



Investigation of Dam Integrity from Electrical Resistivity Methods: A Case of Erelu Dam, Southwestern Nigeria

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Abstract - Erelu dam is geologically within the Precambrian Basement Complex of southwestern Nigeria, which serves a principal source of water supply to an increasing population; currently at about 779,318. In an attempt to investigate the integrity of the dam, horizontal resistivity profiling (HRP) of dipole-dipole and Schlumberger's vertical electrical sounding (VES) approaches were explored to delineate the lithologic layers, facies, and geologic structures in the subsurface of the dam. The HRP revealed changes in subsurface conductivity that depicts lateritic hard pan and saturated rock blankets at shallow depth. The vertical geo-electric section delineated predominant four lithologic units. The regolith is 7 m thick and constitutes the vertical rock fill impervious cores of the dam, which is underlain by saprolitic and fresh bedrock. The region of weathered rock depression coincided the shallow saturated anomalous zone and showed surface manifestation of fractured or unconsolidated terrain within the embankment. The fracture serves as conduit for seepage which could be responsible for possible loss in the reservoir water and increases its susceptibility to failure. It is recommended to keep monitoring the seepage with reservoir levels, by periodical geophysical and geotechnical measurements for the two (dry and wet) seasons.

Keywords: water supply, seepage, geologic structures, reservoir level, dam failure

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INTRODUCTION

Background

Dams are among the most important construction in civil engineering (Coduto, 1999) and are mostly designed with long life expectancy. Dam sites are often investigated to ascertain the fitness of the host earth material using geotechnical tools. Despite the pre-foundation and geotechni-

cal engineering parameters, usually it is impossible to give assurance of completely water-tight structures (Sen and Venkatesha, 1989; Panthulu *et al.*, 2001). Excessive seepage through fractured or unconsolidated terrain within embankments threatens the integrity of the structures and mostly leading to subsidence associated with dam failure (Ogliviy *et al.*, 1969; Sjö Dahl *et al.*, 2009; Di and Wang, 2010; Tabwassah and Obiefuna, 2012).

Oyo Town is an ancient urban community in Oyo State, on a land mass of 2,427 km², southwestern Nigeria. In an attempt to meet the required water supply to the dwellers, the government constructed Erelu dam in 1961, when the population of Oyo was 112,349. It is a principal source of water supply with a reservoir capacity of 10 cm³ and conventional treatment plant that produces 7.5 x 10⁶ l per day (Ufoegbune *et al.*, 2011). Consequently, the plan became ineffective since the dam can no longer serve the increasing population (about 779,318) at growth rate of 1.97% per year (UN, 2014). Water is a vital element for human activities such as municipal, agricultural, and industrial development of an area (Ademiluyi and Odugbesan, 2008; UNEP, 2010). However, the dam is a man-made structure intended for water supplies and flood control; it thus requires routine inspection and maintenance while on the contrary could result to failure that is attributable to loss of water retention (seepage losses) or even loss of life and properties. Leakage through a reservoir wall that exceeds the design range may create serious problems, threatening the stability of the reservoir. This study aims at establishing geological features which directly influence the design of dams and control the character of the foundation; using electrical resistivity approach of geophysical prospecting.

In geophysical prospecting, information on the subsurface lithology and their thicknesses identify the competent bedrock and determines depths to its upper interface (Aina *et al.*, 1996; Soupois *et al.*, 2007). Compact subsoil is characterized by reduced porosity and moisture content with consequent increase in resistivity, while precipitated weak zones in the basement and discontinuities in the structures damage the dam gate. Electrical resistivity measurement is a suitable geophysical tool to evaluate subsoil competence through the determination of structural and stratigraphic features (Olasunkanmi *et al.*, 2011). It is a non-destructive, cost-effective, and rapid measurement of soil electrical properties, and serves as alternative to standard penetration test (SPT)

method in investigating geotechnical parameters of earth material (Panthulu *et al.*, 2001; Sjudahl *et al.*, 2008; Baharom and Fahad, 2012).

