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# NON-INVASIVE GEOPHYSICAL INVESTIGATION OF FAILURE ALONG A SECTION OF AGO-IWOYE MARKET ROAD, AGO-IWOYE, SOUTHWESTERN NIGERIA

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## ABSTRACT

A detailed geophysical investigation was carried out to determine if the subsurface geology is responsible for the failures along this road section. This study aims to image and identify competent, moderately competent, and incompetent zones of the subsurface soil and thus to find out if geology is responsible for the failure along this section of the road. Electrical Resistivity Imaging (ERI) using the Wenner array 2D Imaging, and Vertical Electrical Sounding (VES) using the Schlumberger array were adopted for this survey. The geoelectric section from the VES revealed the presence of 3 lithological layers; topsoil, weathered layer (clay, sandy clay, clayey sand), and basement, which is also true for the electrical resistivity images revealed by the 2D electrical resistivity imaging. The results showed that the shallow subsurface beneath the road section is mostly underlain with clay that is geotechnically incompetent and not suitable for construction. The causes of road failure are believed to be the result of the incompetent clayey topsoil and the weathered layer seen in the profiles, which expand when absorbing water and shrink when drying, thus causing instability beneath the pavement due to the low shear strength and high compressibility, and also due to fractured basement rocks at shallow depths.

**Keywords:** Basement; Clay; Resistivity; Road failure, Subsurface; Topsoil.

## 1 INTRODUCTION

Roads are built to connect different cities, towns, and even communities. Road transportation is one of the most important and most common modes of transportation in Nigeria today due to the poor state of alternative modes of transportation in the country [1]. Road traffic depends on the pattern of human settlements, accounting for more than 90 % of the contribution of the sub sector to the Gross Domestic Product (GDP) [2]. If a road does not provide its required use by not having a smooth surface for vehicles to move on, that road fails.

Pavement failure has been attributed to factors such as excessive traffic load or underestimation of traffic volume, design problems such as poor structural design, the use of substandard construction materials or unethical construction practices [3]. Other factors include inadequate information on the underlying soil layers and the local subsurface geology [4] existence of geological structures such as fractures and faults, stream channels, and shear zones [5]. This failure is not restricted to only one geological terrain, as it can occur in both the basement complex and the sedimentary terrain.

The geophysics method of exploration has proved quite relevant in road and site investigations and several of these engineering and geological problems have been successfully solved by geophysical methods [6,7]. According to Kamil et al. [8], the evaluation of existing road structures has a major potential for the application of the electrical resistivity method, as there is an increasing interest in maintaining and improving the standard of service of the


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current road network. Although the importance of the geophysical method in engineering geophysics exploration work has not been proved, it has also been considered that another method of geoscience exploration approach can serve as a supplement to gather information on the condition of pavement depth and layer thickness, especially for a long continuous pavement assessment, thus reducing the number of coring tests that can cause damage to the pavement structure. A typical example is the combination of the geophysical and geotechnical approach to engineering problems [9,10,11].

Ebhohimen and Mamah [4], who worked on the geophysical investigation of road failure in the case of Opoji Nigeria using electrical resistivity, found out from the resistivity data that the subsurface, just a shallow depth, was underlain with clays/shale and sandstone, and the pseudo-section was able to show that the clays dominated the upper part of the subsurface and this was responsible for the cracks and potholes on the road. Aderemi and Adeola [12] carried out a geophysical investigation of the causes of road failure along the Abadina community road University of Ibadan, Nigeria, using VES and the failed segment of the road contained topsoil, clay, a weathered basement / fresh basement, and that the failure of the road arose from the differential settlement of the subgrade clay due to high porosity and very low permeability that causes it to swell after it absorbs water.

The purpose of this study is to appreciate the importance of geophysical surveys in identifying competent, moderately competent, and incompetent zones, and hence to determine whether the subsurface geology is responsible for the failure along this road section. The objectives are to determine the resistivity and thickness of the subsurface lithology, to deduce the subsurface lithology, to classify the subsurface lithology into competent, moderately competent, and incompetent zones, to suggest solutions to mitigate road failure along this road and to prevent future occurrence.

