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APPLICATION OF ELECTRICAL RESISTIVITY METHOD FOR SAFETY EVALUATION OF ASEJIRE DAM IBADAN, SOUTHWESTERN NIGERIA

[1]Oladejo, Olagoke Peter, *[2]Ogunkoya, Charles Olubunmi, [2]Fasiku, Taiwo Bukola and [3]Olanrewaju, Surat Alaba

[1]Department of Physical Sciences Education, Emmanuel Alayande University of Education, P.M.B 1010 Oyo, Oyo State Southwestern Nigeria
[2]Department of Physics, Ajayi Crowther University, P.M.B 1066, Oyo Town, Oyo State, Southwestern Nigeria.
[3]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

*Corresponding authors' email: co.ogunkoya@acu.edu.ng

ABSTRACT

Dam construction provides economic importance to the environs through, water supply and flood control. Post-construction investigation is however necessary for maintenance stability to avoid irreversible environmental changes. In view of this, horizontal resistivity profiling and vertical electrical sounding (VES) were conducted along the embankments and the downstream of Asejire dam to determine its integrity. The methods used were horizontal resistivity profiling and vertical electrical soundings conducted along the embankments and the downstream. Thirty-one VES and Dipole-Dipole Profiling were occupied along the embankments and downstream using Resistivity meter at 20 m intervals for both the VES and Dipole-Dipole. The Dipole-Dipole data were inverted into 2-D Resistivity Images using DIPPRO™ 4.0 Inversion Software while the VES data were quantitatively interpreted using the partial curve matching technique and Winresist 1.0 Version Software. Results of dipole-dipole image and geo-electric section identified three geo-electric layers; comprising topsoil presumably clayey sand and laterites with resistivity and thickness between 59-760Ωm and 0.7-5.2m respectively. The second layer is weathered layer attributed with clay/clayey sand having resistivity and thickness 18-766Ωm and 3.1-36.7 m. The third layer suspected to be fresh bedrock with resistivity range 121-3672Ωm and 18-766 m thick. The Dipole-Dipole results displayed resistivity less than 500Ωm in the first layer with structural evidence of discontinuous observables, but the underlying sequences displayed no indicative of structural weakness. This significant features play a major role in seepage processes from the dam, therefore lithological composition obtained from these results shows the dam has a good integrity.

Keywords: Dam safety, Embankment, Resistivity, Asejire dam, Electromagnetic, Vertical Electrical Soundings, Resistivity method

INTRODUCTION

A dam is a wall of solid material built across a river to block the flow of water, it creates a permanent water supply for irrigation and community to use (Ahmed and El-akhakhni 2023; Ibeneme et al., 2014). Dam must be an enclosure so that is safe and stops water from escaping downstream and the walls must be strong enough to resist water pressure (De Villers, 2000). The higher the dam, the greater the depth of water stored behind it, and the greater the water pressure on the dam wall. Construction of dams can cause irreversible environmental changes with a significant impact on the host communities (Scudder, (1997). There have been several criticism about dam construction because the merits of the dam does not outweighed environmental and economic costs, also the neighboring communities is believed to reap the least benefits (Oyedotun, 2021; Williams, 1991; Farradas, 1998; Reisner, 2003; Pearce, 2003). Although some are of the opinion that economic and environmental cost can still be minimized to the nearest minimum (Oyedotun 2021; Barrow, 1981; De Villers, 2000). The direct environmental impact on the host communities are erosion, dust, human population and vegetation through flooding (Ludwig, 1982; Goodland, 1986). However the general advantage of Asejire dam is often accrue to distant residents and agricultural interests while the inhabitants of the host communities bear the heavy environmental and socio economic degradation of the dam (Oyedotun 2021).

However some dams have caused various damages to their host communities and the failure may be attributed to poor understanding of subsurface geology, presence of anomalous seepage, poor maintenance among others. Therefore post-construction investigation of dam must be carried out from time to time in order to look out for possible breach or damage in the dam structure.

Dam as one of the containment structures that provide water among many other merits to the populace, but if abandoned, it can pose the risk of property damage, reconstruction cost, loss of life and properties to the neighboring communities. However the use electrical resistivity method in geophysical techniques around the dam can determine the integrity of the dam through provision of information about the internal structure, seepage among others.

