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# Engineering Geophysical Investigation of an Earth Dam Site across River Kiyan, Southwestern Nigeria

[1*]Akinlabi I. A., [2]Adegboyega C. O. and [1]Fadipe O. O.

[1]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[2]School of the Environment, Florida A & M University, Tallahassee, Florida, USA.

*Correspondence Author: E-mail: iaakinlabi@lautech.edu.ng Tel: +234 902 760 4637

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## Abstract
Geoelectrical and geotechnical surveys were conducted across river Kiyan, in Ibapon, Southwestern Nigeria to characterize the subsurface and assess the suitability of the location for siting an earth dam. Vertical electrical sounding (VES) and 2D resistivity profiling were conducted along the dam axis and three parallel axes upstream. The geotechnical investigation involved *in situ* Standard Penetration and Permeability tests performed on subsoils in boreholes drilled along the dam axis, and laboratory tests conducted on eight (8) soil samples collected from test pits dug along the parallel axes. The VES data were interpreted by partial curve matching and 1D computer iteration to obtain the layer parameters which were used to construct the geoelectric sections. The 2D resistivity data were interpreted using 2D resistivity inversion procedure to generate the 2D resistivity sections. The geotechnical tests were conducted and interpreted in accordance with the procedures set out in American Society for Test Materials (ASTM D1586) and British Standards (BS.1377). The results of the resistivity surveys along the dam axis revealed sandy topsoil, clay/sandy clay saprolite and weathered/fractured/fresh bedrock. The topsoil is suitable material for the caprock over the dam embankment while saprolite is fairly good-to-good materials for core of the dam embankment. The subsoils are medium-to-very dense, fairly impervious with medium plasticity. The study area is suitable for site an earth dam provided appropriate remedial measures are applied to the weak/fractured zones beneath the dam axis, and the pervious zones upstream.

Keywords: Dam axis, Fracture zones, Geotechnical tests, Resistivity surveys, Subsoils.

## Introduction
Dams are large engineering structures built across rivers to impound water for various uses which include domestic, irrigation, industrial, flood control, power generation and recreation (Kondolf, 2022, Ahmed *et al*., 2023). The structural integrity of a dam is of utmost importance considering its enormous weight and the pressure of the water acting on it from the upstream end. A dam must be stable, as it stores water, to ensure that lives and property of the downstream population are safe (Adamo *et al*., 2020).

Dam failure can occur when the foundation or the embankment and its appurtenances experience excessive deformation, differential settlement resulting from weak or unstable soil conditions, bedrock instability, slope instability, erosion, anomalous seepage and inadequate site investigation (Bhattarai *et al*., 2016; Clarkson and Williams, 2021). A detailed foundation investigation is thus required to provide information about the subsurface geology, structural setting, and hence assess the competence of the subsoils and the underlying rocks for siting a stable dam (Zewdu, 2019; Sissakian *et al*., 2020).

Conducting a thorough site investigation involves closely-spaced *in situ* geotechnical and laboratory tests on soil and rock samples at the site. A large number of such tests would be required since they are point specific, and the overall cost would consequently be prohibitively high. The techniques are also time-consuming, laborious and invasive. Most times, however, investigations based solely on borehole drilling are poorly planned, and consequently yield deficient and unreliable results. This problem has necessitated the use of geophysical techniques to furnish subsurface information prior to the conduct of geotechnical investigation.

The application of geophysical methods has been an effective approach for characterizing subsurface geology of proposed engineering sites (Camarero and Moreira, 2017; Gołębiowski et al., 2021). The methods are non-invasive and provide rapid evaluation of subsurface conditions essential for guiding the design and construction of engineering structures (Azahar *et al*., 2019, Liu, et al., 2023, Rana *et al*., 2024). The geoelectrical methods have been shown to be apt in providing the information required geotechnical in engineering and damsite investigation (Pasieb, 2019). The effectiveness of the methods derives from the significant and detectable resistivity contrast between the different lithologies of the underlying geology.

Integrating geophysical and geotechnical techniques would thus provide a thorough understanding of subsurface conditions, and is therefore essential for guiding the design and construction of the dam at the proposed site. Geophysics would furnish a broad and composite picture of the subsurface while the geotechnical methods would be deployed to confirm the findings in few selected boreholes and test pits, and determine the engineering properties of the subsoils and rocks underlying the site from the results of both field and laboratory tests conducted on representative samples. This will, in turn, reduce the overall cost of the site investigation without compromising quality.

The need to meet the water requirements to boost agricultural activities as a means to achieving the Millennium Development Goals has led Ogun-Oshun River Basin Development Authority to propose a small earth dam across River Kiyan in Ibapon near Ogbomoso, southwestern Nigeria. Since a thorough understanding of the subsoil characteristics is required to assess the suitability of the site for the proposed dam, a combination of geoelectrical and geotechnical methods was therefore employed to characterize the subsurface at the location. The objectives are to delineate the subsurface profile, determine the character and thickness of the overburden, reveal concealed geologic features which may cause structural failure, and obtain values of engineering soil parameters related to the structural stability and integrity of the dam.

## Materials and Methods

The study area lies within Longitudes 4° 11′ 12″ E - 4° 11′ 15″ E, and Latitudes 8° 06′ 44″ N - 8° 06′ 51″ N (Figure 1). It is about three kilometers south of Ogbomoso along the old Oyo-Ogbomoso highway and occupies a central location among a group of villages including Owolake, Bosanla and Samo, which may benefit from the establishment of the dam project. The topography varies from 289m to 308m Above Mean Sea Level (AMSL). Its climate is characterized by wet season from April to September during which heavy rainfall occur, and dry season, occurring from October to March. The mean annual rainfall ranges from 1100 mm to 1300 mm while the average daily temperature varies from 20°C on a very cold day to about 35°C on a very hot day. The vegetation is basically rainforest but has been reduced to derived savannah by various human activities such as intensive land cultivation, bush burning, and land clearing for agricultural and construction purposes. The proposed dam site is characterized by a V-shaped valley suitable for dam siting. The study area is underlain by the Precambrian crystalline basement complex rocks of southwestern Nigeria, which forms part of the Pan-African mobile belt (NGSA 2020). The dominant rock type is migmatite gneiss probably formed by partial melting of the metamorphic host rock during extreme metamorphism (Pawley *et al*., 2015, Balogun, 2019, Akintola and Obasi, 2020).

