E-ISSN: 1116 - 2759 P-ISSN: 3027-0111
MPRI-EDIR | INTERNATIONAL JOURNAL OF EARTH DESIGN AND INNOVATION RESEARCH
VOL. 10 NO. 4 – OCTOBER, 2025

INVESTIGATION OF THE CAUSES OF ROAD PAVEMENT FAILURE ALONG MARABA KAGORO - GIDAN WAYA ROAD, KADUNA STATE USING ELECTRICAL RESISTIVITY TOMOGRAPHY

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DOI: https://doi.org/10.70382/mejedir.v10i4.062

Abstract

A geophysical survey was undertaken using Electrical Resistivity Tomography to investigate the causes of road failure along Maraba Kagoro - Gidan Waya Road in Jema'a Local Government Area of Kaduna. The resistivity of the study area was measured using ABEM SAS (1000) Tetrameter. Two profiles, one on each side of the affected road, were laid, and the survey involved Vertical Electrical Sounding (VES) with Wenner configuration so as to get a better depth resolution and higher signal strength. The measured VES data were taken by using four electrodes (two current and two potential electrodes) with current electrode spacing (AB/2) varying from 1 to 200 m. Both the two-horizontal profiling (1 and 2) were carried out using electrode separation, $r = 5m$. During the survey, current was injected into the ground through the current electrodes. C_1 and C_2 and the corresponding voltages were obtained through the potential electrodes P_1 and P_2. Resistivity values of the study area with their respective depths were delineated across the entire profiles. Profile P_1 and P_2Have resistivity values (<400Ωm at depth 6.38m, 600 - 1700Ωm at depth >6.38m towards left and 2800 - 4700Ωm at depth 8m between 120 - 180m across the profile) and (<300Ωm between 0-60m to the left of the profile at depth below 6.38m, 44167Ωm between 60-100m at depth >6.38m towards the centre from the left, >8000Ωm between 100 - 140m from the left of the

Keywords: Electrical, Resistivity, Causes, Road, Failure

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profile. It showed that the left of the profile is clayed or high **moisture weak sub-grade, the centre contains s**tronger sub-grade, and toward the right is more **c**ompacted soil. The sandy-clay contents account for the low resistivity values from the left towards the centre, causing uneven ground movement, suspected to be responsible for the perpetual road failure. It is therefore recommended that the portions containing the sandy-clay should be ripped to a depth of 6-7m and be filled with more competent materials of high resistivity, and further research using seismic refraction should also be carried out to strengthen these findings.

Introduction

Nigeria, just like any other country, has been working tirelessly to develop its country to meet the needs of its increasing population in all areas of human endeavour. To develop a nation, there must be an all-round advancement that cuts across all sectors of life. These sectors could be health, education, agriculture, security, transportation, trading, mining, and so on. These sectors are interconnected in one way or another and also depend on some variables, such as roads for accessibility. This means people need roads for transportation irrespective of the sector, thereby making roads indispensable for both economic and structural development.

Road is an open space or route for travelling or transportation, which usually connects villages, just like arteries in the human body (Amadasun et al., 2019). These roads are indispensable to man due to their involvement in every activity. In every event, roads are required to walk or travel on, either on foot or by means of a moving machine, to aid transportation. These roads are constructed using soil and rocks to provide smooth movement and are meant to last for decades. Unfortunately, they fail to offer the intended purposes for which they are constructed shortly after their construction. Their failures are manifested in potholes, cracks, fractures, and so on, and they are prevalent across Nigeria (Aderemi and Adeola, 2021). On several occasions, they become a death trap zone shortly after construction. This sad scenario has prompted several debates and research among Geo scientists. In an effort to investigate the causes of road pavement failure, Layade et al., (2017) carried out a geophysical investigation on the causes of road pavement failure along the Ibadan-Lagos dual carriage road. The findings of their research work showed the presence of sandy-clay formation at both the topsoil and weathered layer, and the fractured bedrock was linked to the geology contacts that absorbed water as a result of its significant porosity and permeability. For a similar reason, Weltime et al., (2022) used Electrical Resistivity Tomography to investigate geological causes of road failure in Taraba State, Nigeria. The results of their investigation clearly depicted the presence of clay on the top segments of the road to be one of the major variables causing the road failure. According to them, the incompetent nature of the top soils due to their

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clay content reduces the ability of the soil to give the needed support to withstand the weight likely to be placed on the road; hence making it vulnerable to failure. Different variables can lead to Road failure, which can either be functional (occurring on the surface pavements) or structural (deep-seated). In most notable cases, road failure occurs due to some factors that are geological, engineering and structural. Results from different research work and laboratory tests have revealed that road failure is largely due to a lack of adequate knowledge of the geology of the subsurface where the road will be constructed (Adiat et al., 2017). Due to a lack of geological information on the subsurface media, road failure is common across Nigeria (Momoh et al., 2008). In line with this, Nolan et al., (2011) carried out a geological survey and laboratory experiments to investigate the causes of road pavement failure, and they found that design and construction problems are only an integral cause of road failures, but stressed that the major cause of road failure is a lack of sufficient information about the characteristics of the sub-grade soil before road construction. Also, Abdusalam et al., (2023) applied electrical resistivity tomography to unravel the causes of Failure Along Ganaja Road, Lokoja, Northcentral Nigeria. The findings of their work revealed that the presence of clay was responsible for the road failure. They further opined that the lack of subsurface knowledge before the road contribution was a contributing factor to the road failure.