Generally, electrical resistivity methods have been used by various researchers in different areas such as overburden character determination, subsurface geological sequence delineation, determining different layers of geo-electric parameters, and variation in subsurface lithology that might lead to structural failure in the dam (Ibeneme et al., 2014; Olatunji et al., 2017). It has also been applied in during dam-site feasibility studies involving foundation investigation, geological and structural mapping of both embankment and reservoir floor (Pedro and Cesar 2017). Recently the methods have also been applied during and after the construction phase of the dam (Olasunkanmi et al., 2021; Slimark, and N. Djordjevic 1987; Butler et al., 1989).

Electrical Resistivity Methods is the geophysical method used in dam embankment investigation because this method is very fast, easy and cost efficient in studying embankment conditions. Resistivity measurements may have the possibility of detecting internal erosion processes and anomalous seepage zone at an early stage before the safety of the dam is at stake (Magawata et al., 2020; Sjodhal 2005).

On this basis, Electrical resistivity surveys involving both vertical electrical sounding (VES) using the Schlumberger Array and 2-D resistivity imaging using the dipole-dipole array were carried out along the embankment and the downstream of Asejire dam, Ibadan, Southwestern Nigeria in order to determine the integrity of the dam in its present state through the determination of geo-electric parameters of the subsurface layers, mapping the lateral and vertical variation in the subsurface strata at the dam site, determine the subsurface lithological units beneath the embankments, downstream and identify the possible seepage zone within the embankment.

Study Area

The study area is located in Asejire town about 30 km east of Ibadan. It lies within Latitude 7°21.5’ N - 7°22’ N and Longitude 4° 07.68’ E - 4° 08.26’ E. Asejire dam is an earth and rock fill embankment dam built in the late 1960s to impound River Osun to provide water for the Asejire and Osegere water treatment plants in Ibadan. The dam embankment is about 818 m long while the dam crest elevation of about 159.4 m. The dam has a capacity of about 8 million litres per day, 80% of which is used for domestic purposes (Oladimeji and Olaosebikan 2017). The area is mainly accessible by foot path and vehicle. The location map of the study location is presented in figure 1 and figure 2 displayed the field Layout at the study area.

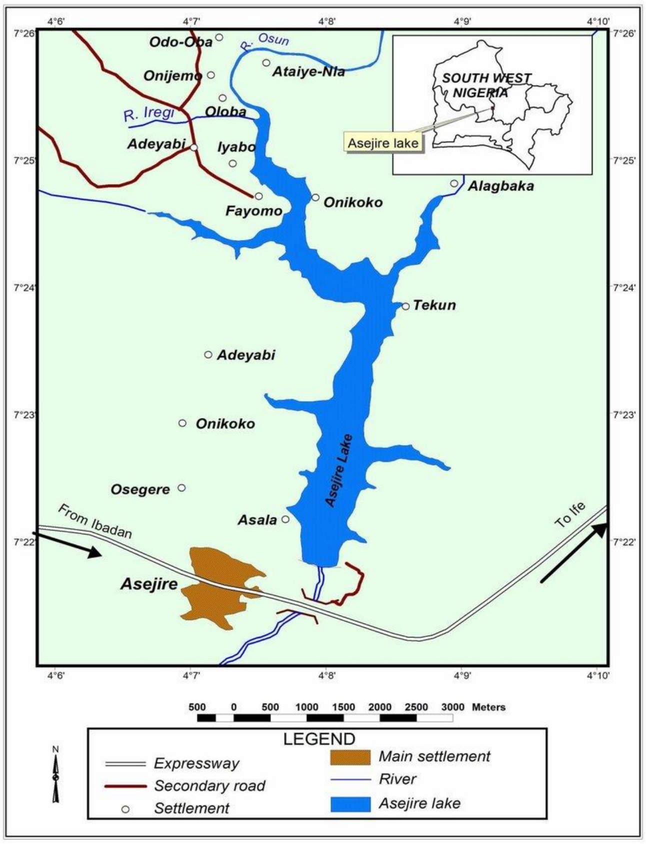

Figure 1: Location map showing Asejire dam (Ajani *et al*., 2014)