An integrated approach of geophysical and geotechnical methods was deployed to assess the competence of the subsurface materials and suitability of the study area for siting a stable dam.

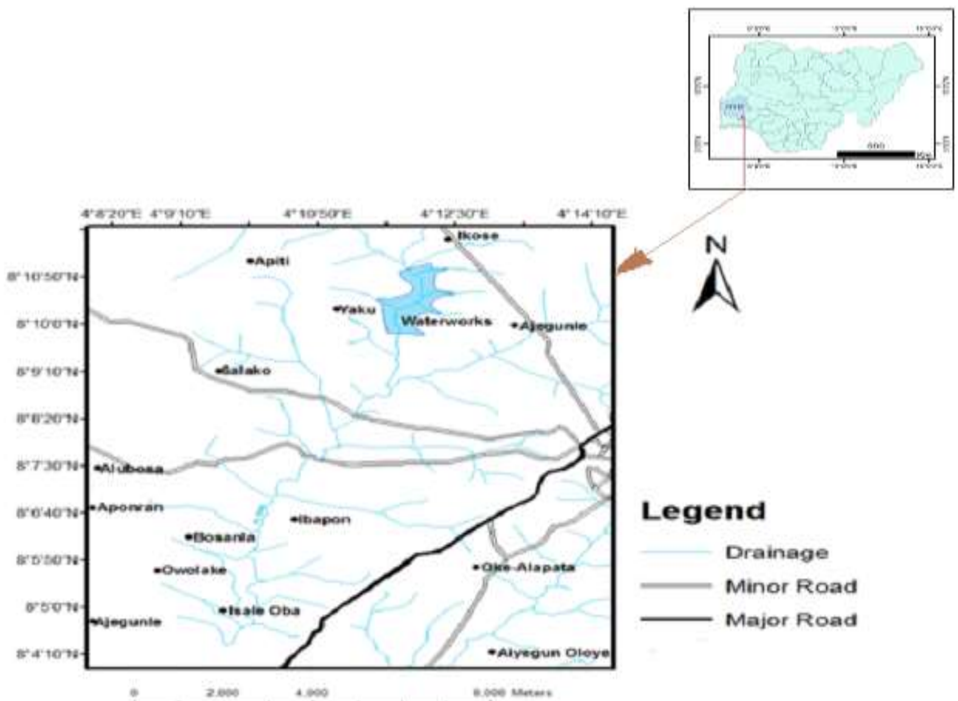


**Figure 1:** Location map of the study area

## Geophysical Investigation

The geophysical techniques involved the Schlumberger Vertical Electrical Sounding (VES) and 2D resistivity profiling. Schlumberger VES were carried out by keeping the electrode array centered over a field station while increasing the spacing between the current electrodes, thus increasing the depth of investigation. Twenty-four VES stations were established 20 m apart along the dam axis and about 50 m apart along three other three profiles parallel to the main axis (Figure 2). The VES data were acquired with a resistivity meter and its accessories using maximum half current electrode spacing (AB/2) of 100 m. The VES data were quantitatively interpreted with the partial curve matching technique in which master curves were superimposed on the sounding curves to obtain the starting models (Orellana and Mooney, 1966). The obtained parameters derived from the graphical curve matching were then used as input for forward modeling technique

employing 1D resistivity inversion algorithm (Zohdy, 1989; Vander-Velpen, 2004) produce the final model (layer parameters) which were then used to construct geoelectric sections.
The 2D resistivity was carried out along both right and left flanks of the dam axis by using the dipole-dipole electrode spread with electrode spacing of a=5 m and an expansion factor of n=5. The data were processed with the 2D resistivity inversion procedure which iteratively computes the resistivity response of a two-dimensional model until an appreciable match is achieved between a theoretical pseudo-section and the Finite Element Method (FEM) of modelling using a second order smoothness constraint (Hohnmann, 1982; Loke, 2010).

## Geotechnical Investigation

The geotechnical investigation involved standard penetration test and field permeability test conducted in boreholes along the proposed dam axis, and laboratory tests conducted on representative soil samples collected from test pits dug along the parallel axes in the reservoir area to determine the subsoil geotechnical properties.

### Standard Penetration Test

Three boreholes were drilled with a "dismountable drill rig" which used the percussion drilling method to progress the hole. Standard Penetration Test (SPT) was performed at regular intervals in each borehole as drilling progressed. The *in situ* test involved driving a split barrel sampling tube into the soil at the bottom of the borehole using a hammer weighing 65kg falling freely through 760mm (ASTM D1586/D1586M–18, 2018). The total number of blows (N-values) required for the 300mm penetration following the first 150mm penetration below the bottom of the borehole was taken as the subsoil penetration resistance. Additional rods were added as required and the hole was advanced to a depth deemed adequate through the overburden or down to refusal to further penetration.

### Field Permeability test

Field (in-situ) Permeability test was conducted at depth in the boreholes to determine the seepage characteristics of the subsoils encountered. The technique used was based on measuring the quantity of water infiltrated into the ground through the open bottom of the borehole casing under saturated conditions over a known time.

### Soil Sampling and Laboratory Geotechnical Tests

Six test pits were dug along the parallel axes in the proposed reservoir area and eight soil samples were collected at depths ranging from 0.20 m to 2.00 min for laboratory tests to determine the geotechnical properties of the subsoils. The laboratory tests which included Sieve analysis, Atterberg limits test, Proctor Compaction test and Permeability test were conducted in accordance with the procedures set out in the British Standards B.S.1377 – "Methods of test for Soils for Civil Engineering purposes" to determine the properties which make them suitable or otherwise for use as construction materials for the proposed dam foundation and embankment. The locations of the geophysical profiles, borehole points and test pits in the study area are shown in Figure 2.