Since most construction companies usually pay little attention to the need for information about the subsurface media, this usually results in road failure on most Nigerian roads. This scenario has been consuming the lives and properties of Nigerians, and maintaining it is a financial burden on the Federal, State, and Local Governments (Goodwin et al., 2021).

To mitigate the rate of deaths caused by the failed roads and also prevent financial waste on road maintenance, different geological surveys such as seismic, electrical resistivity tomography, ground magnetic, very low frequency electromagnetic, etc., have been applied by many scholars to identify the causes that may lead to road failure, and have been effective and reliable tools. These geophysical methods are advantageous, cheap, fast, and non-destructive in investigating discontinuity in road networks resulting from fractures, cracks, bulges, and depressions (Ozegin, 2016).

This study becomes very essential as the Maraba Kagoro–Gidan Waya road is the major road connecting Kaduna State from Maraban Kagoro and Plateau State through Gidan Waya. The growing loss in serviceability of this Kagoro-Gidan Waya road cannot be quantified, as it has become a menace to the road users. This problem is characterised by severe pavement distress ranging from large potholes, alligator cracking, collapse, and clogging of drainage. The occurrence of these failures is a major problem for both motorists and pedestrians, as it has been contributing significantly to loss of lives, properties, and human injuries through accidents, impedance of human movement and flow of economic activities, encouragement of armed robberies along the affected

regions, environmental pollution, degradation, and a host of other negative consequences. This problem could be characterized by some geophysical events that usually occur within the subsurface of the Earth. A particular section of this road keeps collapsing and failing, despite spending huge money by the federal government in repairing it, after being repaired, it fails again and again. The rate at which people lose their lives and properties on a daily basis due to the failed section of this road informed the choice of the roads for the present study. Basically, the objective of this study is to carry out a geophysical investigation of some failed segments of Maraba kagoro - Gidan waya road using electrical resistivity tomography.

Study Area

The failed section of the road under study is between Maraban Kagoro and Gidan Waya. The landscape of the area is largely undulating, featuring a combination of rocky hills, flat plains, and seasonal streams or rivulets that descend from higher elevations to the lowlands during the rainy season. The study area around Gidan Waya lies at an altitude of about 640 to 700 meters above sea level (figure 1). The area is also covered with vegetation, which makes it become good habitat for wild animals (figure 2). Within the axis, a federal road passes, and it connects Kaduna state and Plateau state through Maraban Kagoro - Gidan Waya road, in Jema'a local government Area of Kaduna state. A particular section of this road has been failing repeatedly, and the section is shown in Figure 3

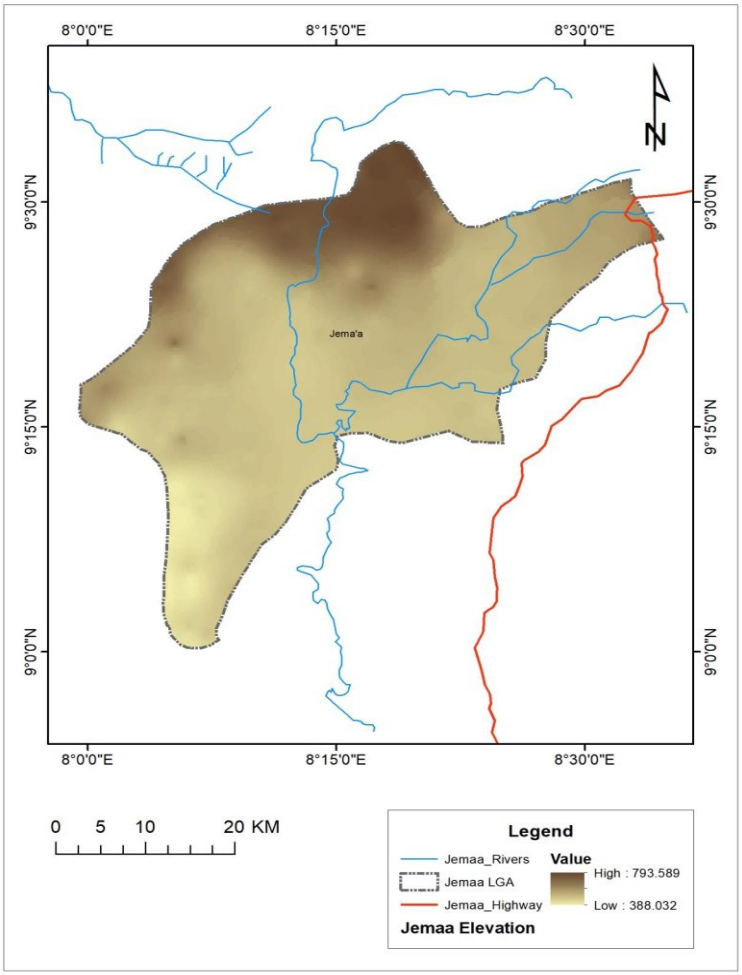


Figure 1: Jema'a map showing elevation (Geographic Information System KASU, 2025)