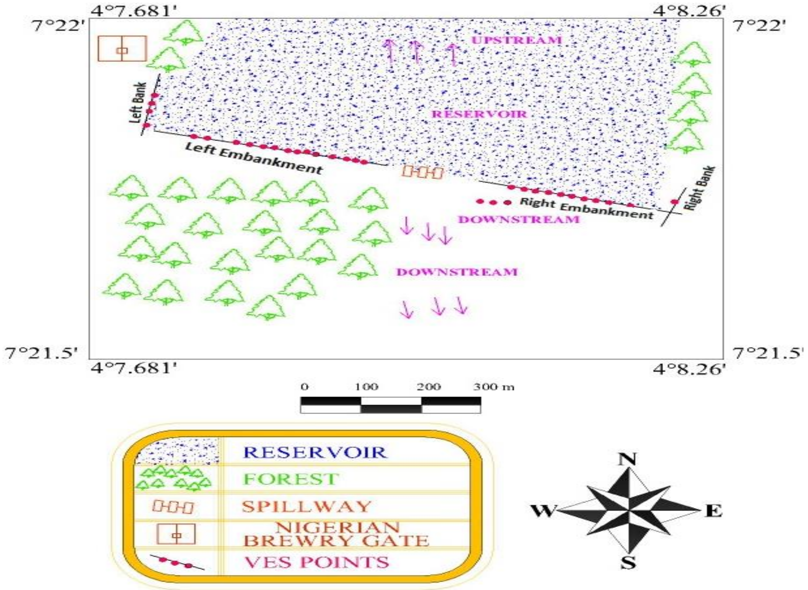

Figure 2: Field Layout at the study location

Local Geology

The dominant rock types underlying the study area are granite gneiss and banded gneiss (figure 3). The granite gneiss is generally pink in colour with fine-to-medium grain size displaying a weak foliation defined by the alignment of light and dark bands of felsic and mafic minerals. The rock is composed of potassium-feldspar, biotite, quartz, plagioclase feldspar and lesser hornblende. The banded gneiss occurs as low lying outcrops and is characterized by porphyroblastic texture. It is generally grey in colour and has medium-to-coarse grain size with persistent banding of alternation of light and dark coloured minerals comprising quartz, plagioclase feldspar, biotite and some opaque minerals.