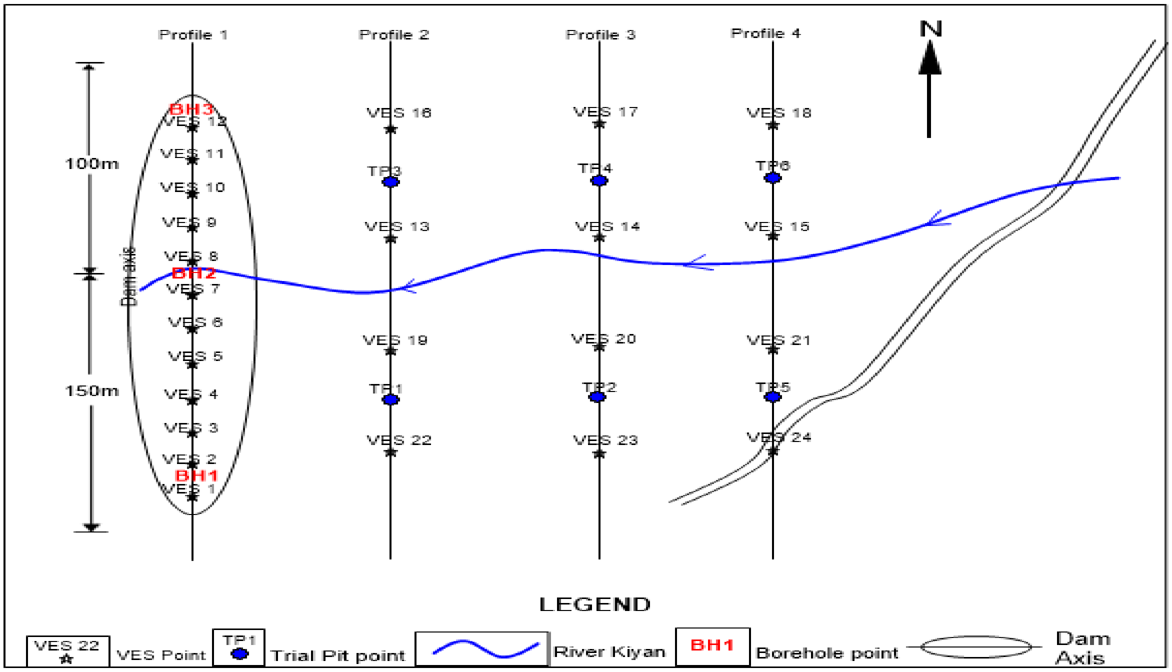


**Figure 2:** Locations of the geophysical profiles, borehole points and test pits in the study area

## Results and Discussion

### Interpretation of VES data

The results of the VES interpretation reveal that the subsurface is inhomogeneous in geological composition and mainly comprises three geoelectrical layers namely topsoil, saprolite and weathered/fresh basement. The VES curves are predominantly H-type. The summary of the Vertical Electrical Sounding (VES) interpretation is presented in Table 1.

The geoelectric section beneath the proposed dam axis (Profile 1) reveals a topsoil whose resistivity ranges from 122 Ωm to 1127 Ωm and its thickness varies from 0.7 m to 1.2 m (Figure 3). The saprolite is a clay/sandy clay mixture whose resistivity and thickness range from 64 Ωm to 230 Ωm and 10 m to 26 m respectively. The bedrock resistivity varies from 623 Ωm to 99989 Ωm indicating a weathered/fresh bedrock while depth to the bedrock varies from 9 m to 27 m.

The topsoil beneath Profile 2 has resistivity ranging from 396 Ωm to 872 Ωm and is 1.0 m to 1.3 m thick (Figure 4). Resistivity of the saprolite ranges from 36 Ωm to 257 Ωm suggesting clay/sandy clay, and its thickness varies from 3.2 m to 16.0 m. Bedrock resistivity varies from 1527 Ωm to 99826 Ωm representing weathered/fresh bedrock while depth to the bedrock ranges from 13.3 m to 20.2 m.

The topsoil resistivity beneath Profile 3 ranges from 368 Ωm to 711 Ωm while its thickness varies from 0.8m to 1.1m (Figure 5). It is underlain by a clay/sandy clay layer whose resistivity ranges from 43 Ωm to 306 Ωm and its thickness varies from 6.1 m to 18.7 m. Resistivity of the bedrock is 330 Ωm - 99905 Ωm suggesting weathered/fresh bedrock while depth to the bedrock varies from 10.4m to 19.8 m.

The resistivity of topsoil beneath Profile 4 is 104 Ωm - 812 Ωm and is 0.9 m - 1.1 m thick (Figure 6). The saprolite has resistivity ranging from 37 Ωm to 143 Ωm typical of clay/sandy clay, and thickness varying from 6.9 m to 16.2 m. The bedrock resistivity is 1615 Ωm - 100000 Ωm indicating fresh/weathered bedrock while depth to the bedrock varies from 9.6 m to 17.1 m.