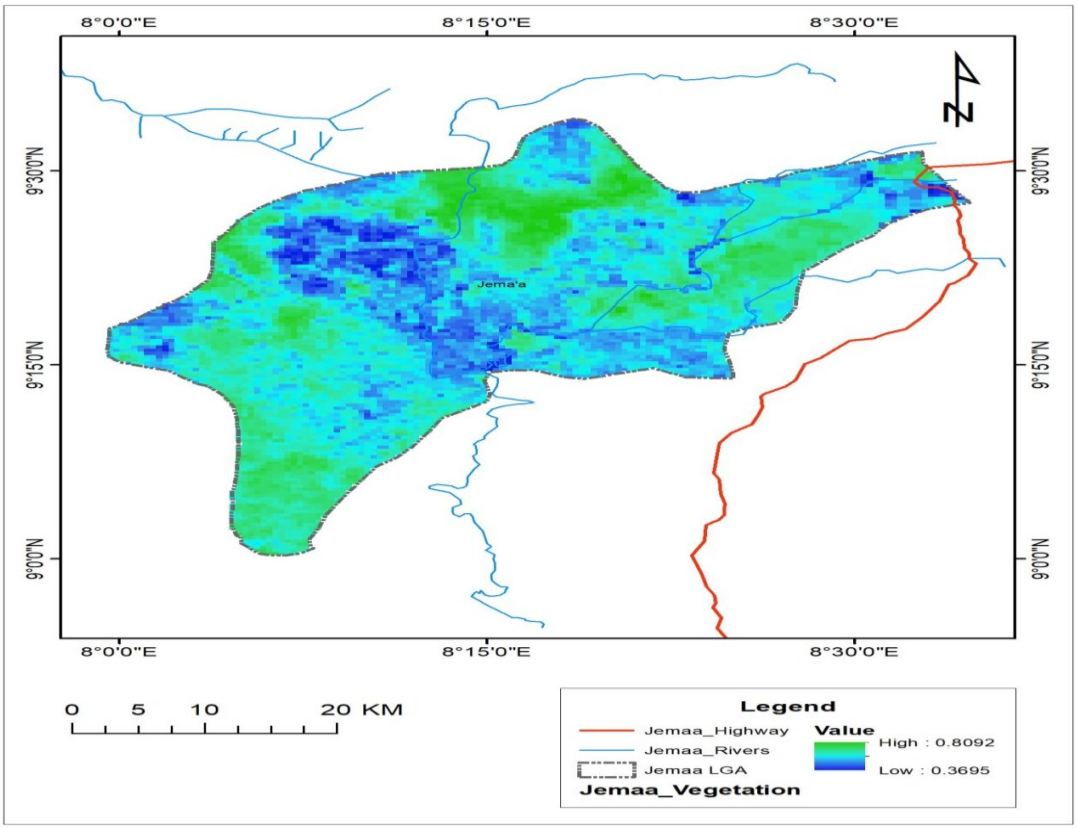


Figure 2: Map of Jema'a showing vegetation (Geographic Information System KASU, 2025)

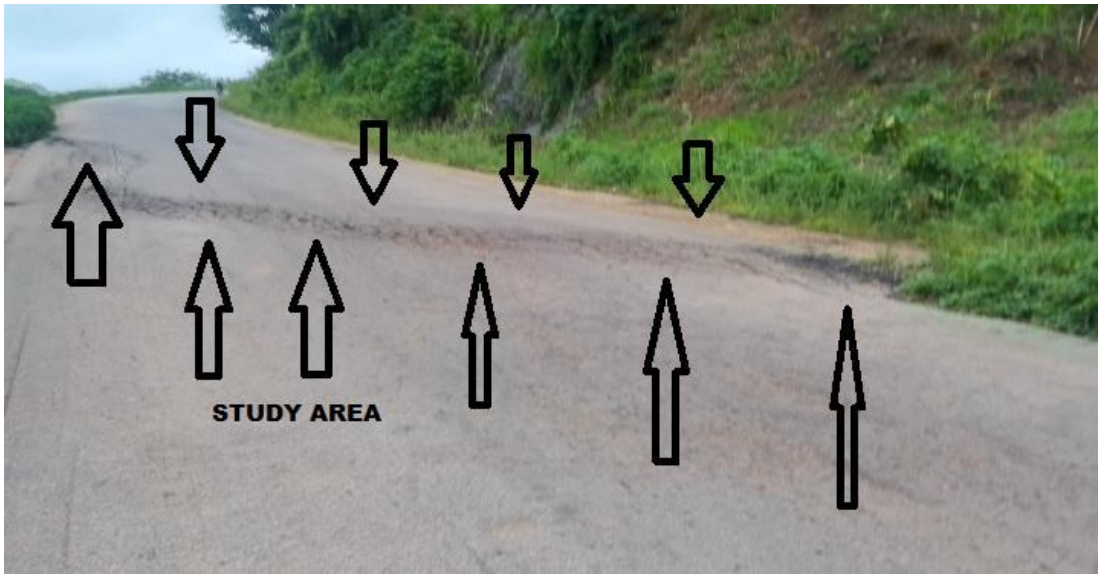


Figure 3: picture of the failed section of the road taking during the research survey (Garba, 2025)

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Geology of the Study Area

The Jema'a region is one of the 23 local government area of Kaduna State, Nigeria, and is underlain by Crystalline Basement rocks, mainly comprising migmatite-gneiss complexes and intrusions of Older Granites. The area is notable for its abundant mineral resources, including tin, sapphire, tourmaline, and mica, which occur within granitic pegmatites formed during the cooling of the granite bodies (Garba et al., 2022).