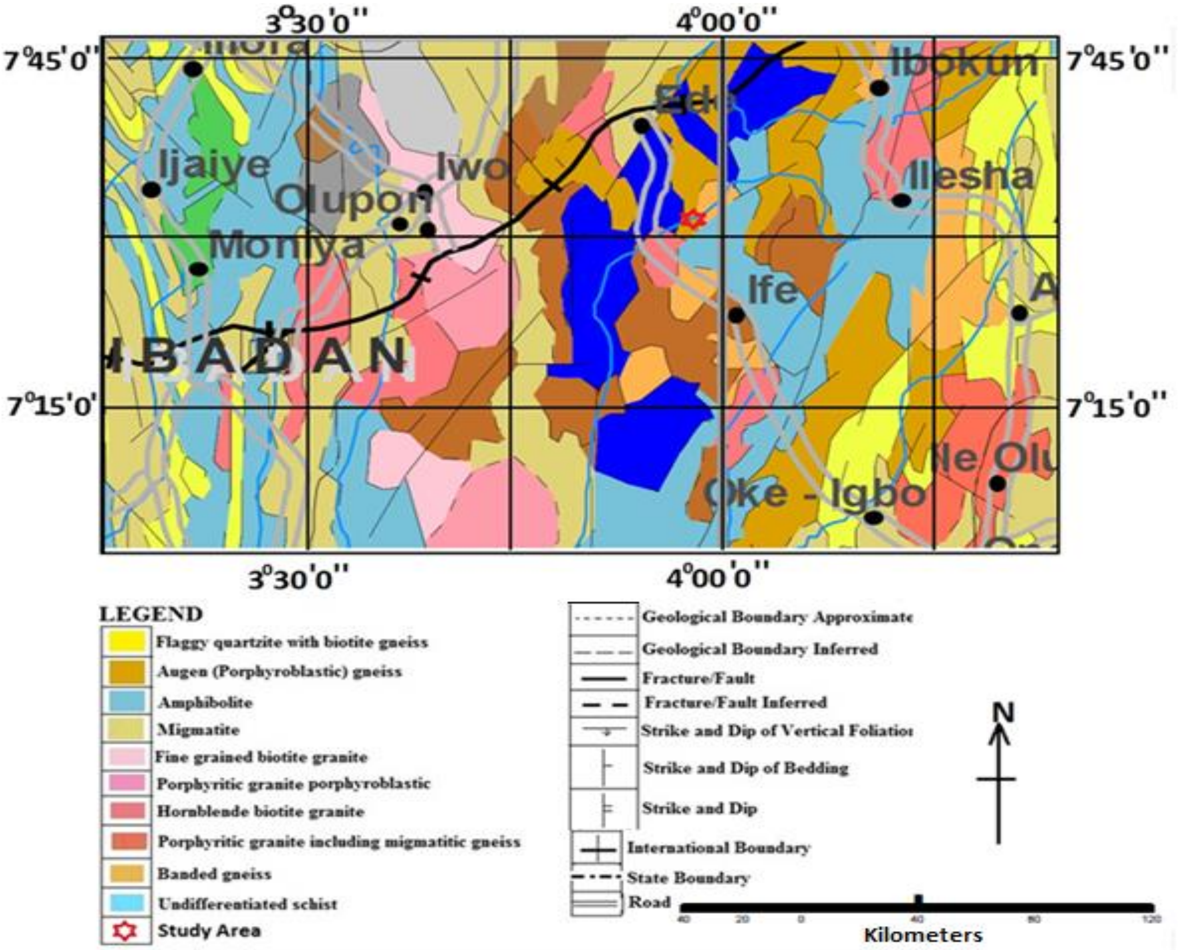

Figure 3. Geological map showing the study area (Modified after NGSA, 2006).

MATERIALS AND METHODS

The VES and dipole-dipole data were acquired using Digital Direct Resistivity Meter (DDR3 Terrameter), four electrodes, four reels of cables for current and potential, clips, pegs and tape. Thirty-One (31) VES stations were occupied at 20 m intervals employing the Schlumberger electrode array with current electrode spacing (AB/2) varied from 1 m to 80 m. The current and potential electrodes were connected to DDR3 Terrameter and the resistance values of the earth at the electrode points were noted from terrameter display and recorded. The apparent resistivity were then determined using the calculated geometric factor and resistance (Oladejo et al., 2023; Layade et al., 2017, 2018, 2021). The VES data acquired were interpreted using WinResist 1.0 software, while the layer parameters obtained were used to construct the geo-electric sections. The geo-electric section attempts to correlate different layers at each sounded point with a range of resistivity values. Thirty-one (31) dipole-dipole profilings were also carried out on already existed locations, with expansion factor (n) varied from 1-5. The 2-D resistivity values conducted were plotted against the intersection points of two 45 degree inclined lines from midpoints of the potential and current electrode. The DIPPRO™ 4.0 Inversion Software were employed to generate the 2-D resistivity subsurface structure of left, right embankment and downstream.

RESULTS AND DISCUSSION

The results of the VES data (using the Schlumberger configuration) were summarized in table which comprises of number of geo-electric layers, the resistivity values, thicknesses of each layer, and different curve types of each thirty-one VES stations. The dominant characteristics depth sounding curve-type observed in the area is the H-type curve (Table 1). According to geo-electric interpretation from the study area, the dam embankments and downstream are underlain by three (3) geo-electric layers. The top soil layer (Cap rock) with resistivity from 54-766**Ω**m, the weathered layer (Core) resistivity ranging from 18-113**Ω**m while the bedrock (third layer) resistivity is between 157-13672**Ω**m. The results were further processed to generate geo-electric sections along the left embankment, right embankment and downstream of Asejire dam.

Table 1: Summary of VES Interpretation

VES No.	No. of Layers	Resistivity (Ωm)	Thickness(m)	Curve type
1	3	82 23 157	0.9 13.3	H
2	3	252 63 96 208	0.7 10.0	H
3	3	118 51 121	1.0 2.9	H
4	3	77 39 910	1.9 25.7	H
5	3	78 34 405	2.3 17.7	H
6	3	93 29 405	1.8 27.1	H
7	3	62 23 320	3.8 33.5	H
8	3	59 44 1816	1.0 35.3	H
9	3	109 43 332	1.0 14.3	H
10	3	77 26 529	5.2 14.3	H
11	3	72 33 499	3.3 27.6	H