Geology of the Area

Erelu dam is located at about 6.4 km northwest of Oyo Town, southwestern Nigeria on an impoundment area of 1.61 km² and catchment area of 243.36 km². It is a gravity dam built on River Awon (Figure 1). It lies within latitude 7°53'0" - 7°55'30"N and longitude 3°53'30" - 3°56'0"E. The area is well drained by River Awon jointly with tributary streams such as Iwon, Ilaka, and Oriko; flowing east-westward and follows the topography to form a dendritic drainage pattern (Figure 2). The dam is located in a tropical savannah climate with two distinct seasons, wet and dry within April to October and November to March respectively (Iloje, 1981). The studied area is geologically within the Precambrian Basement Complex of southwestern Nigeria comprising undifferentiated Migmatite-Gneiss Complex, schist, and quartz (Figure 3). The rocks of the Precambrian Basement Complex have been extensively studied by Oyawoye (1964), Odeyemi (1981), Rahaman (1976, 1988), and others. The quartzites are generally massive occurring as NW-SE trending elongated ridges crosscutting the predominant migmatite. The schistose quartzites occur within the southern region of the area hosting micaceous minerals alternating with quartzose-feldspathic ones. The dam site is situated within the migmatite in the northwestern part of the area.

MATERIALS AND METHODS

Electrical Resistivity Method

Electrical resistivity methods have proven useful and broadly used in engineering applications. It is mainly applied in direct detection of geological features at varying depths (Bhattacharya and Patra, 1966; Butler and Llopis, 1990; Oglivy *et al.*, 1999; Panthulu *et al.*, 2001). Brittle geological features such fracture

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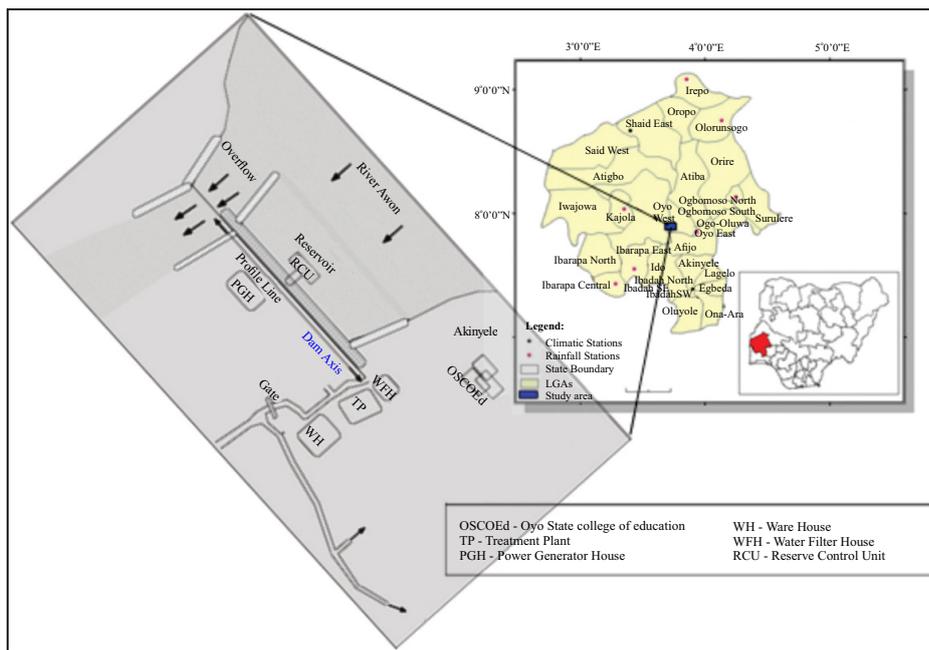


Figure 1. Map of Erelu dam (inset maps of Oyo and Nigeria).