**Table 1:** Summary of the Interpretation of the VES data

| VES | Resistivity (Ωm) | Thick (m) | Depth (m) | Curve Type | Inferred Lithology |
|---|---|---|---|---|---|
| 1 | 671/122/2623 | 1.1/25.3 | 1.1/26.4 | H | Topsoil/sandy clay/Bedrock |
| 2 | 472/99/1721 | 1.1/16.9 | 1.1/18.0 | H | Topsoil/clay/Bedrock |
| 3 | 765/69/99989 | 0.9/15.5 | 0.9/16.4 | H | Topsoil/clay/Bedrock |
| 4 | 291/98/3721 | 1.1/19.5 | 1.1/20.6 | H | Topsoil/clay/Bedrock |
| 5 | 226/136/1791 | 1.0/18.3 | 1.0/19.4 | H | Topsoil/sandy clay/Bedrock |
| 6 | 236/107/743 | 0.9/15.4 | 0.9/16.3 | H | Topsoil/ sandy clay/Bedrock |
| 7 | 122/71/1025 | 1.0/9.2 | 1.0/10.2 | H | Topsoil/clay/Bedrock |
| 8 | 218/151/5211 | 1.0/10.2 | 1.0/11.2 | H | Topsoil/sandy clay/Bedrock |
| 9 | 223/230/1873 | 1.0/17.8 | 1.0/18.8 | A | Topsoil/sandy clay/Bedrock |
| 10 | 1127/138/2328 | 1.4/13.5 | 1.4/15.0 | H | Topsoil/sandy clay/Bedrock |
| 11 | 895/64/2808 | 1.1/13.6 | 1.1/14.6 | H | Topsoil/clay/Bedrock |
| 12 | 861/164/5557 | 1.2/14.4 | 1.2/15.6 | H | Topsoil/sandy clay/Bedrock |
| 13 | 396/78/2885 | 1.1/12.8 | 1.1/13.9 | H | Topsoil/clay/Bedrock |
| 14 | 711/216/1361 | 1.1/18.7 | 1.1/19.8 | H | Topsoil/clay/Bedrock |
| 15 | 104/82/2535 | 1.0/8.5 | 1.0/9.6 | H | Topsoil/clay/Bedrock |
| 16 | 872/40/1527 | 1.3/11.9 | 1.3/13.3 | H | Topsoil/clay/Bedrock |
| 17 | 436/89/99905 | 1.0/13.2 | 1.0/14.1 | H | Topsoil/clay/Bedrock |
| 18 | 812/364/37/100000 | 1.0/3.2/6.9 | 1.0/4.2/11.1 | QH | Topsoil/sandy clay/clay/ Bedrock |
| 19 | 516/103/1678 | 1.1/15.5 | 1.1/16.7 | H | Topsoil/sandy clay/Bedrock |
| 20 | 539/306/43/657 | 0.8/3.5/6.1 | 0.8/4.3/10.4 | QH | Topsoil/sandy clay/clay/Bedrock |
| 21 | 720/107/1615 | 0.9/14.5 | 0.9/15.5 | H | Topsoil/sandy clay/Bedrock |
| 22 | 502/257/56/99826 | 1.0/3.2/16 | 1.0/4.1/20.2 | QH | Topsoil/sandy clay/clay/Bedrock |
| 23 | 368/107/330 | 1.0/10.7 | 1.0/11.7 | H | Topsoil/sandy clay/Bedrock |
| 24 | 484/143/1964 | 0.9/16.2 | 0.9/17.1 | H | Topsoil/sandy clay/Bedrock |

## 2D Resistivity Sections

The 2D resistivity section underlying the right flank of the proposed dam axis (Figure 7) reveals a resistive topsoil, a saprolite composed of sand-sandy clay mixture, and weathered/fractured/fresh bedrock. The resistivity of the topsoil ranges from 210 Ωm to 793 Ωm from Station 1 to Station 19. The relatively higher resistivity values of 442 Ωm to 793 Ωm from surface to about 2 m depth beneath Stations 7-10, and about 5 m beneath Stations 15-17 possibly indicate lateritic hardpan. Part of the topsoil from Station 20 to Station 29 is relatively less resistive (7.22 Ωm to 190 Ωm) indicating clay/sandy clay. The pockets of resistivity lows (7.22 Ωm to 37.8 Ωm) in this zone possibly indicate water-saturated clay.

The saprolite has resistivity ranging from 10.7 Ωm to 210 Ωm characteristic of clay-sandy clay mixture. The resistivity lows ranging from 10.7 Ωm to 25.8 Ωm occurring within the saprolite, beneath Stations 3-15, 17-19 at depths 2.5 m to 10 m, and Stations 20-26 from surface to about 5 m depth, are indicative of high clay content, high porosity and high degree of water saturation. Resistivity of the bedrock ranges from 102 Ωm to 6832 Ωm representing fractured (102 Ωm – 171 Ωm), weathered 250 Ωm – 505 Ωm) and fresh (604 Ωm – 6832 Ωm) bedrock. The fractures occur beneath Stations 1-7, Stations 12-20 and Stations 28-29 at the end of the profile.

The 2D inverted resistivity section beneath the left flank (Figure 8) delineates resistive topsoil with resistivity ranging from 110 Ωm to 2413 Ωm. It is underlain by less resisitive saprolite with resistivity ranging from 2.24 Ωm to 230 Ωm suggesting clay-sandy clay mixture. The pockets of resistivity lows (2.24 Ωm – 39.2 Ωm) in the saprolite may be attributed to high clay content, high porosity and high degree of water saturation. The relatively higher resistivity values (430 Ωm–2413 Ωm) occurring from surface to about 7 m depth beneath Stations 5-10, and to about 2.5 m depth beneath Stations 12-15 and Stations 17-19 suggest lateritic hardpan or weathered fragments of the underlying bedrock. Resistivity of the bedrock ranges from 87.3 Ωm to 5719 Ωm representing fractured (87.3 Ωm – 209 Ωm), weathered (223 Ωm – 398 Ωm) and fresh (640 Ωm – 5719 Ωm) bedrock. The bedrock is fractured beneath Stations 12 – 15. The weathered bedrocks are structurally weak while the bedrock fractures would pose threat to the integrity of the dam as they provide pathway for water into its

