectric layers representing the topsoil, saprolite and bedrock. The resistivity and thickness of the topsoil range from 10 Ωm to 1431 Ωm and 0.2 m to 2.7 m respectively. The saprolite is mainly clay/sandy clay with resistivity ranging from 11 Ωm to 242 Ωm and thickness varying from 0.3 m to 10.2 m. Resistivity of the bedrock ranges from 377 Ωm to 28,304 Ωm. The bedrock is shallow, at depth ranging from 1.6 m to 12.2 m. The clay-rich saprolite is suitable material for dam embankment. The suspected bedrock fractures are not extensive and may pose no threat with geotechnical remedial measures put in place, to prevent seepage and structural failure. Based on the findings above, the study area is suitable for siting an earth dam.

Keywords: Geoelectric layers, Dam embankment, Dam foundation, Bedrock fractures, Structural integrity.

1.0 Introduction

Failure of large engineering structures such as buildings, bridges and dams can be averted if adequate consideration is given to the characterization of subsurface soils and rocks in and around the locations of the facilities. Structural failure is usually caused by imbalance in foundation geomaterials and/or induced by undetected near-surface structures such as fractures, buried cavities and stream channels (Soupios *et al*. 2007, Adeoye-Oladapo and Oladapo, 2011).

Foundation failures have been attributed to differential settlement more than any other possible causes (Olorunfemi et al., 2000; Olayinka and Oyedele, 2001). The design of foundation for dam requires detailed site characterization in order to provide thorough knowledge of the subsurface geology, its structural setting and the variability of the bedrock topography and determine its feasibility for the project (Ako, 1976; Artsybashev and Aseez, 1977; Adeduro et al., 1987; Ojo *et al*., 1990; Okwueze *et al*., 1994; Aina *et al*., 1996; Ako, 2006).

Conventionally, foundation investigation involves drilling of boreholes and establishment of test pits and trenches to reveal the subsurface stratigraphy. Field (in situ) tests, such as Standard Penetration Test (SPT) and Cone Penetrometer Test (CPT) are conducted in order to determine the soil resistance to load while soil samples are collected from boreholes, test pits and trenches for geotechnical laboratory analyses. Since both in-situ and laboratory tests provide information that is localized to the immediate vicinity of the borings, detailed subsoil investigation requires high-density sampling, and is thus invasive, time-consuming and expensive.

Subsurface information devoid of these constraints can be obtained by employing geophysical methods, typical among which is the geoelectrical technique which has been extensively applied in dam site investigation due to its non-invasiveness, rapidity and cost-effectiveness. Its high degree of success in the basement complex terrain results from the significant and detectable resistivity contrast existing between the different lithologic units which constitute the underlying geology (Olorunfemi and Mesida, 1987; Aina *et al*., 1996; Olayinka and Oyedele, 2001; Ako et al., 2006). The technique provides definitive and broad picture of the subsurface faster and cheaper than other direct exploratory methods (Ako, 1976; Sharma, 2002). Fewer points may then need to be selected for geotechnical investigations most likely directed at specific targets (such as anomalous zones) and thereby significantly reduce both duration and cost of site investigation without compromising data quality. In addition, the geophysical equipment can be more easily mobilized to sites in rugged terrain, heavily forested areas, swamp and other areas than geotechnical equipment such as rigs or cone penetrometer (Monier-Williams *et al*., 1997).

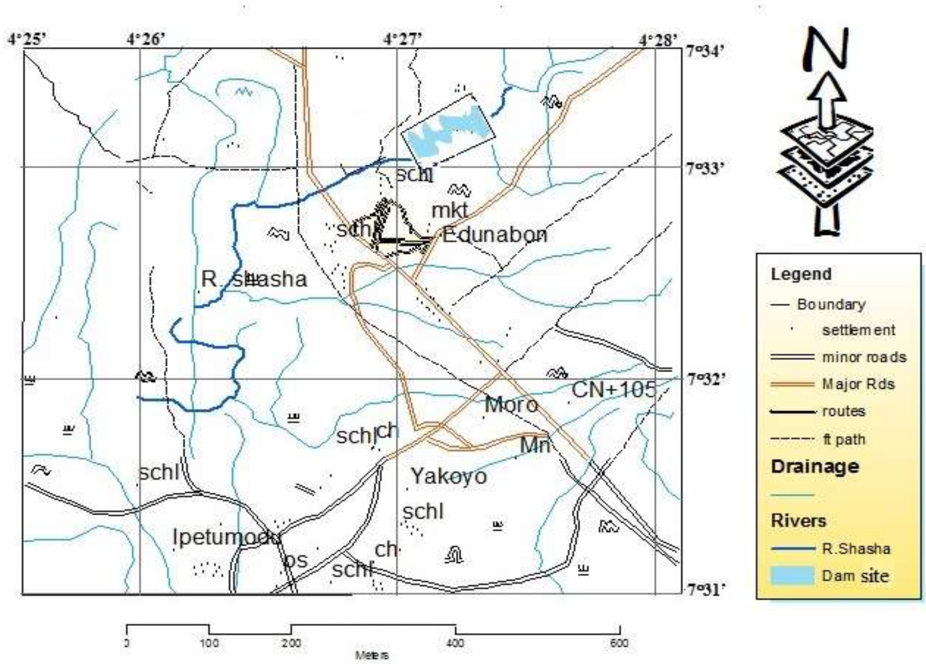
The National Water Resources Master Plan (M/P 2013) takes into account Water development plans for surface water through construction of dam/reservoir, intake facility, channel, etc. to supply safe and clean domestic water, and expand irrigated agriculture in order to meet the soaring water and food demands of the growing national population. In spite of these demands, there are only a few existing dams for water supply due to limited number of sites feasible for dam construction. Basic plans have thus been formulated for proposed dams which include the Shasha catchment region situated in the Sub-Hydrogeological Area, SHA-144 of Ogun-Osun River Basin within Hydrological Area, HA-6. It is imperative that pre-construction site investigation be carried out in order to furnish subsurface information pertinent to the dam design and construction.