12	3	75 31 341	1.8 37.6	H
13	3	129 50 469	1.0 26.9	H
14	3	116 44 949	1.1 37.4	H
15	3	186 55 1033	1.0 28.3	H
16	3	286 73 245	2.2 11.1	H
17	3	303 57 361	1.0 11.3	H
18	3	499 48 857	1.0 12.1	H
19	3	378 77 1407	1.0 3.3	H
20	3	480 110 1608	0.7 8.9	H
21	3	746 109 2027	1.0 36.7	H
22	3	766 113 2209	1.2 36.7	H
23	3	522 103 1764	1.1 3.1	H
24	3	550 162 13672	1.1 12.8	H
25	3	230 92 1350	1.3 12.0	H
26	3	240 83 1920	1.0 9.6	H
27	3	262 73 1479	1.0 6.9	H
28	3	54 26 431	1.0 8.2	H
29	3	87 36 415	1.0 14.3	H
30	3	62 18 341`	1.3 11.5	H

31	3	70 22 400	1.0 14.1	H

Geo-electric Sections

Along Left Embankment

Figure 4 shows the geo-electric section along Left embankment. The section reveals three (3) distinct geologic layers beneath the embankment that constitute the top soil, weathered layer and Bedrock. The top soil layer of the left embankment is characterized by resistivity values ranging from 59 ***Ω***m to 240Ω m and thickness between 0.9 m and 5.3 m between stations, it is composed of clayey sand and laterite. The weathered layer is characterized with clay material with resistivity and thickness values ranging between 23 ***Ω***m - 55 Ωm and from 2.9 m to 37.6 m respectively. The last layer which lies on the basement/bedrock has resistivity values varying from 121 ***Ω***m-1033 ***Ω***m.

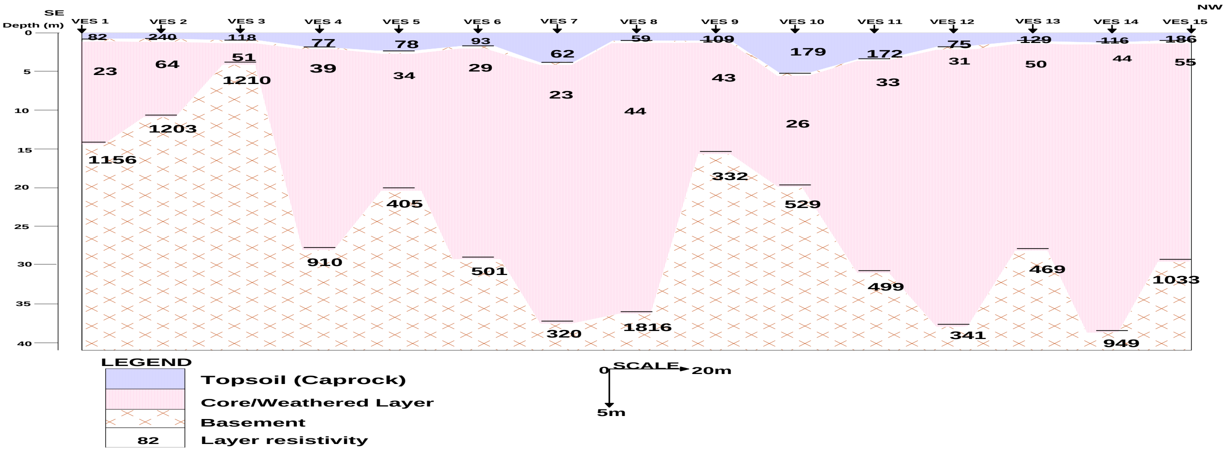

Figure 4: Geo-electric Section along Left Embankment

Along Right Embankment

Figure 5 shows the geo-electric section with three (3) distinct layers beneath the right embankment. The top soil layer is characterized by resistivity values from 289 ***Ω***m to 766 Ωm, thickness between 0.7 m and 2.2 m. This layer is presumably composed of clayey sand. The second layer is the weathered layer and is characterized by clay/clayey sand material with resistivity values ranging between 48 ***Ω***m and 162 Ωm and layer thickness varies from 3.1 m-36.7 m. The basement/bedrock (third layer) has resistivity values varying from 334 ***Ω***m to 3672 ***Ω***m.