## 2 LOCATION OF STUDY AREA AND GEOLOGICAL SETTING

The investigated road is within Ago-Iwoye in southwestern Nigeria (Figure 1) and lies between the longitudes 3°53’60” E to 3°56’6.00” E and the latitudes 6°55’30” N to 6°57’00” N. The road serves as a link between Olabisi Onabanjo University and the main Ago-Iwoye market. At the time of the study, some major cracks and potholes can be seen on the road sections, which are signs of road failure. The study area is located within the tropical rainforest region of West Africa with a climate characterized by alternating dry and wet seasons with heavy rainfall, high temperature, and humidity. The mean annual rainfall is between 1200 and 1500 mm, reaching peaks in the months of June and July [13]. The wet season occurs between March and October or early November. The dry season is rather short with very hot days, which begins in late November and continues until the end of February. The relief is gently rugged, ranging from low to high with an elevation gradient of about 30 m, and has a dendritic drainage pattern; surface water flow is in the northeast-southwest direction.

The Precambrian basement rocks of Southwestern Nigeria are found in the Dahomey basin, which consists of banded gneisses, migmatite, and granite gneisses with low-grade metasedimentary and metavolcanic schists ruled by granites and charnockites of Pan African age [14]. Ago-Iwoye is in southwestern Nigeria and contains some of these rocks (Figure 2). Granite gneiss and biotite gneiss are often intruded by pegmatite veins and dykes. Older granite, granodiorites, and syenites with dolerite dykes also form part of the Precambrian basement of Nigeria. The crystalline basement rocks include biotite-hornblende gneiss, kyanite gneiss, migmatite gneiss, and granites are well fractured [15].