Based on the afore-mentioned, geoelectrical surveys were conducted across river Shasha in Edunabon, Suthwestern Nigeria with a view to determining the suitability of the location for construction of a small earth dam. The objectives are to delineate the subsurface strata, determine the nature and thickness of the overburden, depth to the bedrock, and identify subsurface geological structures (e.g. fractures and buried cavity) which might compromise the structural integrity of the dam foundation**.** The findings of the study are expected to serve as guide in the engineering design of the dam structures for construction of safe and stable dam.

The study location is situated within Longitudes 04° 27.072′ E - 04° 27.233′E and Latitudes 07° 33.107′N - 07° 33.548′N in Ife North, Southwestern Nigeria (Fig. 1). It lies within the tropical climate of Nigeria, experiencing two rainfall seasons, one from March to July with a peak in June, followed by the "August break", and the other from September to November (Iwena, 2018). The area is underlain by rocks of Precambrian Basement complex of southwestern Nigeria (Rahaman, 1989) comprising migmatite gneiss (Fig. 2). The topography is generally undulating with elevation varying between 230m and 250m above sea level. River Shasha is one of the major rivers that discharge directly to the lagoon but there is no record that it has been dammed anywhere along its course. The choice of the proposed dam axis was made based on the confined nature of the valley (V-shape) with its steep flanks, which is suitable for large-scale water impoundment.

METHODOLOGY

The Schlunberger Vertical Electrical Sounding (VES) was conducted at eighty-seven stations occupied along five traverses comprising the proposed dam axis, two parallel axes upstream and two downstream (Fig. 3) using a resistivity meter. The half current electrode spacing (AB/2) was varied from 1 to 100 m while the station spacing ranged from 10 m to 25 m. The VES data were quantitatively interpreted using partial curve matching technique in which sounding curves were superimposed on the master curves and their corresponding auxiliary curves to obtain the starting model i.e. layer parameters in terms of resistivities and thicknesses (Orellana and Mooney, 1966). The layer parameters were then used as input for computer-aided 1D forward



`Fig.1: Location Map of the Study area

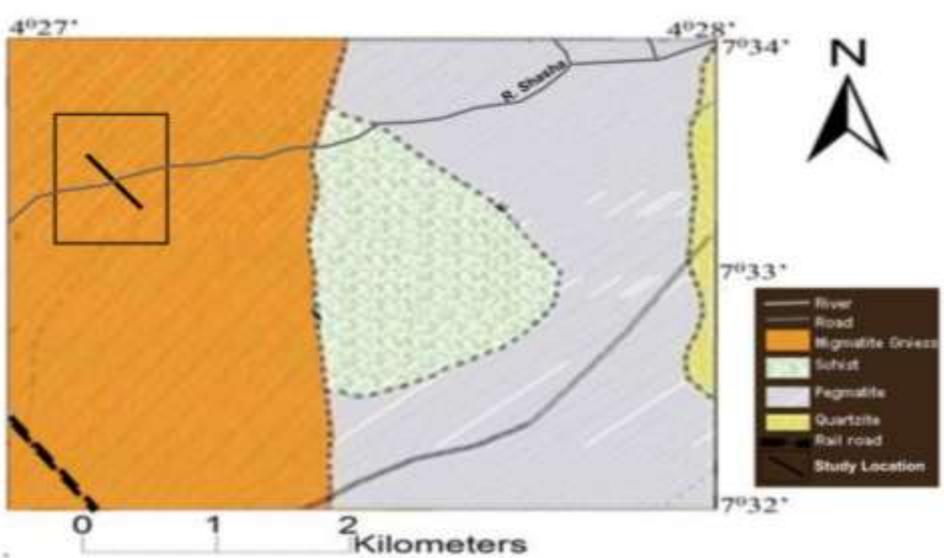


Fig. 2: Geological Map of Study area (Inset is the dam axis)