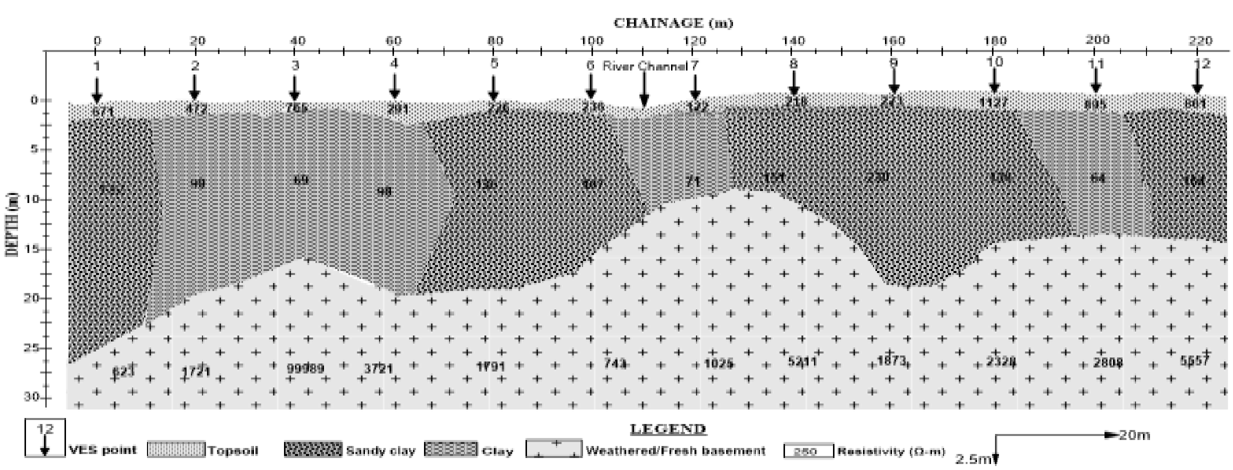


**Figure 3:** Geoelectric section beneath the proposed dam axis (Profile 1)

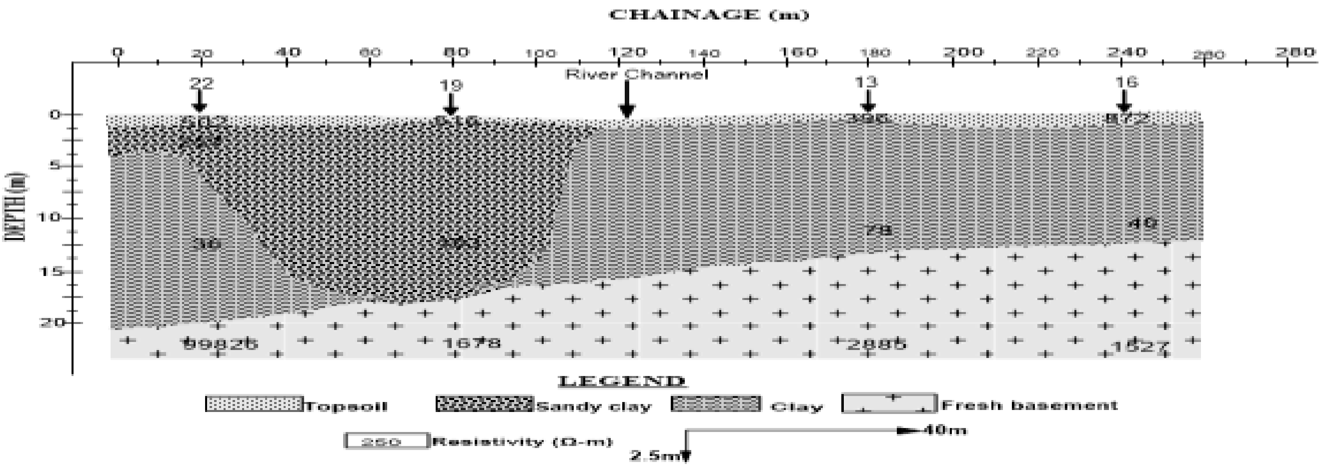


**Figure 4:** Geoelectric section beneath parallel Profile 2

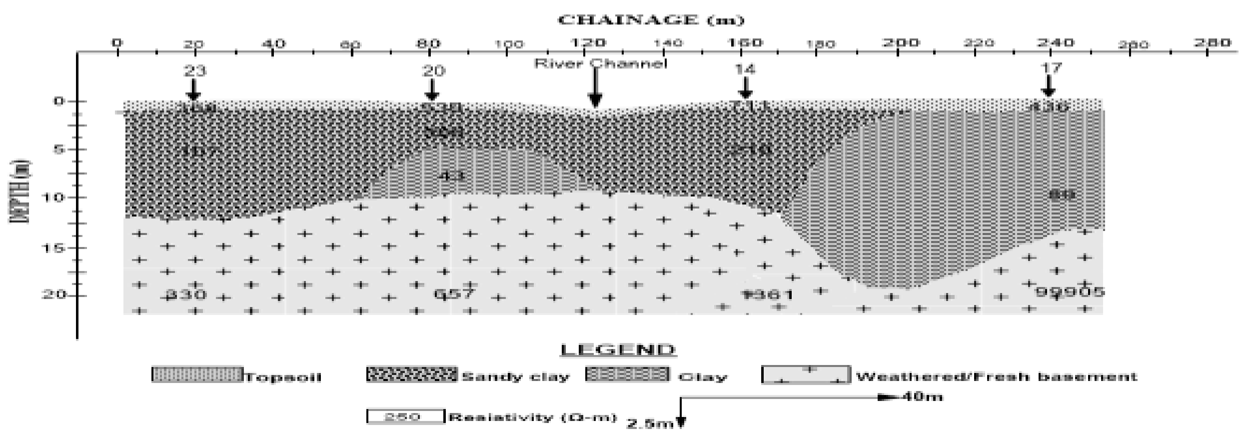


**Figure 5:** Geoelectric section beneath parallel Profile 3

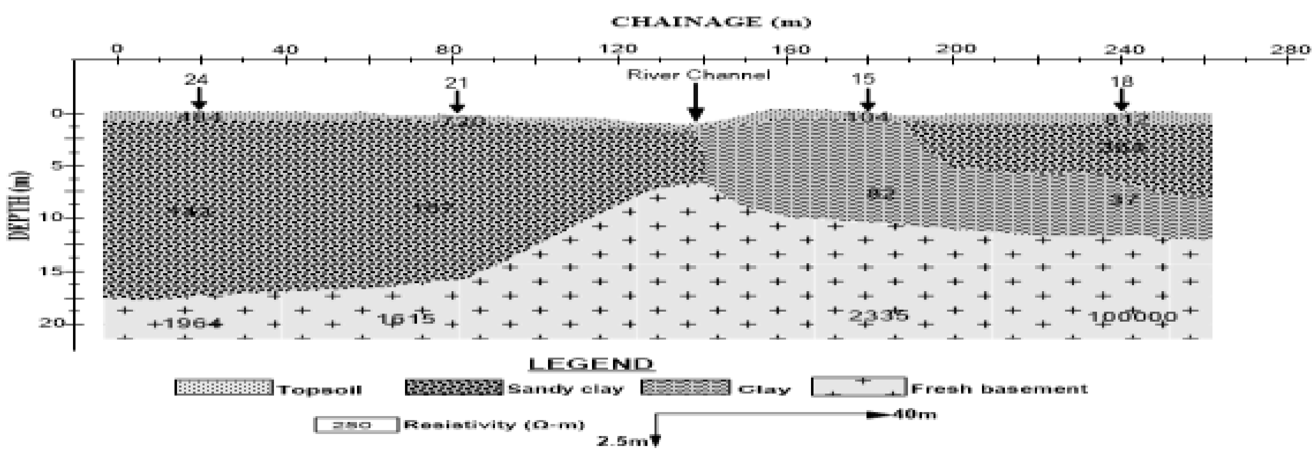


**Figure 6:** Geoelectric section beneath parallel Profile 4

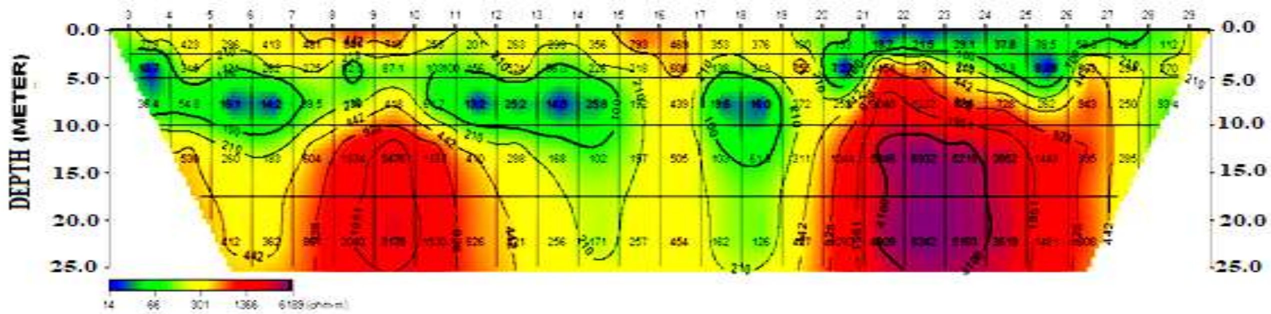


**Figure 7:** 2D inverted resistivity section beneath the right flank of the proposed dam axis

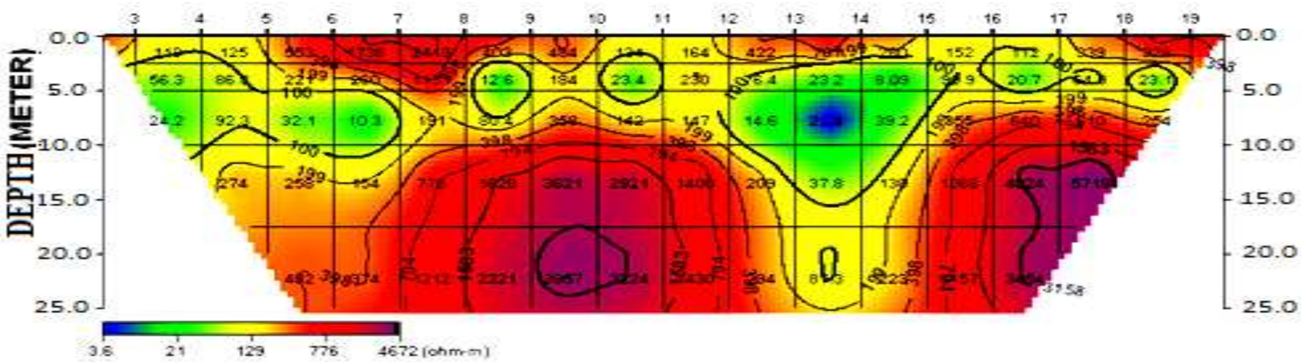


Figure 8: 2D inverted resistivity section beneath the left flank of the proposed dam axis

foundation (Akinlabi and Oladunjoye, 2018; Gao *et al.*, 2018; Hassan *et al.*, 2018). This undesirable soil condition requires adequate consideration in the design of the dam.

A good earth embankment is composed of resistive caprock underlain by impervious low-resistivity clayey core or fill lying on high-resistivity competent bedrock (Olorunfemi *et al*., 2000). The topsoil is resistive and are suitable materials for the caprock over the dam embankment.

The clay/sandy clay constituents of the saprolite are good/fairly good materials for core of the dam embankment over the competent bedrock after the weathered bedrock has been evacuated up to the competent bedrock and the fractures have been treated, for example by cement grouting, to ensure that the dam foundation is structurally stable and safe from anomalous seepage.

## Results of Geotechnical Investigation

### Dam Axis

The subsoil stratification encountered in the boreholes BH 1 –BH 3 drilled along the dam axis consists of three to four layers identified as dark brown silty sand topsoil about 0.50 m thick in BH 1 and brown coarse to fine sand about 2.80 m thick in BH 2 and 0.25 m BH 3. The topsoil is underlain by reddish brown gravelly/sandy clay layer about 15.80 m thick in BH 1, dark brown/brown sandy clay about 3.9 m thick in BH 2, and dark brown gravelly/sandy clay about 3.95 m thick in BH 3. The boreholes were terminated as weathered bedrock was encountered at depths of about 16.25 m in BH 01, 6.55 m in BH 02, and 4.20 m in BH 03. Groundwater was encountered at the depth of 12.4 m in BH 1. The lithologic sections and SPT curves through the boreholes along the dam axis are shown in Figure 9.