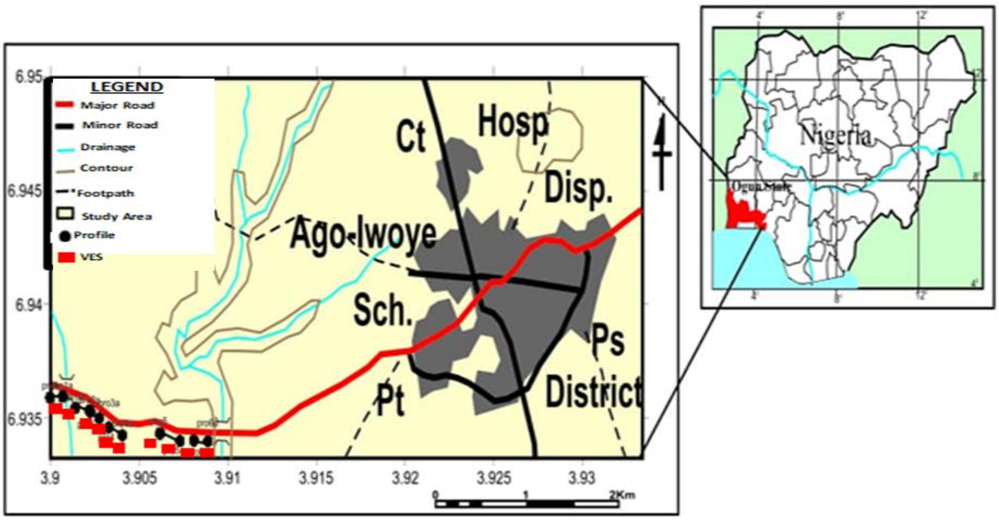


***Figure 1.*** *Base map of the study area showing the road along which the study was carried out*

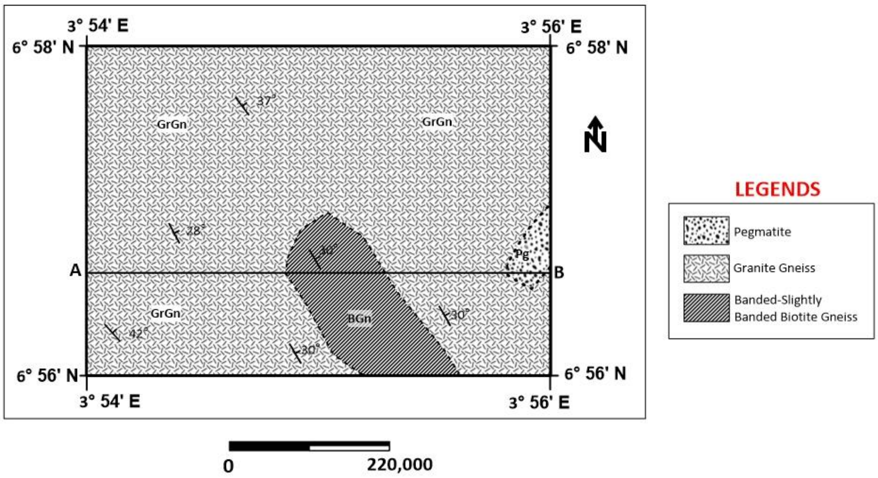


***Figure 2.*** *Geological map of Ago-Iwoye (adapted from [16])*

## 3 METHODOLOGY

In this study, Vertical Electrical Sounding and Electrical Resistivity Imaging (ERI) were used for the survey. The latter was used to get the 2D resolution of the subsurface because it probes vertically downward and then laterally along the profile while the former probes only vertically downward, and can show the approximate thickness of the overburden seen in the 2D electrical image gotten from the ERI. The instruments used for this survey are the Ohmega resistivity meter, 4 reels of cable and connecting wire, 4 electrodes, 4 hammers, a handy GPS receiver, field notes and measuring tapes.

The vertical electrical sounding method entails the establishment of 10 VES points to a current spread (AB/2 = 100 m), while the field procedure for the 2D imaging survey entails the use of the Wenner array configuration to establish a total of 6 profiles (Figure 3), 3 of which were 120 m long and the others 100 m in length with a length of 120 m and 100 m, respectively, for a 5-level measurement.

The data processing of the vertical electrical sounding method was achieved by plotting the obtained resistivity values against the half-current electrode spacing (AB/2) on a bi-logarithm graph. The obtained curve is then manually matched with a Schlumberger master curve to delineate the number of layers and estimate the corresponding resistivity and thickness of the layers, after which the geoelectric parameters were modeled using computer iteration on a WinResist program to obtain the geoelectric parameters for the delineated layers. Similarly, the 2D apparent resistivity data were processed and inverted concurrently using the RES2DINV inversion code [17]. The RES2DINV program uses a non-linear optimization technique that automatically determines the inverse model of the 2D resistivity distribution of the subsurface for the measured apparent resistivity data [18].

# 4 RESULTS AND DISCUSSION

## 4.1 Vertical Electrical Sounding (VES) Results

The results of the VES inversion produced the geoelectric parameters in the form of layer resistivity, depth, thickness, and lithology, and are presented in Table 1 below. The geology of the study location, which is a basement terrain, aided in the inference of the lithology of the study area to be topsoil, weathered materials (clay, sandy clay, clayey sand, sand), and basement rock, which helped to classify the subsurface into competent, moderately competent, and incompetent zones. The curve types obtained in the area are H, HA, and KH, which means the subsurface is three to four layers, the topsoil and weathered layer are composed of clay, sandy clay, and clayey sand, with clay being the predominant material while the basement rock is fresh, weathered, or fractured. The resistivity of the topsoil varies from 17.8 to 197 Ωm and has an average thickness of 0.85 m, the weathered layer has a resistivity range of 9.3 to 50.1 Ωm, and the basement rock has a resistivity range of 603.3 to 7710.6 Ωm. A summary of the VES results can be seen in Table 1, and a cross section of the six VES points on the profiles can also be seen in Figure 3. It can be seen that the resistivity of the topsoil and the weathered layer for all the VES points are <200 Ωm and the roads are in poor to bad conditions. VES 1, 3, 4, and 5 have topsoil resistivity values between 17.8 and 109 Ωm, which corresponds to clay and sandy clay soils which are incompetent soils that should not be used for construction. While VES 2 and 6 have resistivity values of 165 and 197 Ωm, which corresponds to more competent clayey sand, the layer is not thick enough (0.5–1.4 m), and also the weathered layer beneath all the VES points is filled with clay (9.3–38.9 Ωm), the very low resistivity means the conductivity is higher, showing that the clay contains a high moisture content. This low resistivity is proof that soil is not ideal for engineering construction due to the absence of drainage, low shear strength, and high compressibility. From lithology (Table 1), it can be inferred that clay <100 Ωm is incompetent, sandy clay is moderately competent, clayey sand is competent, and the basement is competent when not fractured and present at a shallow depth.