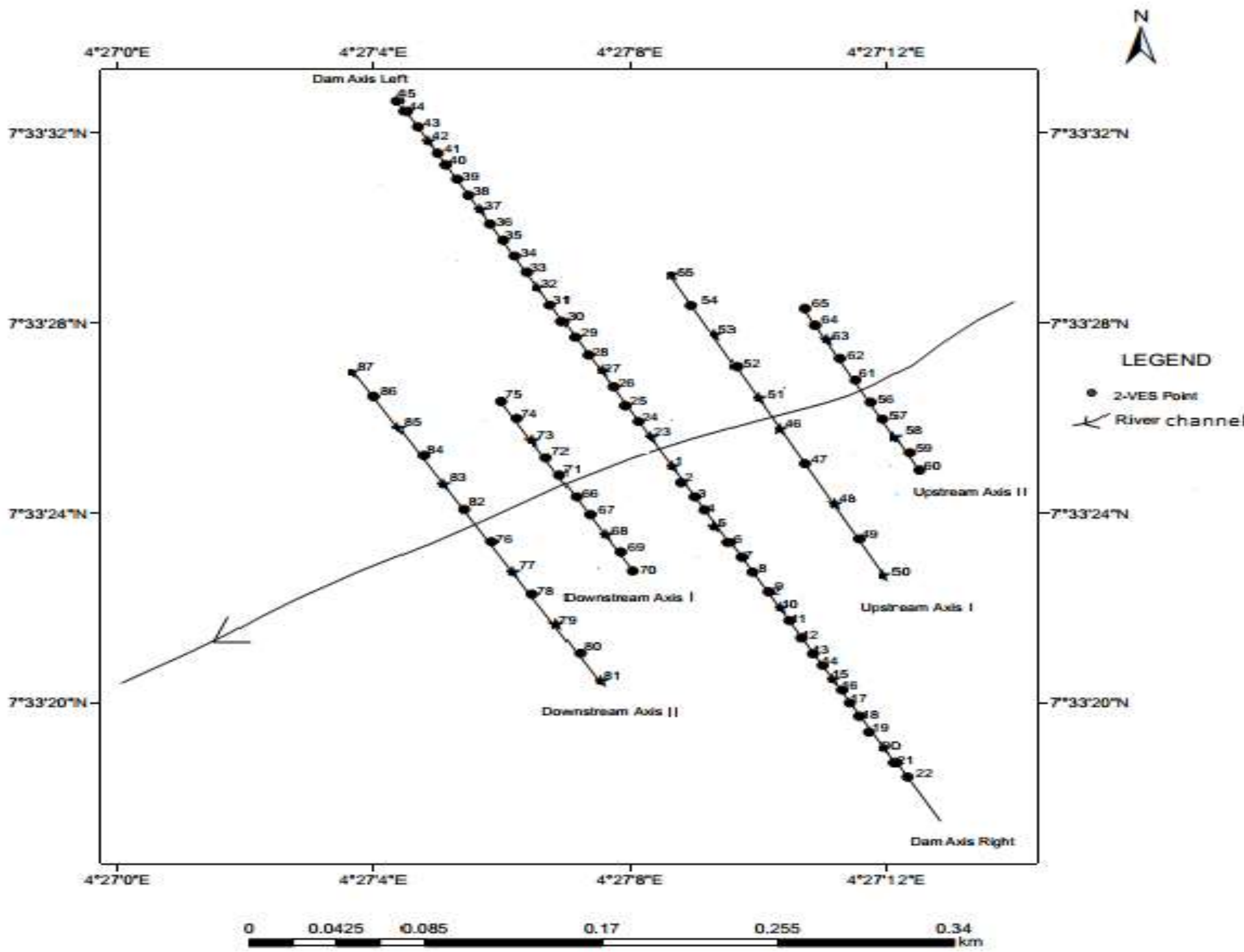


Fig. 3: Map showing VES Points along the Traverses

modeling technique (Zohdy, 1989) to determine the final model used to generate the geoelectric sections. The dipole-dipole profiling was carried out along the established axes upstream and downstream with electrode spacing a=10 m and expansion factor n=5. The data were interpreted by using 2D inversion procedures which iteratively computes the resistivity response of a two-dimensional model until a reasonable match is achieved between a theoretical pseudosection and the observed pseudosection, based on the finite element method (FEM) of modeling using a 2nd order smoothness constraint (Dey and Morrisson , 1979; Hohnmann, 1982).

Results and discussions

The results of VES interpretation reveal that the subsurface is remarkably inhomogenous in geological composition comprising mainly three geoelectrical layers namely topsoil, saprolite and bedrock. Most of the VES curves (75 out of the 87) are H-type while 9, 2 and 1 are A, KH and QKH respectively. A typical VES curve is shown in Fig. 4.

The geoelectric section beneath the dam axis (Fig. 5) shows that the topsoil has resistivity varying from 10 Ωm to 920 Ωm and is 0.2 m to 2.4 m thick. The saprolite is mainly clay/sandy clay with clayey sand beneath only VES 1, 11 and 22. The resistivity and thickness range from 28 Ωm to 600 Ωm and 1.1 m to 9.7 m respectively. The bedrock resistivity ranges from 929 Ωm to 16,870 Ωm representing fresh bedrock. The bedrock is however suspected to be fractured beneath VES 1 as the low reflection coefficient (R=0.44) at the subsoil-bedrock interface indicates. Depth to the bedrock varies from 1.8 m to 11.3 m with a mean value of 5.5 ± 2.6 m. The overburden is thicker beneath the left flank of the axis.