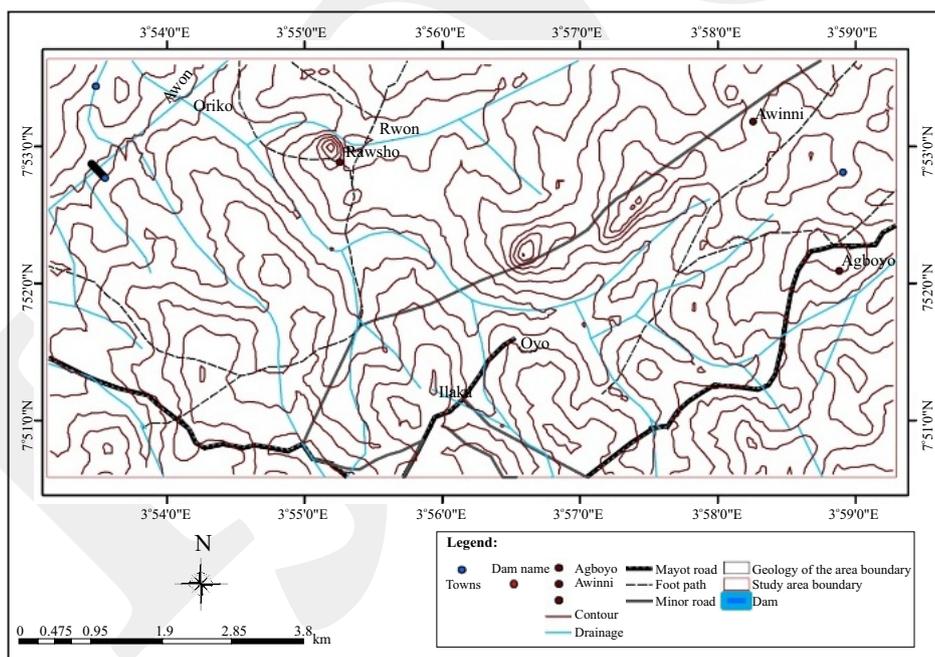


Figure 2. Topographic map of Oyo Town showing Erelu dam.

and other weak zones or occurrences of clay or weathered materials are associated with low resistivity anomalies and serve as potential conduits for seepage. In attempting to investigate the subsurface geologic parameters (such as porosity and degree of water saturation in the bedrock) associated with resistivity distribution

within Erelu dam axis, horizontal/lateral and vertical electrical measurements on the ground surface were employed.

Lateral and Horizontal Profiling

The lateral and horizontal profilings involved Wenner and dipole-dipole approaches, which