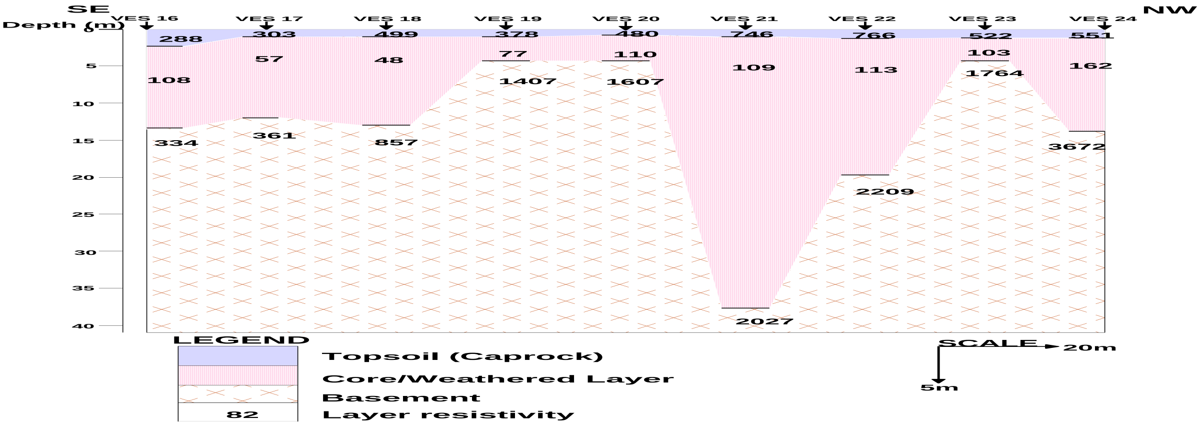

Figure 5: Geo-electric Section along Right Embankment

Along the left Banks

Figure 6 is the representation of the geo-electric section along the downstream displaying the same number of geologic layers with right and left embankment. These layers constitute the topsoil, weathered layer and the bedrock. The topsoil is basically of clayey sand, characterized by resistivity values of 54***Ω***m to 87Ωm, thicknesses is between 1.0m- 1.3m. This layer was followed by weathered layer with resistivity and thickness values ranging from 18***Ω***m to 36 Ωm, and 8.2m-14.3m respectively. The layer is presumably clay/clayey sand material. The last layer is basement/bedrock with resistivity values varying from 341***Ω***m to 431***Ω***m.

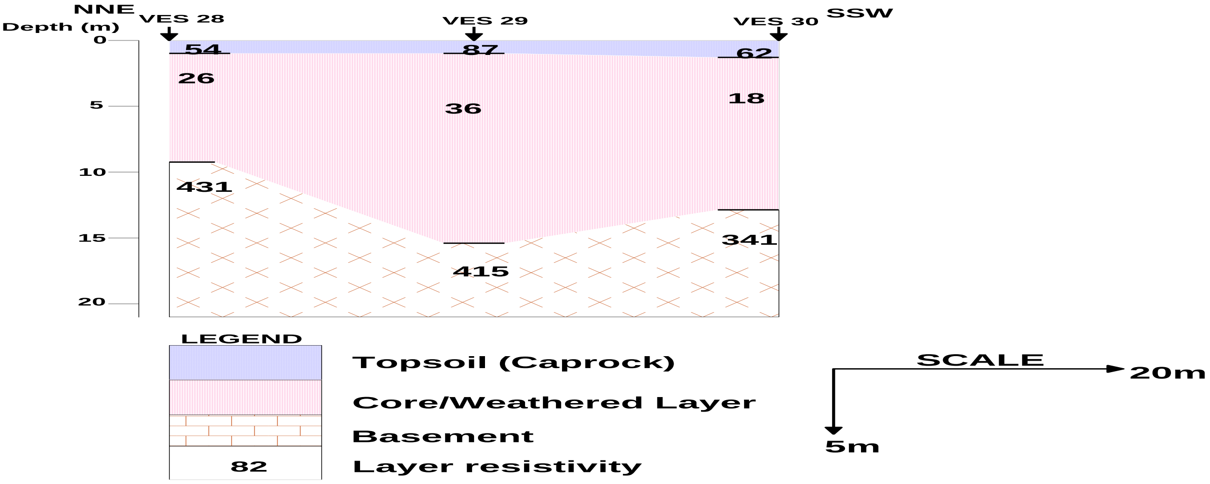

Figure 6: Geo-electric Section along Left Bank

2-D Resistivity Structure

Along Left Embankment

Figure 7 represent the 2-D resistivity structures along the left embankment of the study area consisting of three (3) distinct layers categorized into lowest resistivity layer (top soil layer), moderate resistivity layer (the weathered layer), and highest resistivity values (resistive bedrock). The first layer is an indicative of topsoil with resistivity values less than 100 Ωm, its highest thickness of 50 m were observed at lateral distance of 17 m. The layer were represented by continuous green color with discontinuity features observed at station distance 4-6 m and 11-13 m. The second layer depicts weathered layer with moderate resistivity values less than 1000 Ω m, it is represented by a continuous yellow color. The third layer is the highest resistive layer with resistivity values greater than 1000*Ω*m which revealed a continuous red and deep red color representing the basement bedrock at lateral distance from station 6-16.