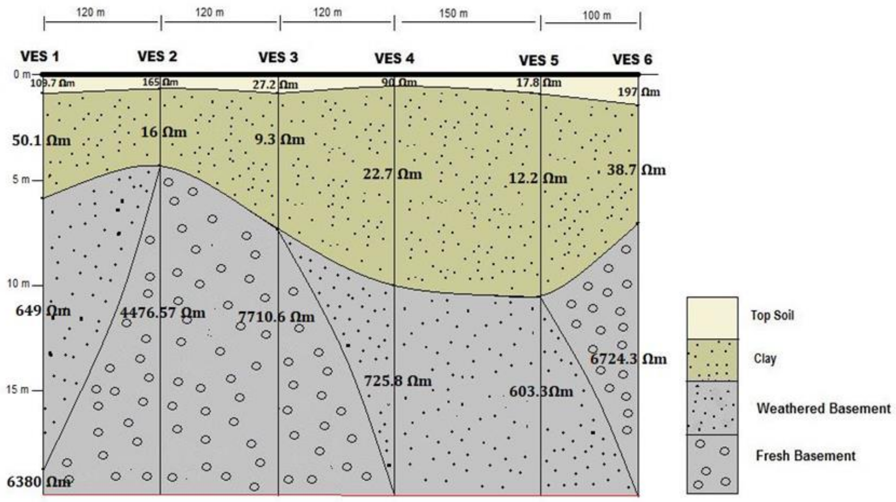


***Figure 3.*** *Geoelectric section of VES points on profile showing depth, resistivity and the correlation of lithology along the traverse*

***Table 1.*** *Geoelectric parameters of the Vertical Electrical Sounding points*

| VES No | Resistivity (Ωm) | Thickness (m) | Depth (m) | Curve type | Lithology |
|---|---|---|---|---|---|
| 1 | 109.7 | 0.8 | 0.8 | HA | Topsoil |
| | 50.1 | 5 | 5.7 | | Clay |
| | 649 | 13 | 18.7 | | Weathered basement |
| | 6380 | | | | Fresh Basement |
| 2 | 165 | 0.6 | 0.6 | H | Topsoil |
| | 16 | 3.7 | 4.2 | | Clay |
| | 476.5 | | | | Fresh Basement |
| 3 | 27.2 | 0.8 | 0.8 | H | Topsoil |
| | 9.3 | 6.5 | 7.3 | | Clay |
| | 7710.6 | | | | Fresh Basement |
| 4 | 90 | 0.5 | 0.5 | H | Topsoil |
| | 22.7 | 9.5 | 10 | | Clay |
| | 725.8 | | | | Weathered basement |
| 5 | 17.8 | 0.8 | 0.8 | H | Topsoil |
| | 12.2 | 9.7 | 10.4 | | Clay |
| | 603.3 | | | | Weathered basement |
| 6 | 197 | 1.4 | 1.4 | H | Topsoil |
| | 38.7 | 5.6 | 7 | | Clay |
| | 6724.3 | | | | Fresh Basement |
| 7 | 97.1 | 1.1 | 1.1 | HA | Topsoil |
| | 31.6 | 17.8 | 19 | | Clay |
| | 149.9 | 27.3 | 46.2 | | Sandy Clay |
| | 2246.6 | | | | Fractured Basement |
| 8 | 68.4 | 1.1 | 1.1 | HA | Topsoil |
| | 37.4 | 0.9 | 2 | | Clay |
| | 101.5 | 7.5 | 9.6 | | Sandy Clay |
| | 1782.9 | | | | Fractured Basement |
| 9 | 87.3 | 0.7 | 0.7 | KH | Topsoil |
| | 149.9 | 1 | 1.8 | | Sandy Clay |
| | 32.1 | 6.9 | 8.7 | | Clay |
| | 7709.4 | | | | Fresh Basement |
| 10 | 91.7 | 0.7 | 0.7 | KH | Topsoil |
| | 184.7 | 1.8 | 2.5 | | Clayey Sand |
| | 49.3 | 6.8 | 9.2 | | Clay |
| | 1523.1 | | | | Fresh Basement |

## 4.2 Electrical Resistivity Imaging (ERI) Results

The data were collected in order to automatically generate a two-dimensional 2D resistivity image for the subsurface that can be referred to as the 'Electrical Image'. These values obtained were used for the qualitative interpretation of the profiles. The essence of the data collected from these profiles was to understand the subsurface geology in the study area and to deduce how it affects the pavement above it.