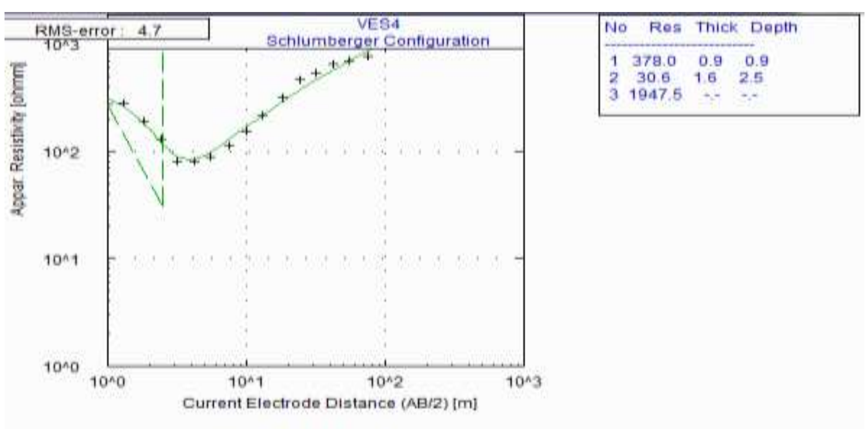


Fig.4: Typical VES curves

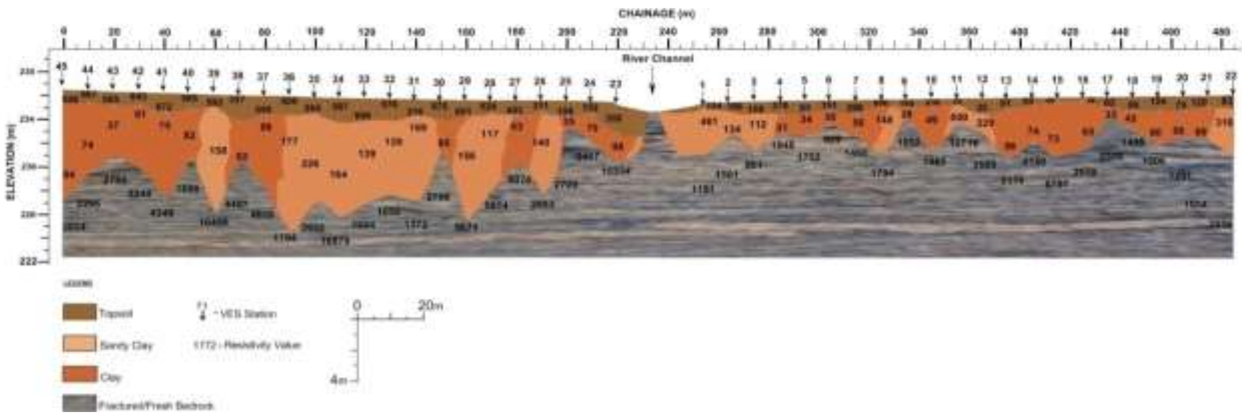


Fig. 5: Geoelectric section beneath Dam axis

The topsoil beneath Upstream I axis (Fig. 6) has resistivity values ranging from 28 Ωm to 1260 Ωm and thickness ranging from 0.8 m to 2.0 m. Resistivity of the clay/sandy clay layer ranges from 34Ωm to 235Ωm and is 0.3 m to 10.2 m thick. Bedrock resistivity varies between 980 Ωm and 25762Ωm while depth to the bedrock ranges from 1.9 m to 12.2 m.

The topsoil underlying Upstream II axis (Fig. 7) has resistivity ranging from 502 Ωm to 1431 Ωm and thickness varying from 0.4 m to 1.8 m. It is underlain by 2.2 m to 5.5 m thick clay having resistivity of 11 Ωm to 77 Ωm between VES 59 and VES 65, and lateritic hardpan about 0.6 m to 3.4 m thick, beneath VES 56-58 on the right flank. A clayey sand layer of 2.2 m thickness lies between the topsoil and lateritic hardpan beneath VES 56. The bedrock has resistivity ranging from 878 Ωm to 11203 Ωm and is apparently fractured beneath VES 56-58. Depth to the bedrock varies from 1.0 m to 8.4 m.

Downstream I axis is underlain by 0.7 m to 2.0 m thick topsoil having resistivity ranging from 46 Ωm to 1315 Ωm (Fig. 8). The saprolite is clay/sandy clay, with resistivity and thickness ranging from 11 Ωm to 234 Ωm and 0.9 m to 8.0 m respectively. The bedrock resistivity ranges from 377 Ωm to 26304 Ωm and indicating fresh bedrock while the depth to the bedrock ranges 1.6 m to 9.1 m.

The topsoil beneath Downstream II axis (Fig. 9) is 0.6 m to 2.7 m thick and has resistivity values between 22 Ωm and 524 Ωm. It is underlain by clay/sandy clay layer, 0.9 m to 6.5 m thick with resistivity ranging from 20 Ωm to 242 Ωm. Bedrock resistivity varies from 1464 Ωm to 15081 Ωm suggesting fresh bedrock while depth to the bedrock varies from 2.8 m to 7.5 m.