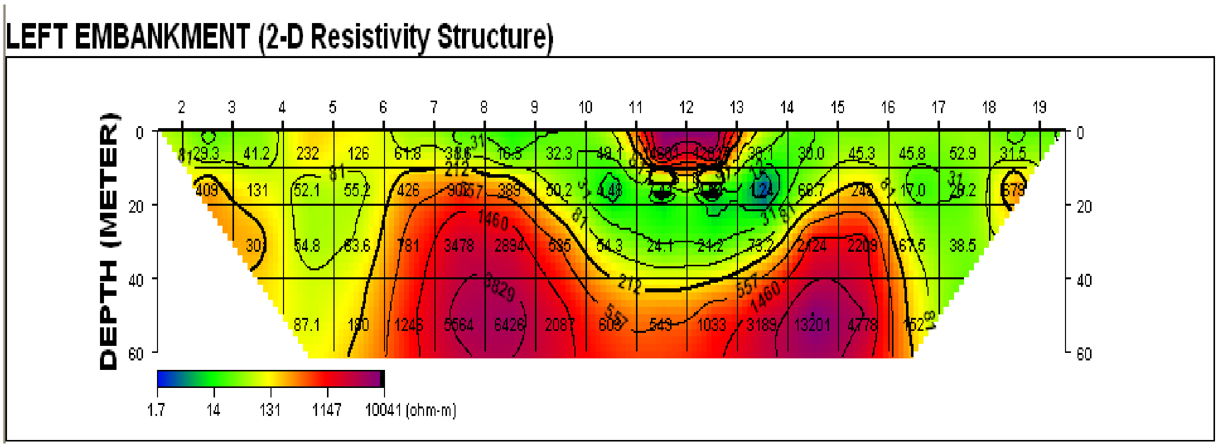

Figure 7: 2-D Resistivity Structure along Left Embankment

Along Right Embankment

Figure 8 shows the 2D resistivity structure along the right embankment. The lowest layer with resistivity values less than 200Ωm is the first layer at depth 20 m, it depicts the cap rock/topsoil representing a continuous green color range. However anomalous features such as voids and cavities were observed in the first layer, these abnormal structures can presumably play a role in leakage processes in Asejire dam.

The second layer depicts a weathered layer represented by continuous yellow and light red color band, it has a moderate resistivity values greater than 600Ωm but less than 10000Ωm at 30-60 m deep. The third layer has resistivity value greater than 10000*Ω*m at 40-100 m deep, the layer is presumable interpreted as resistivity bedrock with no interface discontinuity observed.