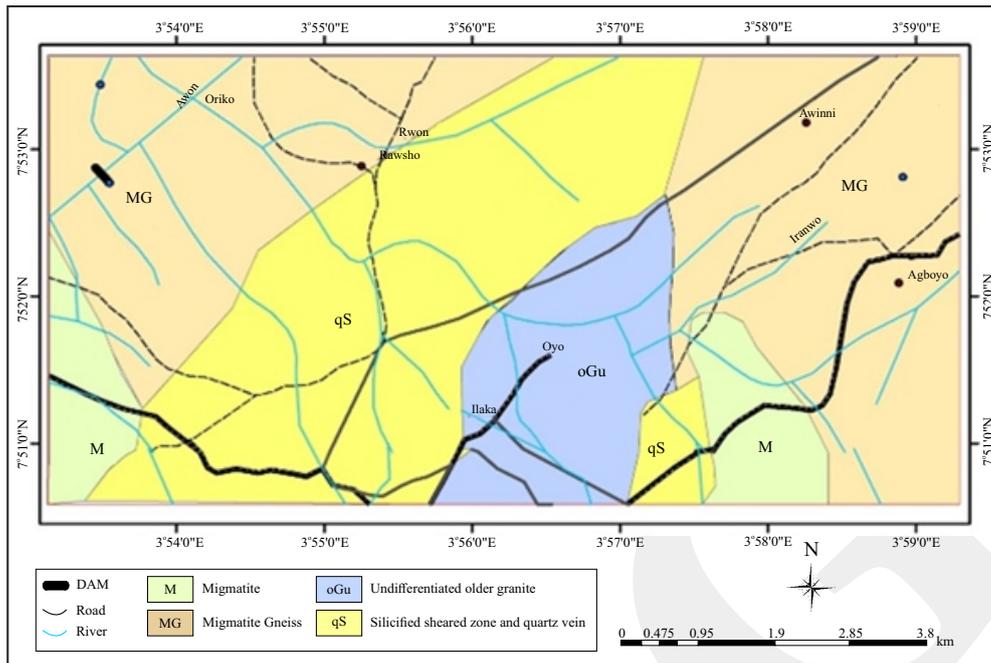


Figure 3. Geology map of Oyo Town showing Erelu dam.

use collinear symmetrical four electrode arrays (Sharma 1986; Griffiths and Barker, 1993). Dipole-dipole has low electromagnetic coupling between the current and potential circuits and it is most sensitive to resistivity changes between the electrodes in each dipole pair. It is suitable in mapping vertical structures, such as dykes and cavities, but relatively poor in mapping horizontal structures such as sills or sedimentary layers, while Wenner array configuration complements the horizontal structures since it is less sensitive to horizontal changes in the subsurface resistivity (Keller and Frischknecht, 1966; Loke, 1999).

Wenner array data acquisition procedure along the dam axis involved driving the electrodes into the ground at constant spacing of 30 m and subsequently moved at 5 m interval; covering a profile length of 260 m. A corresponding dipole-dipole array were configured along the profile using inter-electrode spacing of 5 m, and inter dipole separation factor varied from 1 to 5. The potential differences across the two current electrodes were estimated and the corresponding resistance ‘R’ values were recorded on R-50 resistivity meter instrument. The estimated resistance was inserted

into Equation 1 in order to obtain the apparent resistivity,

$$\rho_a = kR \dots\dots\dots (1)$$

where ‘k’ is the geometric factor determined by the distances between the electrodes.

The data were recorded on Microsoft Office Excel worksheet used for horizontal resistivity-distance plots. The apparent resistivity-distance plot of Wenner configuration is depicted in Figure 4a. The dipole-dipole resistivity data were processed using Geosoft DIPROwin 2D inversion software and the equivalent two dimensional pseudo-section plots of the raw real data. Theoretical and near vertical geo-electric sequences are as represented in Figures 4b, 4c, and 4d respectively.

Vertical Electrical Sounding

Although dipole-dipole data provide information on the depth of an anomaly (Keller and Frischknecht, 1966), yet the depth were complemented with the depth parameters obtained from vertical electrical sounding (VES). The Schlum-