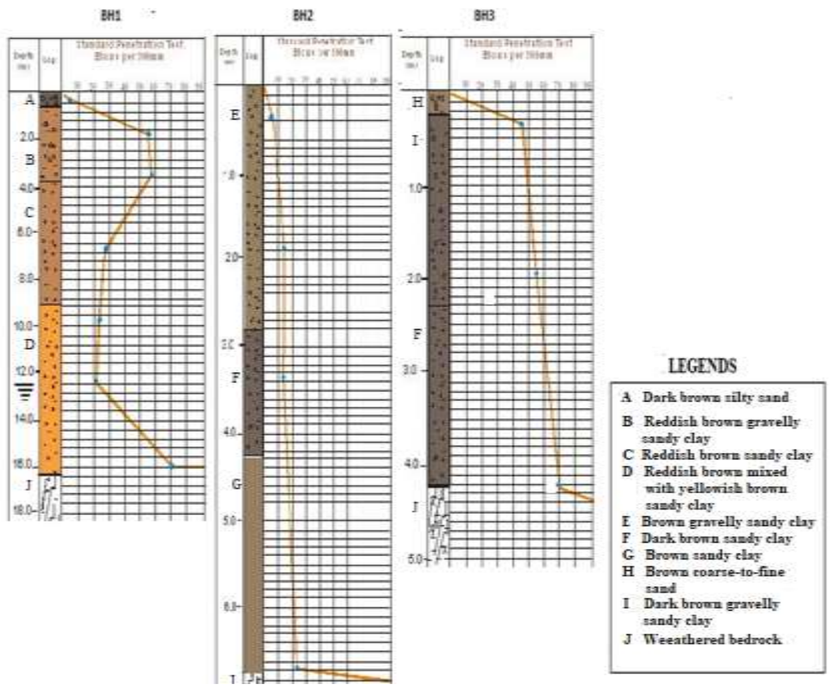


**Figure 9:** Lithologic sections and SPT curves through the boreholes along the dam axis

**SPT 'N' values and Soil Strength**

The SPT 'N' values measured in the boreholes range from 7 to >70 from the topsoil to the weathered bedrock (Table 2). The N values indicate that the top 0.45 m comprises loose sandy soil underlain by hard and very stiff cohesive soils up to the weathered bedrock at about 16.75 m depth in BH 1. The decrease in soil strength in from hard to very stiff can be attributed to the groundwater encountered within the interval. The topsoil in BH 2 is firm cohesive soil and is underlain by very stiff-to-hard soils while the topsoil in BH 3 is very dense sandy soil underlain by hard cohesive soil.

**Field Permeability Test**

The results of the in-situ (field) permeability test on soils in the borehole along the proposed dam axis show that the coefficient of permeability (k) of the soils along the dam axis at depths between 1.50 m and 3.50 m varies from 5.50 x$10^{-7}$ cm/s to 1.15 x $10^{-6}$ cm/s (Table 3). The results show that k decreases with depth of the soil. Lambe (1951) quoted coefficient of permeability value of $10^{-5}$ cm/s as the borderline between pervious and impervious soils. This indicates that, in the natural state, the soils are fairly impervious and the rate of groundwater infiltration is fairly low**.** This soil condition may favour the design of the dam foundation.

**Table 2:** SPT 'N' values and Relative density of the subsoils beneath the dam axis

| Borehole No. | Depth (m) | SPT 'N' value | Relative density |
|---|---|---|---|
| BH01 | 0.00-0.45 | 9 | Loose |
| | 1.50-1.95 | 57 | Hard |
| | 3.00-3.45 | 58 | Hard |
| | 6.00-6.45 | 29 | Very Stiff |
| | 9.00-9.45 | 25 | Very Stiff |
| | 12.00-12.45 | 21 | Very Stiff |
| | 16.75 | >70 | Hard |
| BH02 | 0.00-0.45 | 7 | Firm |
| | 1.50-1.95 | 24 | Very Stiff |
| | 3.00-3.45 | 26 | Very Stiff |
| | 6.75 | >70 | Hard |
| BH03 | 0.00-0.45 | 46 | Very dense |
| | 1.50-1.95 | 56 | Hard |
| | 4.25 | >70 | Hard |

**Table 3:** Summary of Field Permeability Test Results

| Borehole No. | Test Depth (m) | Coefficient of Permeability (cm/s) |
|---|---|---|
| BH 01 | 1.50 | $8.30 \times 10^{-6}$ |
| | 3.50 | $5.50 \times 10^{-7}$ |
| BH 02 | 2.00 | $2.18 \times 10^{-6}$ |
| BH 03 | 1.50 | $1.15 \times 10^{-6}$ |

## Soil classification

Coarse- and fine-grained soils are classified based on Grain size distribution and Atterberg limits respectively.

### Grain size distribution

Based on the Unified Soil Classification System (USCS), the sieve analysis conducted on representative soil samples from the reservoir area identified clayey sand in TP 1-TP 4 and gravelly sand TP 5 and TP 6 (Table 4). The soils are sandier and gravellier at distances beyond 100 m upstream from the dam axis. This is in close agreement with the soil profile observed in BH 1. These soil types are suitable caprock materials on the proposed dam embankment.

### Atterberg limits

Results of Atterberg limit tests on the soil samples from the reservoir area show that the soils have Plasticity Limit ranging from 8% to 20%, Liquid Limit (LL) from 24% to 49%, and Plasticity Index (PI) from 16% to 29% (Table 5). All the PI and LL values plot above the A-line on the Casagrande (1948) PI-LL chart (Figure 10), indicating that the fines are clay and the soils are clayey sand. They have medium plasticity and compressibility and are thus suitable foundation soils for engineering structures. The clays are normal clays with activity (A) ranging from 0.83 to 1.21. The swell potential is medium, based on Nelson and Miller (1992) classification. The swell percent is low, ranging from 4% to 10.4%. Soil materials with low-to-medium swell-shrink potentials do not compress appreciably under load or shrink extensively when dried. The soils can therefore be said to be suitable materials for embankment core.

### Compaction test Laboratory Permeability Tests on soils from the Reservoir area

The results of Proctor Compaction test conducted on representative samples from the reservoir area indicate that the maximum dry density (MDD) ranges from 1.80 Mg/m$^3$ to 1.93 Mg/m$^3$ at optimum moisture content (OMC) varying from 9% to 15% (Table 6). The soils tend to be impervious when compacted, and would hence hindering excessive loss of water.

The values of coefficient of permeability, K obtained from the laboratory range from 2.8 x 10$^{-2}$ to 4.6 x 10$^{-6}$ cm/s (Table 6) suggesting that soils from TP 1-TP 4 are fairly impervious. The high values of K for TP 5 and TP 6 indicating pervious soils can be attributed to their coarse sand and gravel contents.