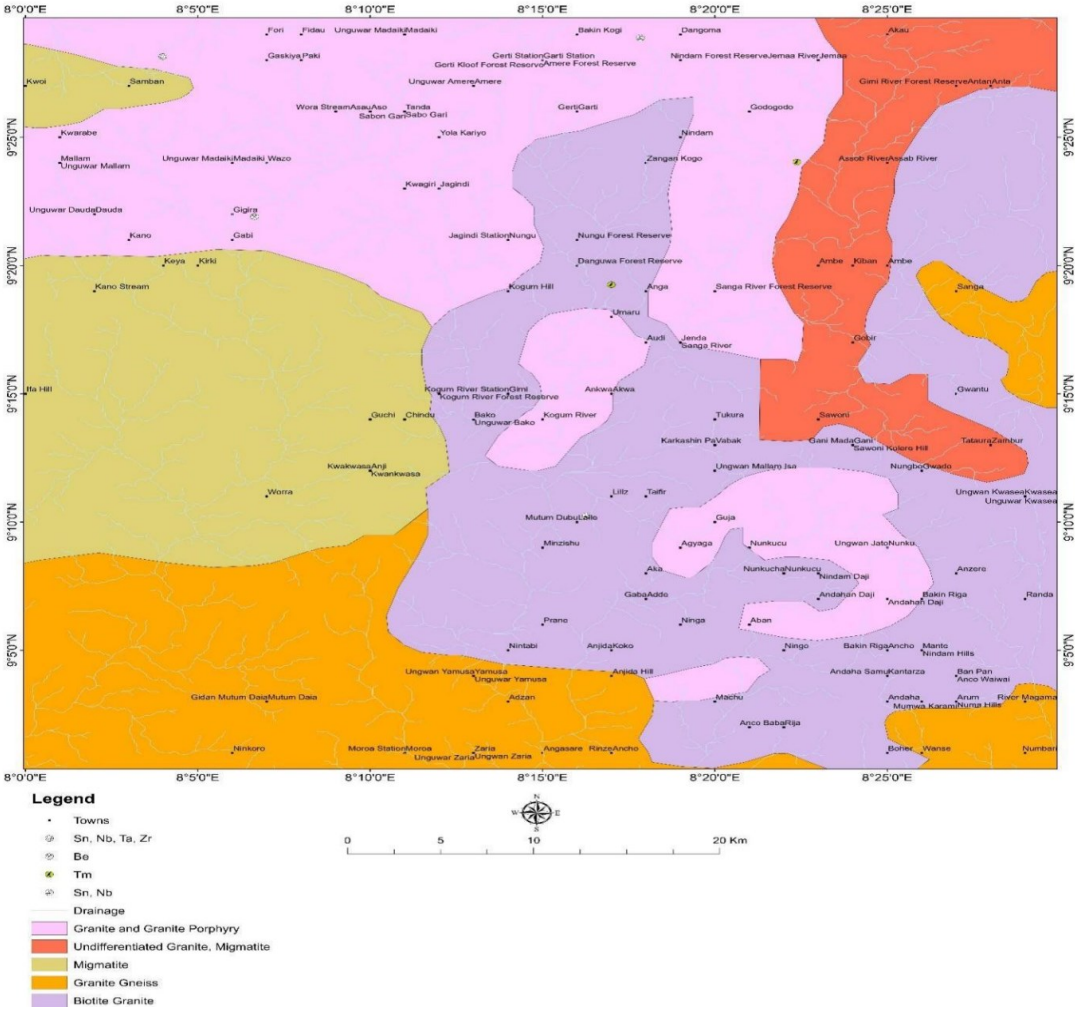


Figure 4: Geological map of Jema'a (Garba et al., 2022)

Materials

The materials used for this survey were GPS, a voltage source, geophones, a power inverter, connecting wires, an electric blaster, a resistivity meter, electrodes, cables, a hammer, Data processing software, a laptop, suffer 13 software, grapher software, RES2DINVER software, and Micro Excel.

Electrical Resistivity Survey and data Acquisition

A geophysical survey was carried out using Electrical Resistivity Tomography to investigate the causes of road failure in the study area. The resistivity of the study area was measured using ABEM SAS (1000) Tetrameter. Two profiles, one on each side of the affected road was laid and the survey involved Vertical Electrical Sounding with Wenner configuration configuration so as to get a better depth resolution and higher signal strength. The measured VES data was taken by using four electrodes (two current and two potential electrodes) with current electrode spacing (AB) varying from 1 to 200 m. Both the two horizontal profiling (1 and 2) were carried out using electrodes separation, r = 5m. during the survey, current was injected into the ground through the current electrodes C_1 and C_2 and corresponding voltages were obtained through the potential electrodes P_1 and P_2.