The 2D resistivity structures beneath the dam axis show that both flanks are underlain by an overburden composed of clay-sand mixture, generally less than 10 m thick (Fig. 10a & b) in

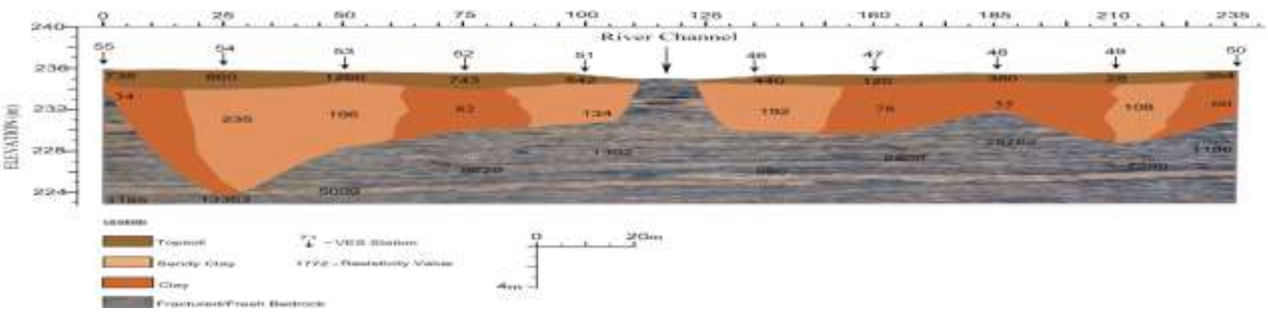


Fig. 6: Geoelectric section beneath Upstream I axis

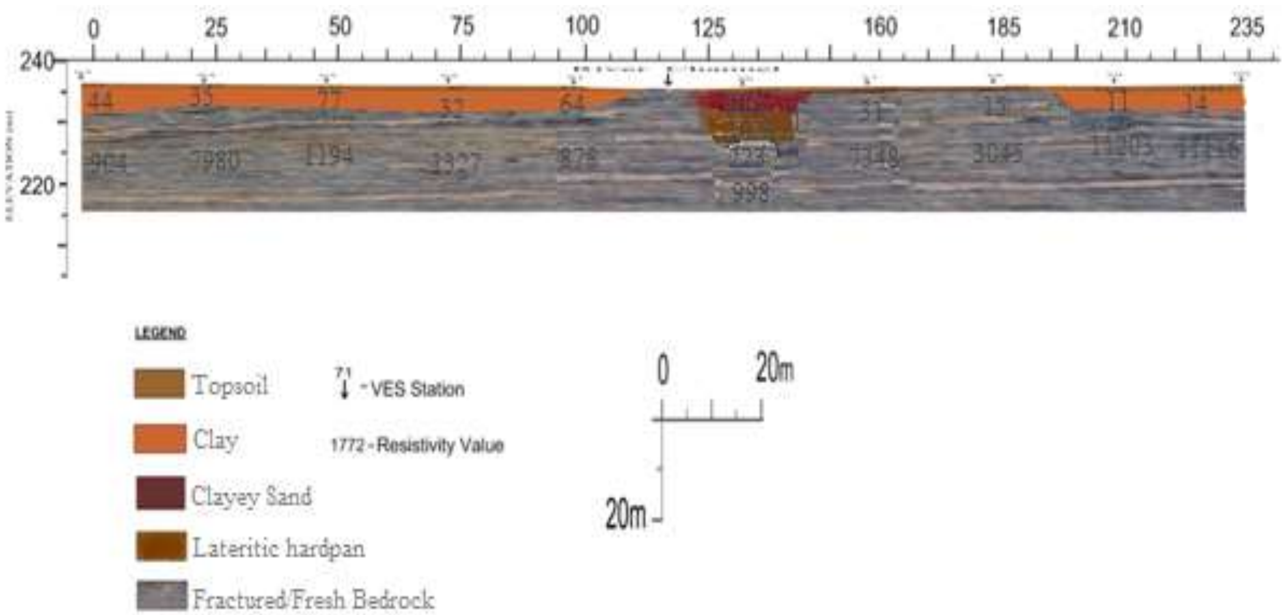


Fig. 7: Geoelectric section beneath Upstream II axis

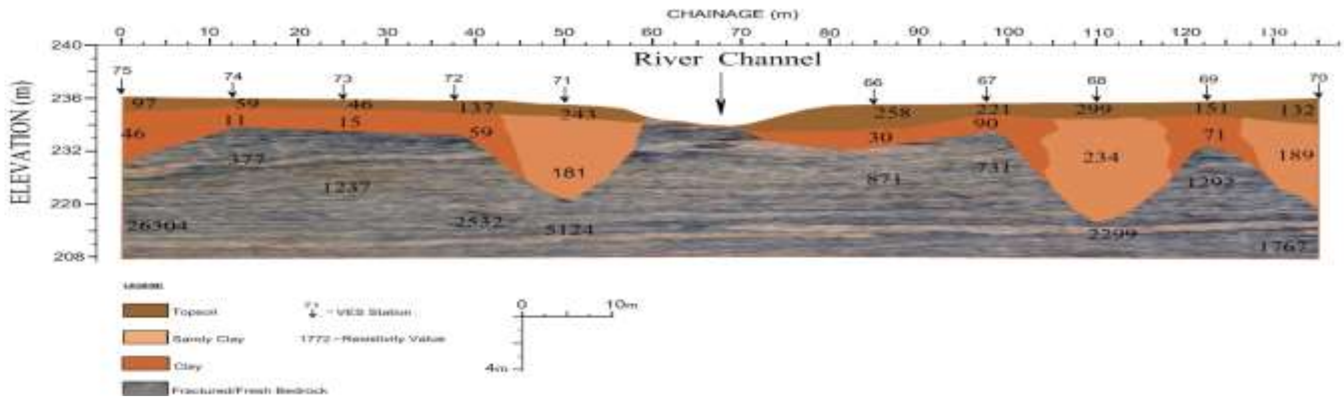


Fig. 8: Geoelectric section beneath Downstream I axis

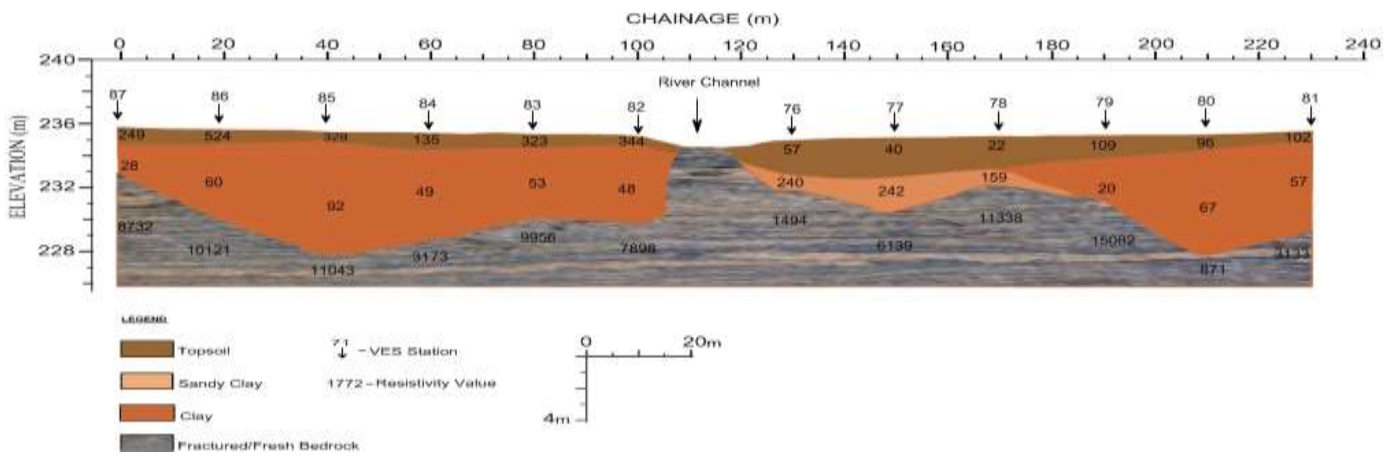


Fig. 9: Geoelectric section beneath Downstream II axis

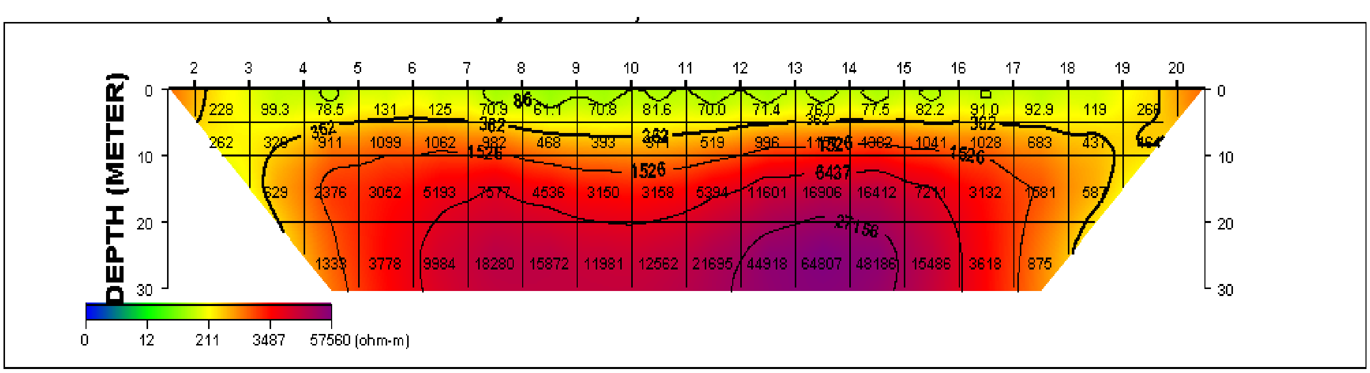


Fig. 10a: 2D Resistivity structure beneath right flank of dam axis

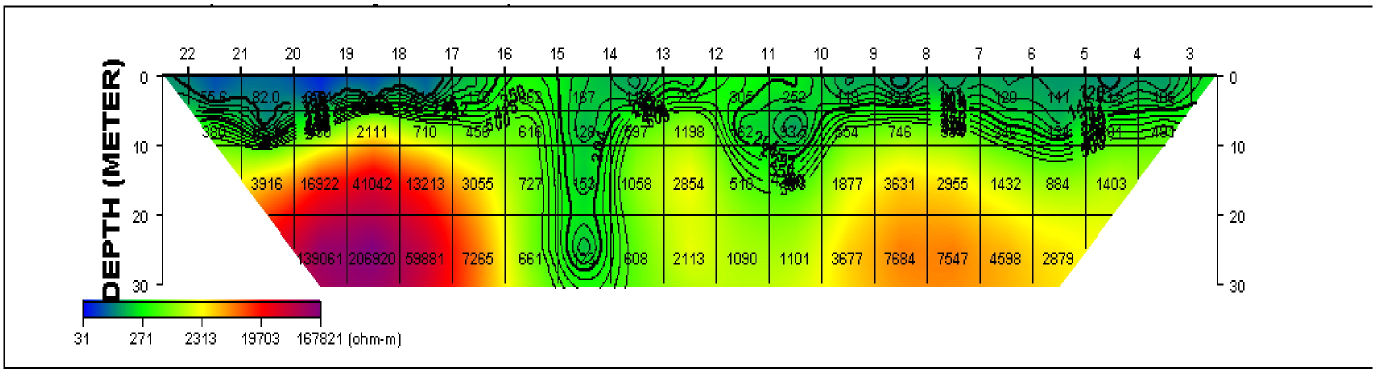