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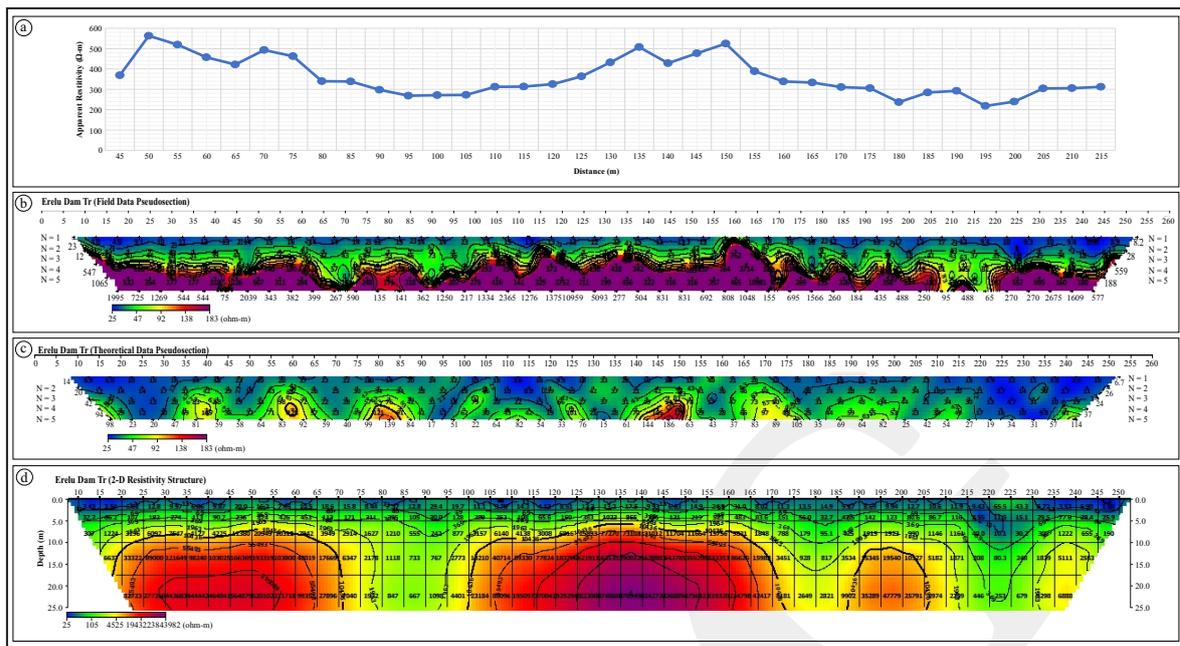


Figure 4. Geo-electric pseudosections along Erelu dam. (a) Wenner lateral profile; (b) Horizontal virtual resistivity; (c) Imaginary resistivity data; and (d) 2-D resistivity structure.

berger array technique for electrical probing was used to acquire resistivity distribution at carefully selected seven anomalous zones on resistivity profiling and at varying depth; using the configuration of Barker *et al.* (1996) and Reynolds (2000). The VES traverses were established E-W with half current electrode probe range from 1 to 100 m, while the apparent resistivities ' ρ_a ' for the configuration were estimated using the geometrical factor 'k', obtainable in Equation 1 but dependent on the distances between the adjacent electrodes (Barker *et al.*, 1996; Reynolds, 2000). Corresponding sounding curves of each point were obtained by plotting the apparent resistivity on the ordinate against half current-electrode spacing on a bilogarithmic transparent paper. The curves were matched with two-layer-master curves and interpreted using auxiliary charts. The possible errors in the geoelectric parameters from manually generated curves were corrected using computer iteration on WinResist software based upon the algorithm of Vander Velpen (2004), and the resulting geoelectric series and corresponding depths are represented in Figure 5. The contrasting resistivity models were correlated with standard range of expected resistivities for common

rock types using the standard of Palacky (1989) and were used to construct lithologic sections.

RESULTS AND ANALYSIS

Horizontal Earth Model

The lateral apparent resistivity contrast along the dam axis enabled qualitative interpretation of linear geologic features and possible depth of occurrences. The response varied within 218 to 563 Ωm (Figure 4a) showing low resistive to moderately high resistive topsoil. Figures 4b and 4c present the real and imaginary resistivity component responses of the dipole-dipole configuration showing changes in subsurface conductivity along the profile at shallow depth. The equivalent 2D model of the resistivity distribution (Figure 4d) revealed the topsoil as underlain with rock fill impervious cores at distance within 0 to 85 m and 95 to 215 m; covering the dam extent. The region of low resistivity constituent at distance around 86 to 94 m corresponds possible penetrative weak zone or cut-off trenches due to slightly weathering rocks. It is attributable to possible upstream clay blankets which could have been considered