The electrical resistivity method involved the characterization of subsurface resistivity distribution by taking ground surface measurements. During the process, electrical current (***I***) was injected into the earth through a pair of electrodes and the corresponding potential differences (***ΔV***) were measured between another pair of electrodes. This was done in accordance with the relationship given below

$$\rho_a = G\frac{\Delta V}{I} \quad \text{.....1}$$

Where ρ_a the apparent resistivity and G is the geometric factor which value depends on the electrode arrays configuration. In acquiring the data, the choice of electrode array was taken into consideration since it determines the quality of resolution, reliability and the nature of imaging and the depth of investigation, based on the findings of (Aizebeokhai, 2010).

The change in potential was based on the principle given by the equation

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right] \quad \text{.....2}$$

Where r_1, r_2, r_3 and r_4 are electrodes' separations

The inversion model was carried out using RES2DINVER. The least-squares inversion method was used to carry out the inversion model.

Results

Electrical Resistivity Tomography values of Maraba Kagoro - Gidan waya, Jema'a local Government area of Kaduna state are shown in Table 1. The results of the research conducted on the failed section of the road were presented as pseudo sections and 2-D

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resistivity images. The summary of the layer resistivity and thickness, and inferred lithology of each geoelectric layer interpretation results are also presented in Table 1.

Table 1: Electrical resistivity values of Maraba - Gidan way road

Profile	Layer	Resistivity Values Ω-m	Distance (m)	Colour Code	Inferred Lithology
$P_1(A_1)$	Left	< 376Ωm	0 - 60m	Red - Orange	Clayed rich axis
	Center	600 - 1700Ωm	60 - 120m	Green - yellow	Sandy soil
	Right	< 400Ωm	120 -160m	Blue - green	Clayed rich axis
A_2	Left	133 - 300Ωm	70m	Deep blue	Clayed rich zone
	Center	600 - 1700Ωm	>70 < 120	Green - Yellow	Lateritic zone
	Right	2800 - 4700Ωm	120 -180m	Red/purple	Gravel area
$P_2(B_1)$	Left	<300 Ωm	0 - 40m	blue–green	clay-rich soil, a weak zone
	Center	500–2000 Ωm	40 - 120m	yellow–orange	Stronger subgrade
	Right	<300 Ωm	120m -200m	Blue - Green	Clay axis
B_2	Left	54 - 230Ωm	0 - 60m	Blue - Green	Clayed rich axis
	Center	474 - 4167Ωm	60 - 100m	Yellow - Red	Weathered rock, Mixed soil
	Right	>8000Ωm	100 -140m	Dark red/purple	Compacted soil, Dry rock

The 2D inverted resistivity maps of the two profiles (P_1 & P_2) are given in Figures 5 -10. Some hidden features of the subsurface which could be responsible for the road pavement failure are revealed by pseudo sections, as depicted in figure 5. The sections from 0 to 120m to the left and at a distance > 160m to the right hand-side at shallow depth have near surface low resistivity (<400 Ωm) indicated in blue color. These sections of the road are likely clayed or contain poor fill materials.

The resistivity increased above 2000Ωm at a depth greater than 6.38m towards the left, suggesting a competent bedrock.

Below it is the Chargeability Section (from Induced Polarization) depicted in blue and **purple Color which is given** from **1.61 ms (blue)** to **49.6 ms** (purple)

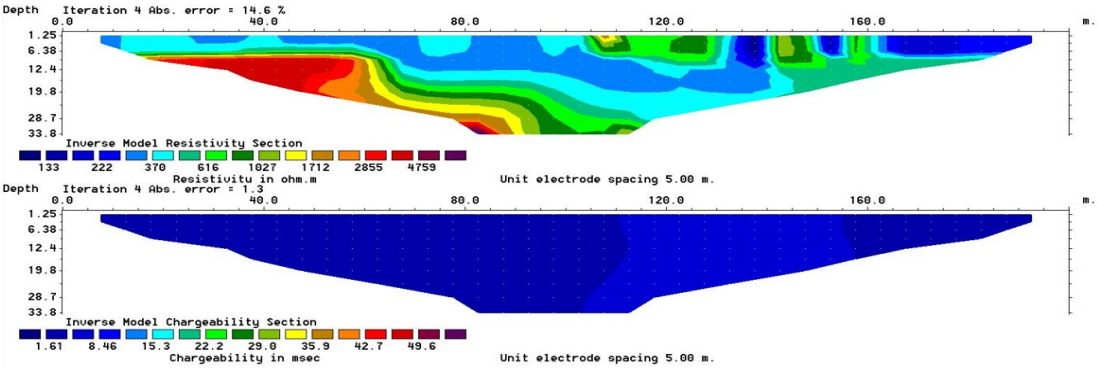


Figure 5: 2D:Pseudo-section plots showing Inverse model Resistivity section and inverse model Chargeability section of profile P_1