**Interpretation of profile 1:** bad road portion; the electrical image shows that the study area reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement in VES1 (Figure 4). The RMS error is 4.1 %, and the electrical image shows shallow to near-surface layers, the resistivity of which is between 17 to 120 Ωm and a thickness of about 4.5 m, which shows that the topsoil down to the weathered layer is clayey to sandy clay. It is quite similar to VES1 and not competent for engineering construction because there would be a differential settlement of the sub-base and sub-grade, which will lead to failure. There are also low resistivity areas between high resistivity, which is diagnostic of a shallow fracture/fault present at the southern and middle part of the profile, which could also have contributed to the failed section.

**Interpretation of profile 2:** bad road condition; the electrical image shows that the study area reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement in VES 2 (Figure 5). The electrical image shows shallow to near-surface layers, the resistivity of which is between 10 and 200 Ωm with a thickness of about 7 m, below there are layers with higher resistivity, which means the entire near-surface is mostly clayey in nature, which is not competent material for road pavement construction. A portion of the profile has a resistivity between 10 and 60 Ωm, indicating a highly saturated zone with high moisture content, as clay swells upon absorbing water and shrinks on drying, which is likely responsible for the potholes seen in this road section.

**Interpretation of profile 3:** bad road condition; the electrical image shows that the study area reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement in VES 3 (Figure 6). The electrical image shows shallow to near-surface layers, the resistivity of which is between 9 and 100 Ωm with a thickness of approximately 4.5 m, which means the entire profile is clayey. In the presence of clay, the permeability of a geotechnical material decreases [19] as it can retain water. The mid-region of the profile has a resistivity between 10 and 25 Ωm, indicating a highly saturated zone with high moisture content. The darkest part of the middle portion is within the weathered layer and has a very low resistivity of <10 Ωm indicating a weathered layer of VES 3. This low-resistivity soil is likely responsible for the bad state of the road section.

**Interpretation of profile 4:** bad road condition; the electrical image shows that the study area reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement in VES4 (Figure 7). The electrical image shows shallow to near-surface layers, the resistivity of which is between 12 and 100 Ωm with a thickness of about 5 m, which means the entire near-surface is clayey. The dark blue portions of the profile have resistivity <30 Ωm, which is a highly saturated zone that occurs at different depths along a lateral distance of 0 to 100 m of the traverse. It may have helped to differentially settle the subgrade and then the subsequent failure of the road section [20, 21]. The lower middle portion is within the weathered layer and has a very low resistivity between 20 and 30 Ωm, which corresponds to the weathered layer of VES4. A large pothole was present at the time of the survey; other sections of this road will soon follow as vehicles continue to ply the road.

**Interpretation of profile 5:** fair road condition; the electrical image of this profile reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement, as in VES 5 (Figure 8). The image shows shallow to near-surface layers, the resistivity of which is between 8 and 200 Ωm with a thickness of about 10 m, which means the entire near-surface is clayey. The deep blue portions of the profile have resistivity <50 Ωm, indicating a highly saturated zone with high moisture content that may be responsible for road conditions because there is a differential settlement as vehicles move over them. Although this road is not as bad as the others, there are signs all over the pavement that it will fail soon.

**Interpretation of profile 6:** bad road portion; the electrical image shows that the study area reveals the presence of 3 lithological layers corresponding to the topsoil, the weathered layer, and the basement in VES 6 (Figure 9). The electrical image shows shallow to near-surface layers, the resistivity of which is between 23 and 250 Ωm and a thickness of about 10 m, which shows that the first few meters are mostly clayey with a small amount of clayey sand. It is not competent for engineering construction because there would be differential settlement of the sub-base and sub-grade, which could lead to failure and may be responsible for the bad state of the road section.