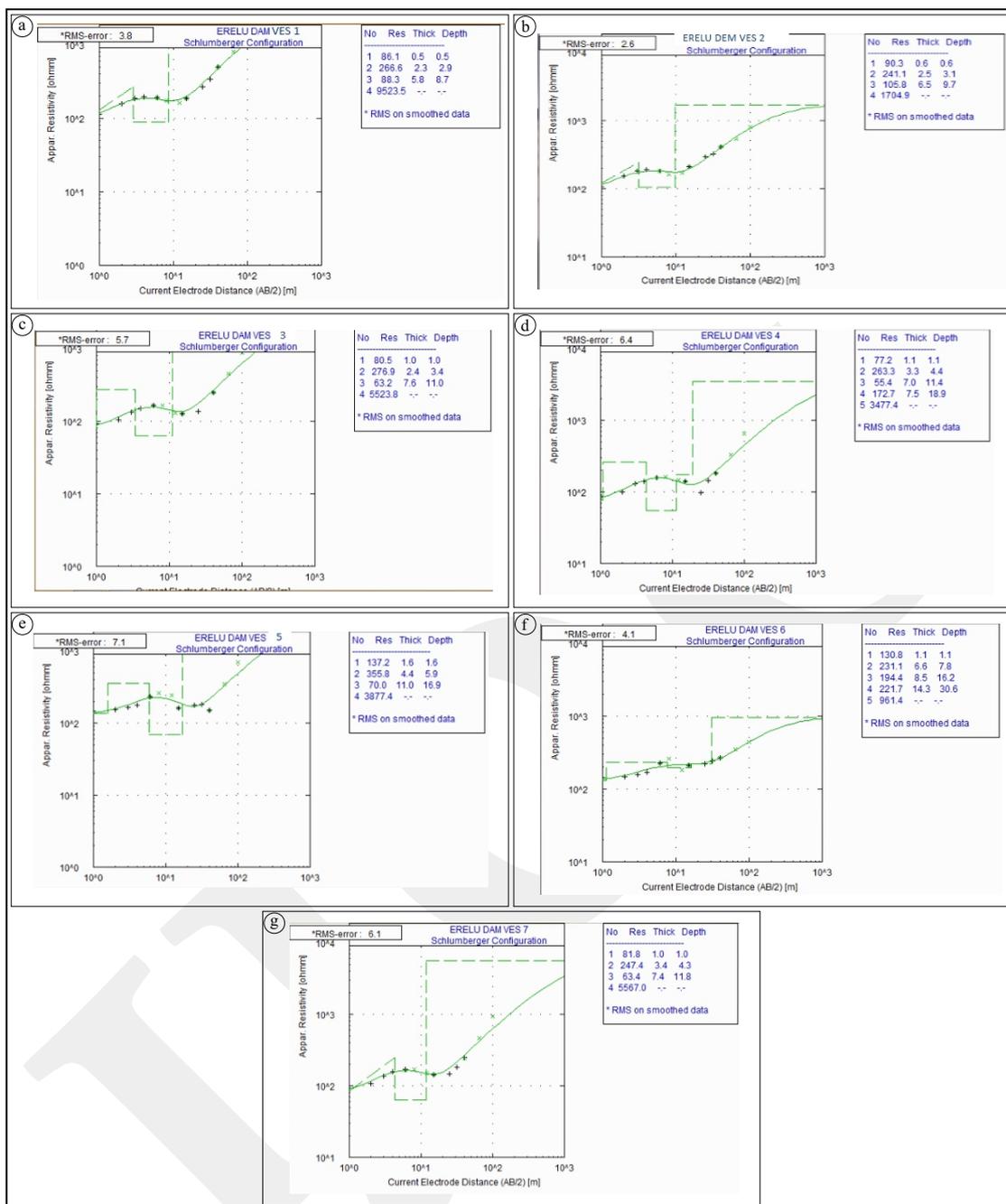


Figure 5. Results from computerized sounding curve interpretation, the estimated geo-electric parameters and depths estimate. (a) VES 1; (b) VES 2; (c) VES 3; (d) VES 4; (e) VES 5; (f) VES 6; and (g) VES 7.

during construction design. The vertical electrical sounding (VES) curves (Figure 5) corroborated the inhomogeneity in the subsurface sequence along the profile.