Figure 6 showed three pronounced zones across the profiles with the top panel having resistivity range from 54 Ω·m (blue) to 8599 Ωm (purple) at depths between 0.0 and 33.8 m. the resistivity values were very low at shallow depths (<6.38m) towards the centre and at the right hand side of the profile

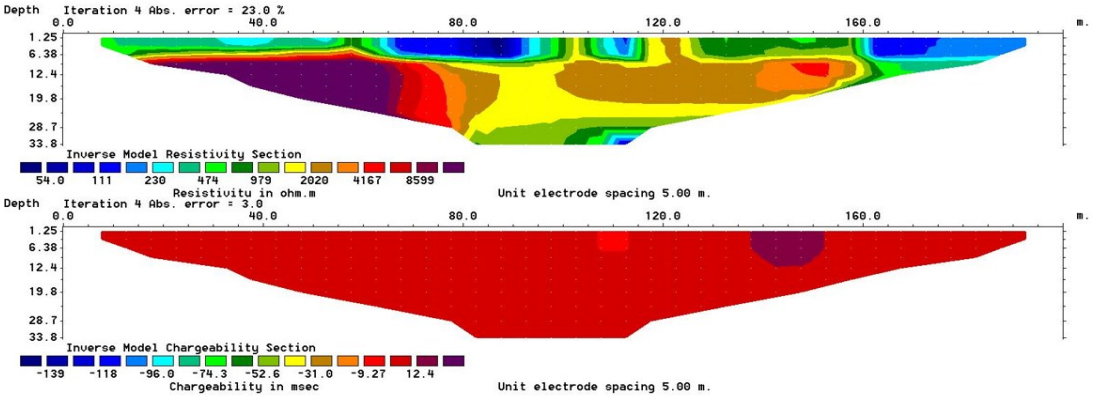


Figure 6: 2D:Pseudo-section plots showing Inverse model Resistivity section and inverse model Chargeability section of profile P_2

Figure 7 are the *Measured apparent resistivity pseudosection* (**Top panel**), calculated *apparent resistivity pseudosection* (**Middle panel) and** true 2D resistivity structure (*final the inverse model resistivity section) as displayed by the b***ottom panel.**

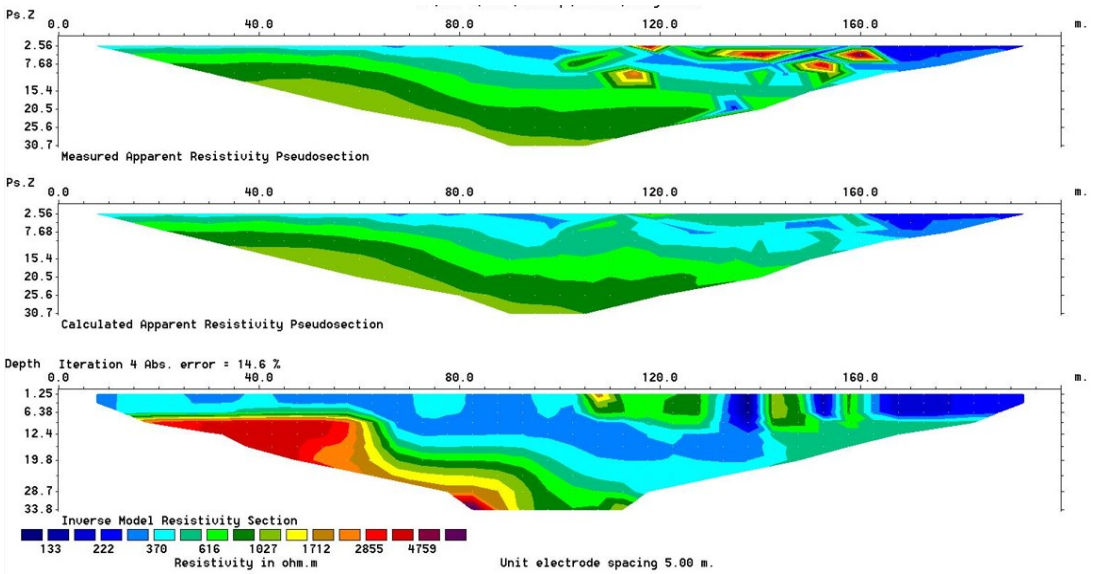


Figure 7: 2D:Pseudo-section plots showing measured apparent resistivity, calculated apparent resistivity and inverse model resistivity section of profile P_1

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Figure 8 pseudo sections obtained across profile 2 with b**lue/green having a near surface low resistivity in the range 54 – 230 Ω·m towards the centre of the profile at a depth** < 6.38m**. This section of the road is saturated or clay-rich material.**
The next is the Intermediate resistivity depicting **Yellow to red with resistivity values ranging from 474 - 4167 Ωm. This section contains mixed soil that is** partly saturated.
The bottom panel displayed Dark red/purple having a very high resistivity greater than 8000 Ωm. This section of the road contains compacted materials with little water.