Fig. 10b: 2D Resistivity structure beneath left flank of dam axis

agreement with the VES results. The bedrock resistivity is indicative of fresh bedrock. Inversion results for both flanks of the upstream axis (Fig. 11a & b) and downstream axis (Fig. 12a &b) also reveal clayey overburden underlain by shallow bedrock.

A good earth embankment is made up of resistive caprock laid on an impervious low-resistivity clayey core or fill overlying high-resistivity competent bedrock. The saprolite beneath the dam axis constitutes 76.75% of the overburden. It is composed of clay/sandy clay which is Good/Fairly Good for dam embankment (Olorunfemi et al., 2000) and can thus be retained *in situ* as the basal material of the dam foundation after the resistive topsoil is excavated. The saprolite beneath the reservoir area is predominantly clay/sandy clay and can be excavated and used for the dam embankment. The topsoil excavated from the dam axis and reservoir area can be used to cap the clayey core of the dam embankment.

Conclusion

The study area is suitable for siting a stable and safe earth dam. The clay-rich saprolite beneath the dam axis and the upstream axis are suitable dam embankment materials while the resistive topsoil can be used as the caprock above the clayey embankment core. The suspected bedrock fractured zones require geotechnical remedial measures to prevent seepage through the dam foundation and the reservoir.