Vertical Goelectric Sequence

Vertical variation of resistivities within a particular volume of the earth and sequence of

electrical horizon are revealed with 2D geo-electric sections of the results obtained from interpreted VES curves. The sections are characterized by the thickness of the layers and true resistivity, which is a revelation of the lateral and vertical facie changes inferred from the apparent resistivity pseudosection. The curves of VES 1, VES 2, VES 3, VES 5, and VES 7 revealed

prominent four layers (conductive, resistive, conductive, resistive) model attributable to four lithologic units viz: topsoil, impervious cores, weak or slightly weathering, and fresh basement. VES 4 and VES 6 show five-layer earth (conductive, resistive, conductive, resistive, resistive) materials which revealed vertically continuous basement complex rocks beneath the area. VESs 4 and 6 correspond the anomalous zones on the horizontal profiling at distances around 86 to 94 m and 175 to 185 m. The proportion of the earth models is represented in a pie chat (Figure 6) while the geo-electric characteristics of the apparent resistivity curves are depicted in Tables 1 and 2.

A maximum of five subsurface geo-electric units were delineated beneath the traverse. How-

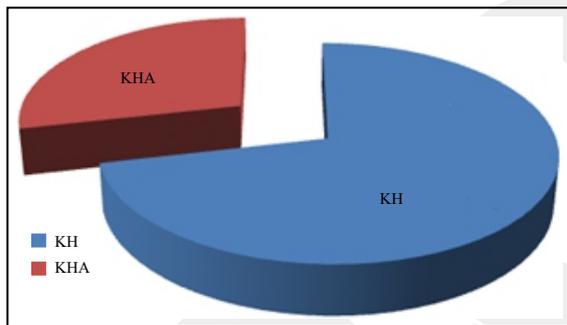


Figure 6. Pie chart illustrations of apparent resistivity curves along Erelu dam.

ever, the prominent four layered earth model correspond KH-type curves, while the five layer models depict KHA-type curve (Figure 5). The geo-electric section (Figure 7) showed no discrete variation in resistivity of 55 to 356 Ωm forming the regolith at estimated depth range 0.5 to 7 m which correspond the vertical extent of the dam floor. The first layers indicate resistivity distribution within 81 to 157 Ωm which depict sandy topsoil; with VES 4 has the most conductive topsoil constituent, while VES 5 possesses the relatively most resistive or less conductive lateritic hard pan cover that is 1.6 m thick. The second layer revealed impermeable rock fill having resistivity contrast 241 to 356 Ωm and at depth range of 2.8 to 6.0 m.

It is underlain by 5.8 to 11.0 m - thick saprolitic rock having resistivity range of 63 to 106 Ωm , and fresh basement rock having high resistivity range of 1705 to 9524 Ωm at 11 m downward. The five-layer parameters only accentuate the unconsolidated bedrock depicted in the KH-type curves. The region of weathered rock constituent at deeper depth range of 18.9 - 30.6 m beneath VESs 4 and 6 corresponds the anomalous region of horizontal profiling and shows the signature of weathered bedrock/fracture having surface manifestation.

Table 1. Layering Parameter Range and Geo-electric Characteristic of KH-type Apparent Resistivity Curves Obtained along Erelu Dam

Layer	Resistivity Range (Ωm)	Thickness Range (m)	Probable lithology
1	81 - 157	0.5 - 1.6	Topsoil
2	241 - 356	2.8 - 6.0	Hard rock fill
3	63 - 106	8.7 - 11.8	Weathered basement
4	1705 - 9524	-	Fresh bedrock

Table 2. Layering Parameter Range and Geo-electric Characteristic of KHA-type Apparent Resistivity Curves Obtained along Erelu Dam

Layer	Resistivity Range (Ωm)	Thickness Range (m)	Probable lithology
1	77 - 131	1.1	Topsoil
2	231 - 263	4.4 - 7.8	Hard rock fill
3	55 - 194	11.4 - 16.2	Weathered basement
4	173 - 222	18.9 - 30.6	Weathered/Fractured bedrock
5	961 - 3477	--	Fresh bedrock