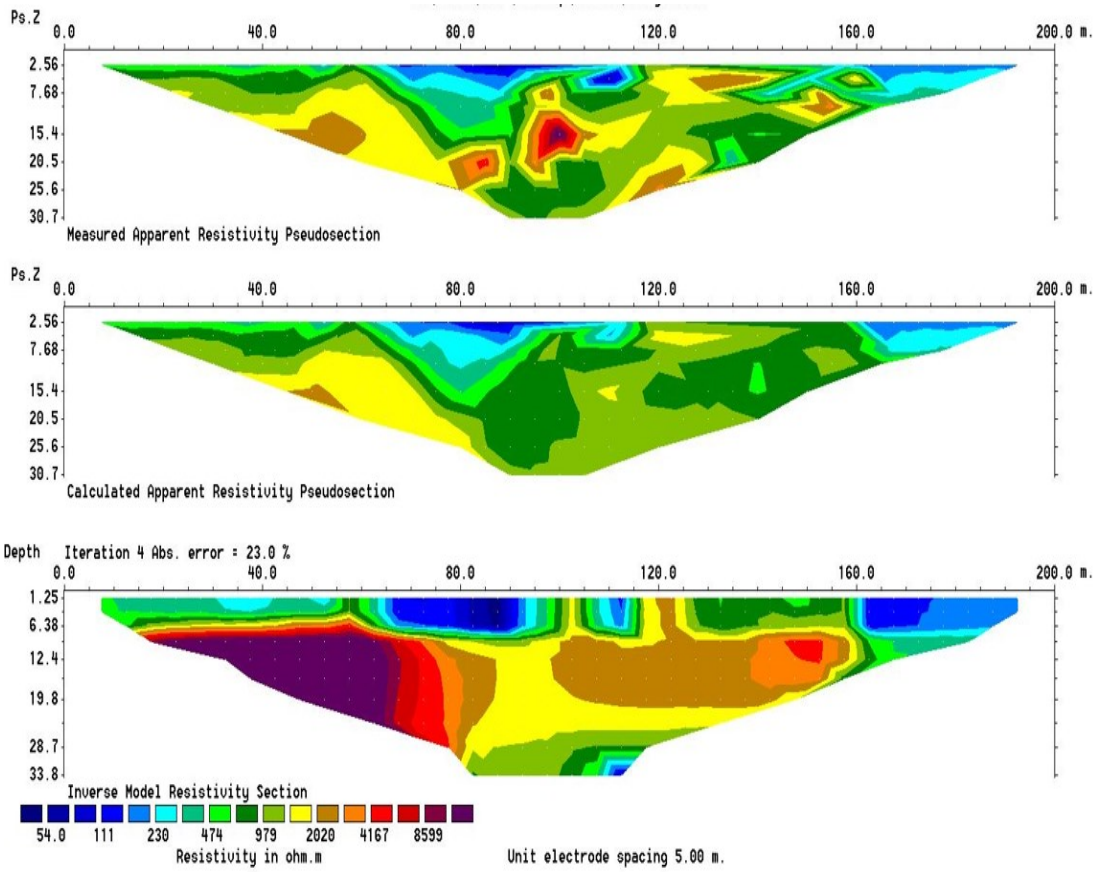


Figure 8: 2D: Pseudo-section plots showing measured apparent resistivity, calculated apparent resistivity and inverse model resistivity section of profile P_2

Figure 9 below consists of Top, middle and bottom panels that measured apparent chargeability. The top was the field data, middle was the calculated apparent chargeability while Inverse model chargeability section was given by the **Bottom panel. It coud be seen in all the three, the section with very low chargeability (about 0 - 5mS) was in blue color,** moderate chargeability (about **10–30 mS)** in green-yellow color and high chargeability (above 40mS) was in red.