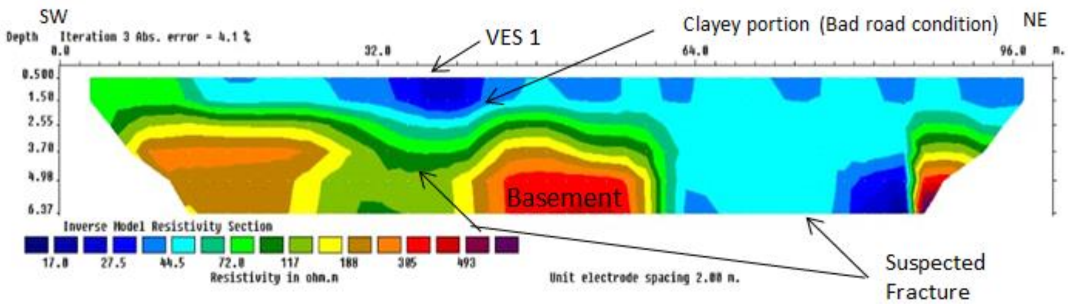


***Figure 4.*** *A 2D electrical resistivity image of profile 1*


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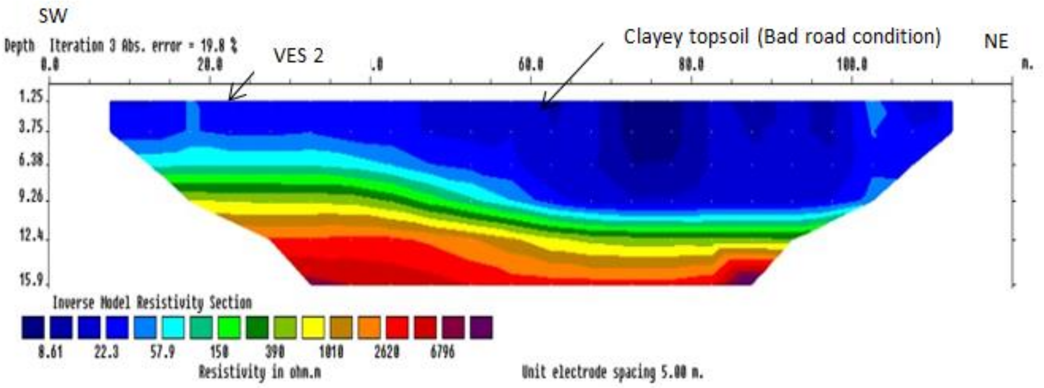