**Table 4:** Grain size Distribution of soil samples from the Reservoir area

| Sample No. | Sampling Depth (m) | % Fines | % Sand | | | % Gravel | Soil Description |
|---|---|---|---|---|---|---|---|
| | | | Fine | Medium | Coarse | | |
| TP 1 | 0.25 - 0.90 | 16 | 7 | 20 | 54 | 3 | Clayey Sand |
| | 0.90 – 2.00 | 22 | 25 | 33 | 17 | 3 | Clayey Sand |
| TP 2 | 0.25 – 1.20 | 24 | 25 | 30 | 18 | 3 | Clayey Sand |
| | 1.20 – 2.00 | 35 | 26 | 30 | 9 | - | Clayey Sand |
| TP 3 | 0.25 – 1.80 | 14 | 8 | 22 | 50 | 6 | Clayey Sand |
| TP 4 | 0.20 – 1.80 | 16 | 9 | 21 | 48 | 8 | Clayey Sand |
| TP 5 | 0.25 – 2.00 | 4 | 6 | 13 | 60 | 17 | Gravelly Sand |
| TP 6 | 0.20 – 2.00 | 8 | 8 | 13 | 55 | 16 | Gravelly Sand |

**Table 5:** Consistency Characteristics of clay in soil samples from the Reservoir area

| Sample No. | Depth (m) | LL (%) | PL (%) | PI (%) | Casagrande Chart Classification |
|---|---|---|---|---|---|
| TP 1 | 0.25 - 0.90 | 31 | 12 | 19 | Medium Plasticity |
| | 0.90 – 2.00 | 40 | 17 | 23 | Medium Plasticity |
| TP 2 | 0.25 – 1.20 | 40 | 16 | 24 | Medium Plasticity |
| TP 3 | 0.25 – 1.80 | 30 | 13 | 17 | Medium Plasticity |
| TP 4 | 0.20 - 1.80 | 33 | 14 | 19 | Medium Plasticity |
| TP 5 | 0.25 - 2.00 | 24 | 8 | 16 | Low Plasticity |
| TP 6 | 0.20 – 2.00 | 28 | 10 | 18 | Low Plasticity |

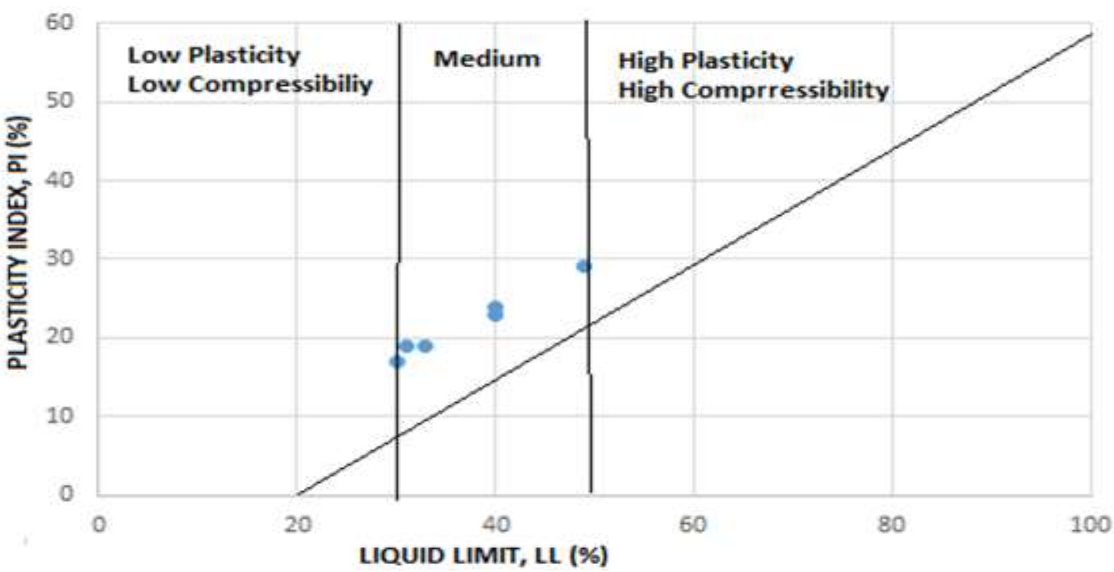


**Figure 10:** Casagrande Chart Classification of the soils

**Table 6:** Compaction and Laboratory Permeability on Remoulded Soil Samples from the Reservoir area

| Test pit No | Depth (m) | OMC (%) | MDD (Mg/m$^3$) | K.(cm/s) |
|---|---|---|---|---|
| TP 1 | 0.25 - 0.90 | 11 | 1.89 | $3.5x10^{-5}$ |
| | 0.90 – 2.00 | 15 | 1.81 | $4.3 x10^{-6}$ |
| TP 2 | 0.25 – 1.20 | 15 | 1.80 | $4.6 x10^{-6}$ |
| TP 3 | 0.25 – 1.80 | 12 | 1.88 | $3.3 x10^{-5}$ |
| TP 4 | 0.20 – 1.80 | 11 | 1.87 | $3.9 x10^{-5}$ |
| TP 5 | 0.25 – 2.00 | 9 | 1.93 | $2.8 x10^{-2}$ |
| TP 6 | 0.20 – 2.00 | 10 | 1.92 | $3.1 x10^{-2}$ |

OMC=Optimum Moisture Content, MDD=Maximum Dry Density, K= Coefficient of Permeability

## Conclusions

Geoelectrical and geotechnical investigations were conducted to characterize the subsurface and assess the competence of the subsoils at the site of a proposed small earth dam across River Kiyan in Ibapon, near Ogbomoso, southwestern Nigeria. Based on the results of the study, it was concluded that:

(i) The study area is underlain by sandy topsoil, clay/sandy clay and weathered/fractured/fresh bedrock. The clay/sandy clay layer has a mean thickness of 14.6 m and is good-to-fairly good material for the core of the dam embankment. The bedrock is fractured in places beneath the dam axis.

(ii) The subsoils from about 1.5 m depth beneath the dam axis are medium-to-very dense and can support the proposed dam embankment and the pressure from the water to be impounded upstream. They are fairly impervious and have medium plasticity.

(iii) Parts of the reservoir area farther than 100 m from the proposed dam axis are, however, pervious due to their sandy nature and can be replaced by competent impervious soils suitable for water impoundment.

(iv) The overburden can be excavated to access the bedrock for geotechnical remedial work, such as cement grouting, on the fractured zones beneath the proposed dam axis.

(v) The study area is feasible for siting an earth dam if the subsurface information provided by this study is adequately considered in the geotechnical design.

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