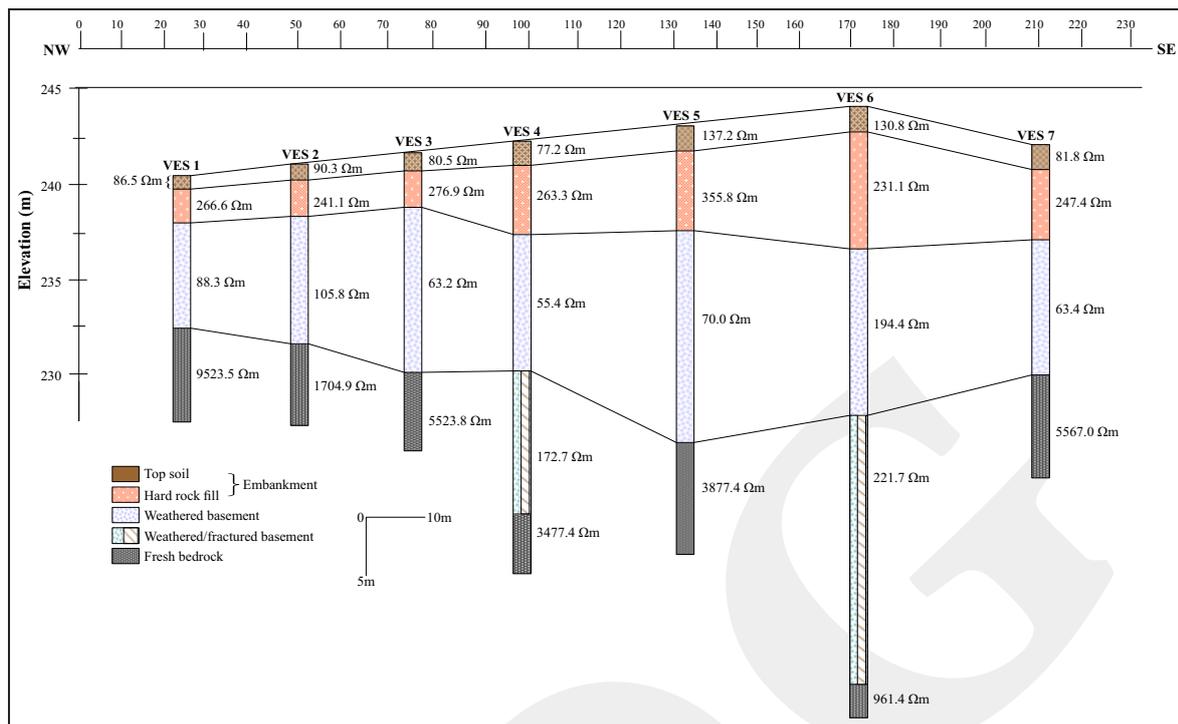


Figure 7. Geo-electric section of the dam axis, showing the lithologic sequence and equivalent electrical resistivity parameters.

CONCLUSIONS

Electrical resistivity approach has been used to establish the lithologic layers, facies, and geologic structures in the subsurface of Erelu dam within the basement complex of southwestern Nigeria. The horizontal resistivity profiling along the dam axis revealed changes in subsurface conductivity that depicted the lateritic hard pan and saturated rock blankets at shallow depth. The vertical geo-electric section delineated predominant four lithologic units. The regolith is 7 m thick and constitutes the vertical rock fill impervious cores of the dam; which is underlined by saprolitic and fresh bedrock. The region of weathered rock depression coincided the shallow saturated anomalous zone and showed surface manifestation of fractured or unconsolidated terrain within the embankment. The fracture serves as a conduit for seepage which could be responsible for possible loss in the reservoir water and increases its susceptibility to failure. However, periodic (dry and wet seasons) geophysical and geotechnical measurements are recommended in order to monitor the seepage with reservoir levels.

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