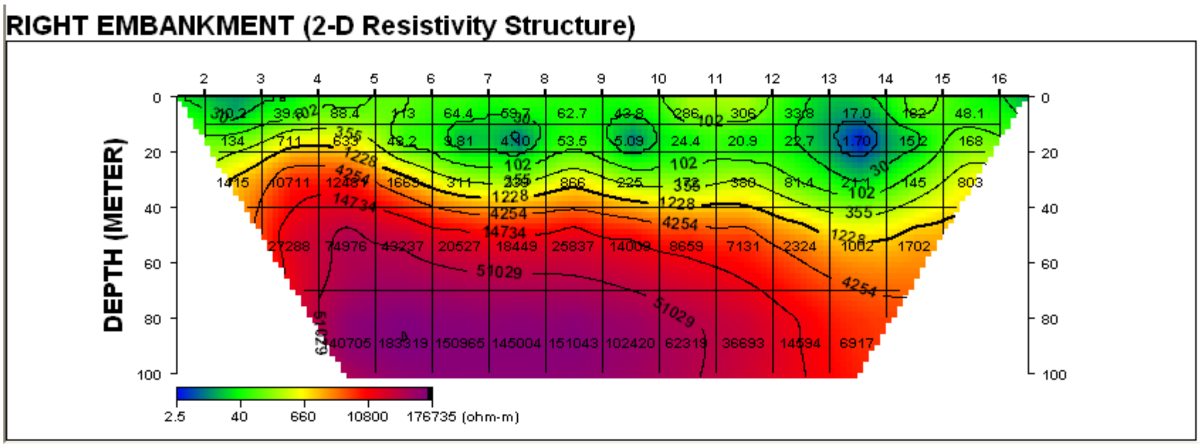

Figure 8: 2-D Resistivity Structure along Right Embankment

Along Downstream

Figure 9 represents the downstream image of 2D resistivity structure of Asejire dam. The first layer is the lowest resistivity layer indicating the topsoil (Cap rock) with resistivity less than 500Ωm at 40 m deep. The second layer (yellow and light red colors) depicts the weathered layer at resistivity less than 1000Ωm. The last layer is presumably the resistive bedrock with no presence of discontinuities, it has resistivity values greater than 1000*Ω*m. However abnormal features like cavities and fractures were observed in the first layer, these low resistivity layer were presumably caused by seepage flow along this embankment and can cause structure failures.

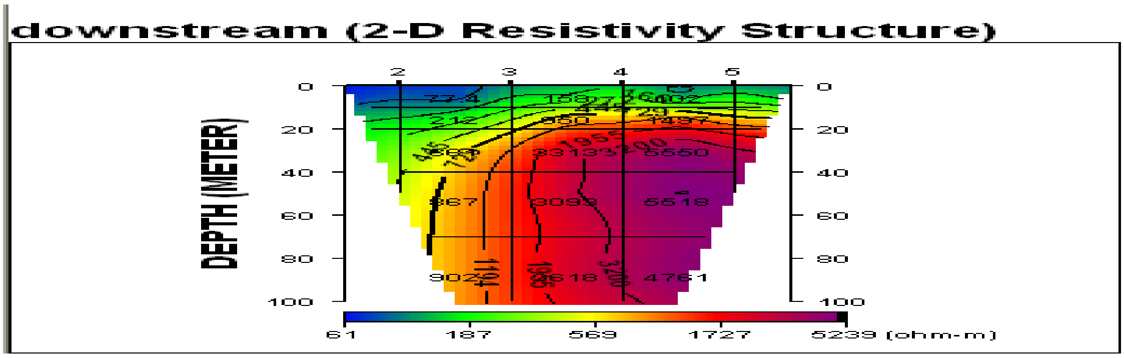

Figure 9: 2-D Resistivity Structure along the downstream.

The integrity rating of the dam is based on lithology and resistivity of the layers as represented in table 2. According to the rating in table 2, the integrity of Asejire dam is good to very good with a pocket of poor at VES points 20, 21, 22, 23, and 24 are suspected to be suspected weak area within the Asejire dam.

Table 2: Dam integrity rating based on lithology and resistivity layer of the core (Bayowa et al., 2019)

Core Lithology	Layer Resistivity Range	Dam Integrity Rating
Plastic Clay	1-20	Very Good
Clay	20-100	Good
Sandy Clay	100-250	Fairly Good
Clayey Sand/Sand	>250	Poor

Recommendation

Additional survey should be carried out to monitor the changes in electrical anomalies as a result of filling of the dam and environmental changes.

Limitation

The variation in mechanical properties in determining the rise in seepage flow and voids formation were not considered in the report.

CONCLUSION

The results from the interpretation of field acquired data revealed information about the integrity of Asejire dam through application of electrical resistivity approach. These methods involved horizontal resistivity profiling of the dipole-dipole array and Schlumberger's VES. The integrity of the dam has been rated based on the resistivity/lithological composition of the layers. The 2-D electrical resistivity structures and geo-electric section results delineates three (3) distinct geo-electric layers. The lithology delineated were topsoil (cap rock) presumably clayey sand and laterites, the weathered layer (Core) attributed with clay/clayey sand and the third layer suspected to be fresh bedrock. However there were abnormal features which were considered as anomalous structures in the right embankment, and downstream, but plays an insignificant role in causing the structural failure of the dam. Therefore the lithological composition of Asejire dam obtained from 2-D electrical resistivity structure and geo-electric section along the left embankment, right embankment and downstream shows the dam was of good integrity.

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