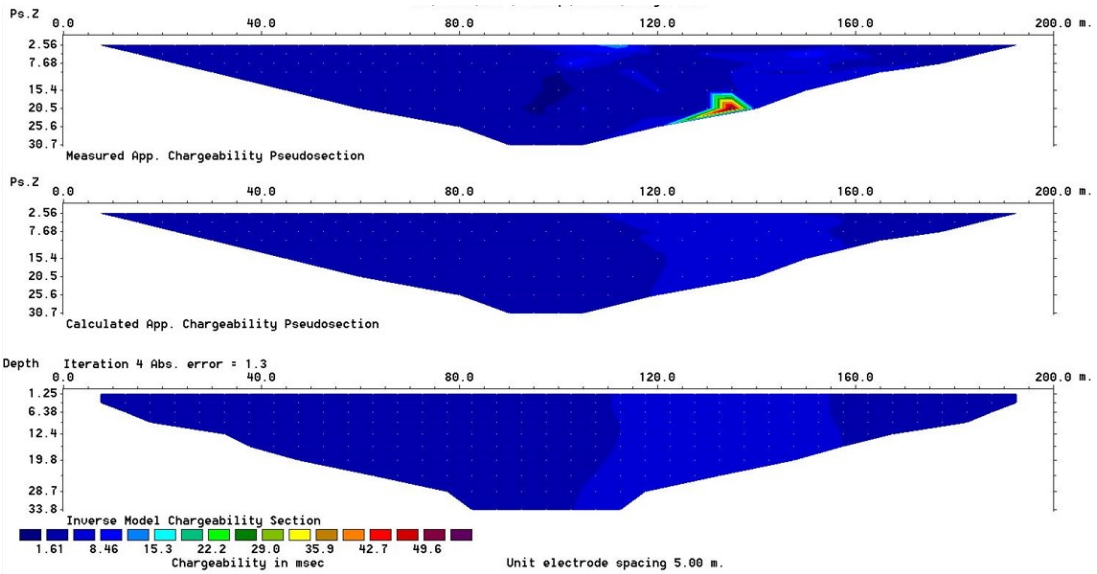


Figure 9: 2D:Pseudo-section plots showing measured apparent Chargeability, calculated apparent Chargeability and inverse model Chargeability section of profile P_1

Figure 10 below gave the results obtained from induced polarization with Chargeability values falling between **14 and 139 mS. Towards the centre of the profile there was high chargeability zones (orange/red) which** extending downward **and low chargeability zones (blue/green)** dominating the flanks and shallow cover.

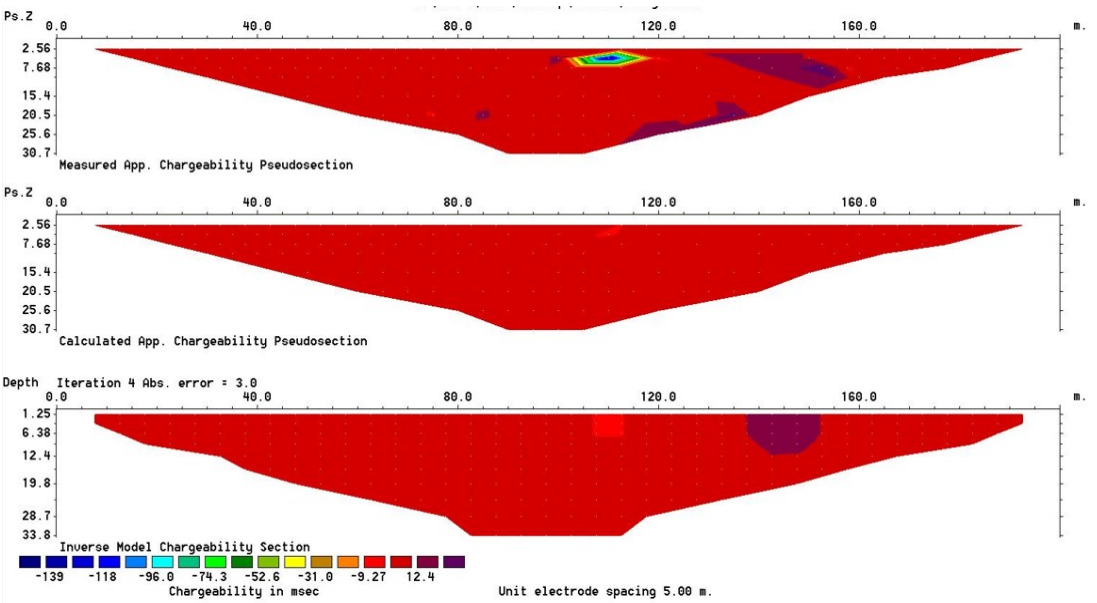


Figure 10 :Pseudo-section plots showing measured apparent Chargeability, calculated apparent Chargeability and inverse model Chargeability section of profile P_2

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Discussion

An electrical resistivity tomography survey was conducted, and the results across all the profiles contained measured, calculated, and inverted resistivity in each case. The resistivity results generally produced areas of low resistivity values **< 400 Ωm appearing** near-surface in several lines and notably towards the centre of the profile from the left side of the profiles. These areas are likely containing clay or high **moisture weak sub-grade which adversely affected the** road stability by reducing it bearing capacity. At some spots near the surface, were areas **whose resistivity values are very high > 4000 Ωm. These spots with high resistivity values indicates areas with competent rock, dry gravelly filled, or void spaces**.

In all the panels there were mixed colors in the middle, suggesting heterogeneous materials, poor compaction, or water infiltration pathways.This could be linked to the causes of the perpetual road failure being witnessed at that section of the road.

Conclusion

The findings of this work showed that the culprit causing road failure in the study area is the presence of clay and **poor compaction notably from the left towards the centre of the profile**. The top layers of all the failed segments of the roads in the study area are incompetent with either clay or poor fill materials as the m**ain culprit towards the** central section from the left at a distance 80–140 m stretch at a shallow depth, which sit in a bedrock depression.

Recommendation

Following the outcome of this study, the researchers wish to recommend that:

i) Geophysical surveys are always essential and should always be adopted and applied as reconnaissance tools in road construction.

ii) There seems to be clay at some locations along the study area and therefore, it should be ripped out and replaced with more competent materials

iii). proper drainage is needed with a view to resolving the problems of flooding and washing away of the pavement in all locations.

iv). There is a need for more research on this particular study area by using other geophysical methods to strengthen the findings.

Acknowledgement

The authors wish to register their appreciation to the Tertiary Education Trust Fund (TETFund) for granting financial support for this noble research

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