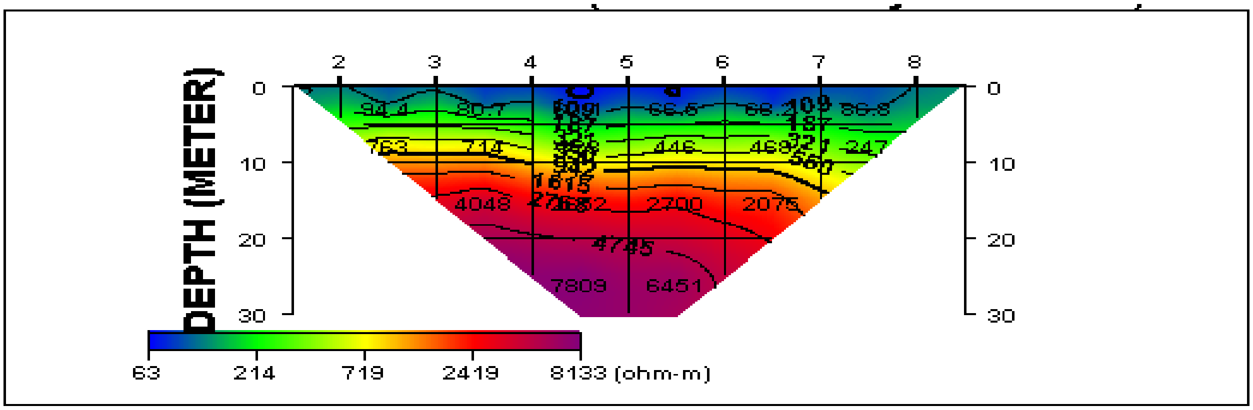


Fig. 11a: 2D Resistivity structure beneath right flank of Upstream II axis

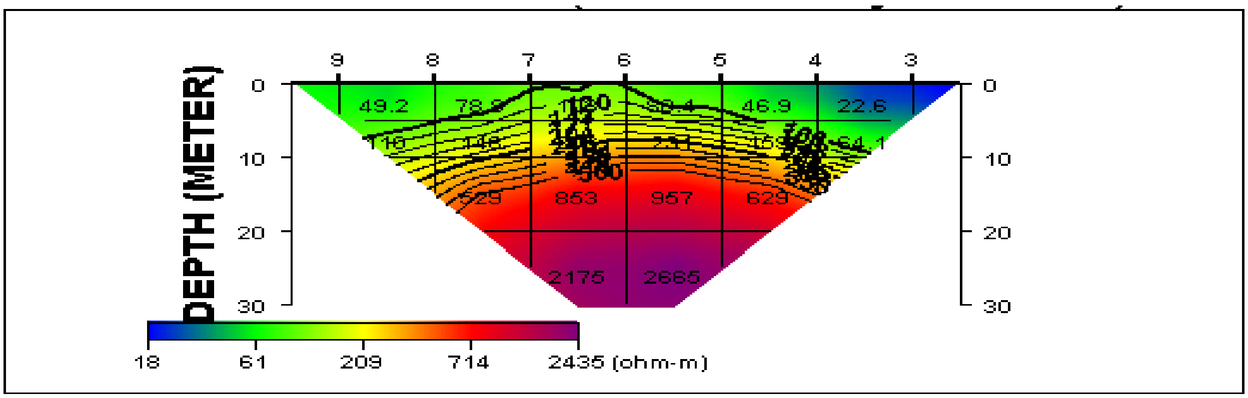


Fig. 11b: 2D Resistivity structure beneath left flank of Upstream II axis

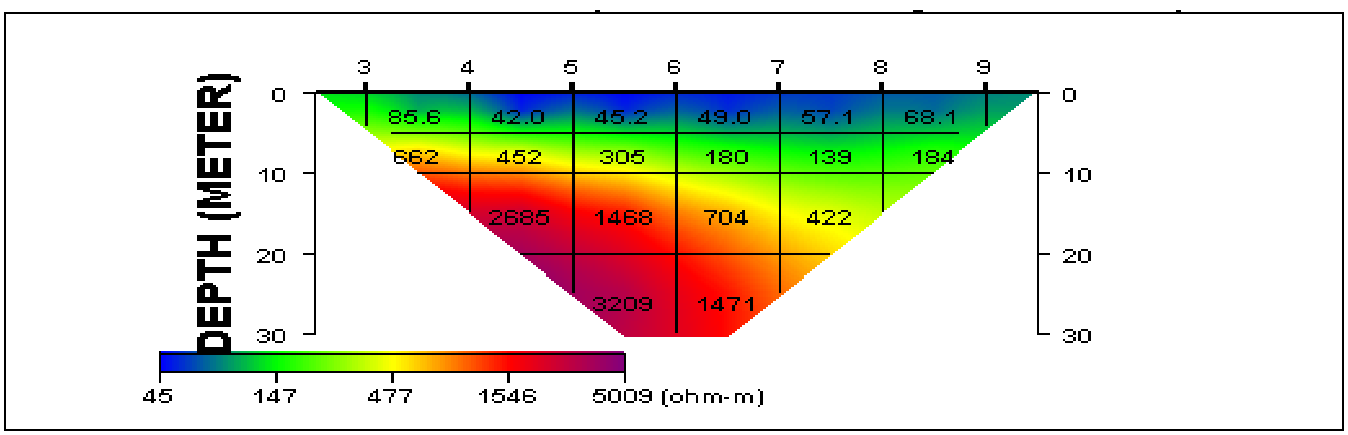


Fig. 12a: 2D Resistivity structure beneath right flank of Downstream II axis

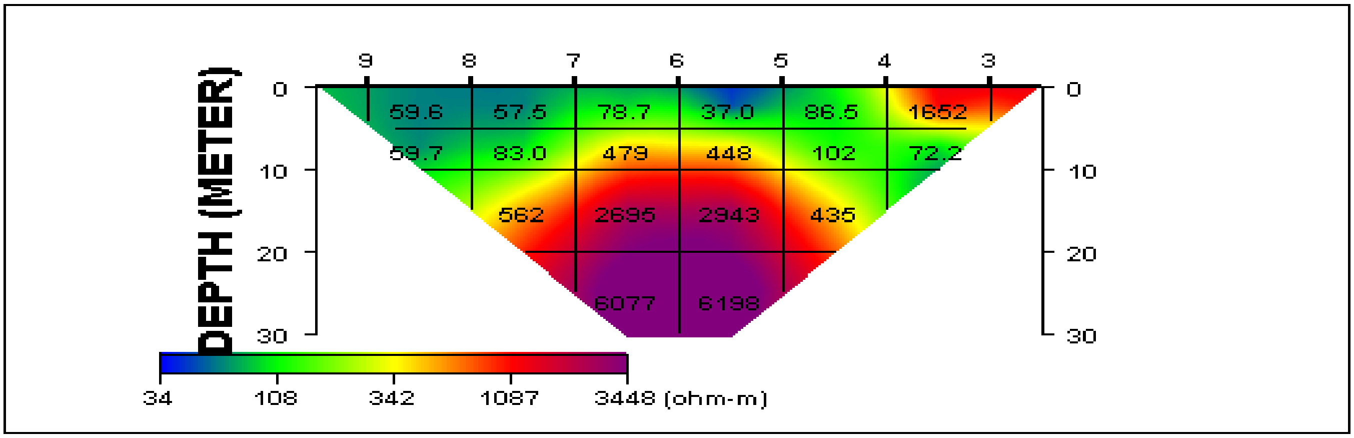


Fig. 12b: 2D Resistivity structure beneath the left flank of Downstream II axis

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