***Figure 5.*** *A 2D electrical resistivity image of profile 2*

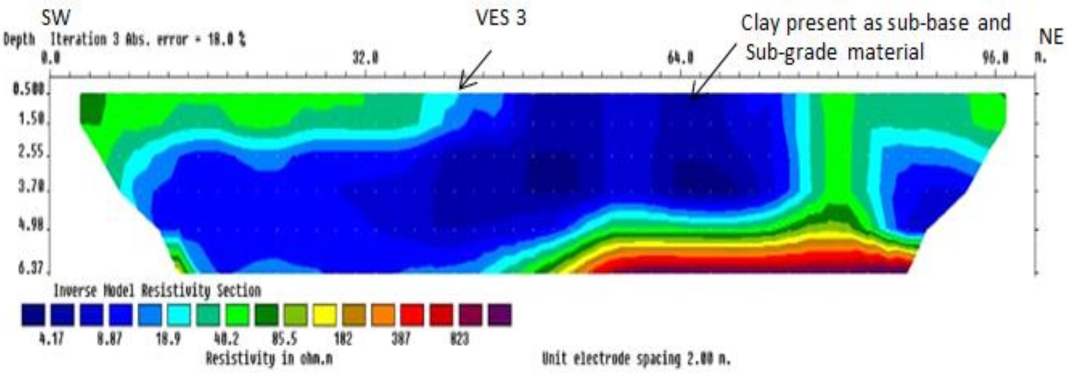


***Figure 6.*** *A 2D electrical resistivity image of profile 3*

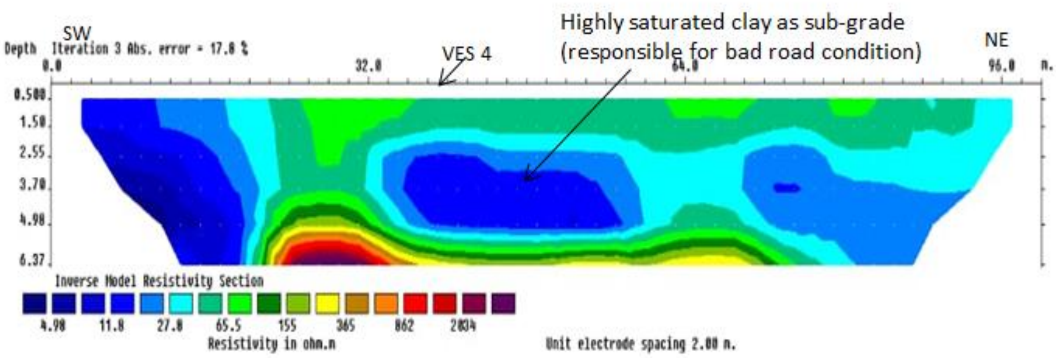


***Figure 7.*** *A 2D electrical resistivity image of profile 4*


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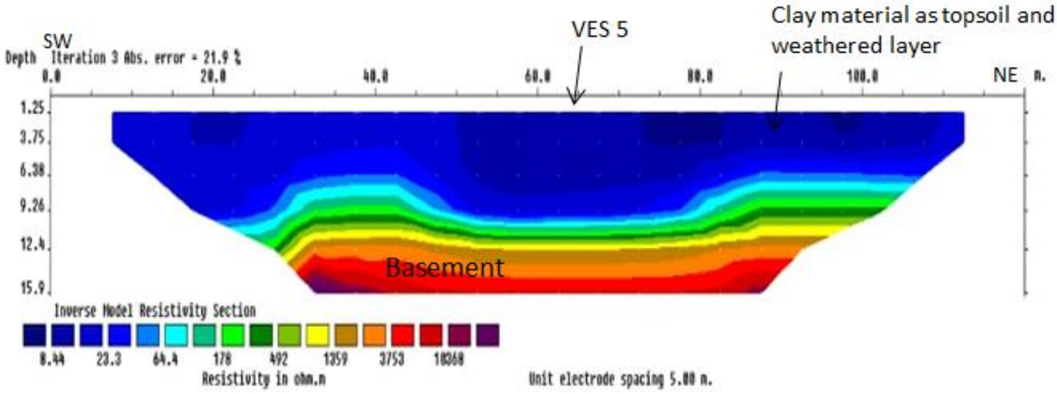


***Figure 8.*** *A 2D electrical resistivity image of profile 5*

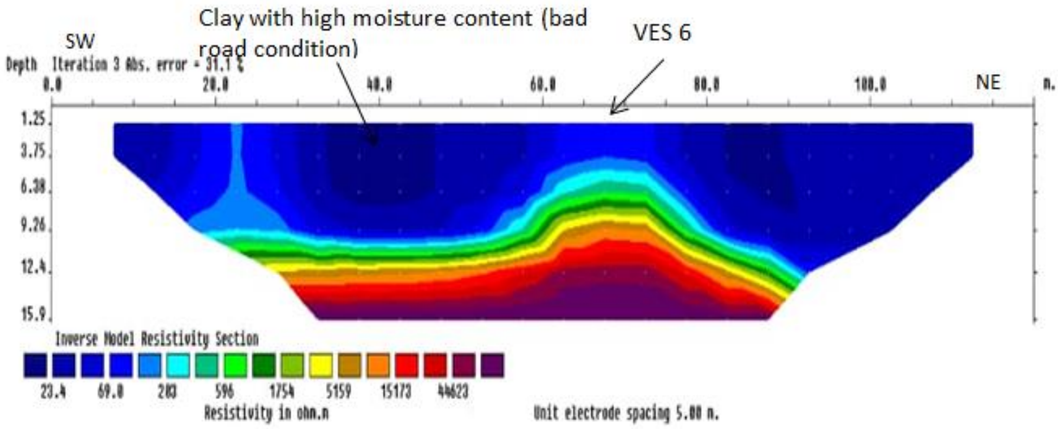


***Figure 9.*** *A 2D electrical resistivity image of profile 6*

## 5 CONCLUSION

A geophysical investigation was carried out using the electrical resistivity method (2D ERI and VES) to determine whether the geology beneath the subsurface is responsible for the incessant failure along a section of the Ago-Iwoye market road. The electrical image and the VES cross section indicated that the subsoil beneath the pavement is characterised by low resistivity soils as both sub-base and sub-grade and are thus geotechnically incompetent. The low-resistivity soils are clay, being highly saturated at some locations along the traverse, sandy clay, and clayey sand, which is more competent than the others but was not thick enough where present.

The result obtained at the end of this geophysical survey has helped to determine the resistivity and thicknesses of the underlying layers at the subsurface. It aided in inferring the subsurface lithology, classifying them into competent, moderately competent, or incompetent layers, and has revealed that clay is the predominant soil in the topsoil and the weathered layer. This clay could swell upon absorbing moisture (water) and shrink upon drying, thus causing instability beneath the pavement as vehicles move due to the low shear strength and high compressibility. Also, the presence of shallow faults/fractures could be responsible for the road failure.

The result of the electrical resistivity probing and imaging with the understanding of the behavior of earth's subsurface materials electrical properties with the knowledge of the geology of the study area result in the conclusion that the failure of the road is due to the underlying clayey layer.

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