



## 2D ELECTRICAL RESISTIVITY IMAGING INVESTIGATION ON CAUSES OF ROAD FAILURE ALONG KUTIGI STREET, MINNA, NORTH CENTRAL, NIGERIA

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| Received | 12 April 2018 |

| Accepted | 10 May 2018 |

| Published 20 May 2018 |

### ABSTRACT

**Background:** Road failure is most common in developing countries and this has led to the loss of billions of dollars over decades due to either poorly constructed road and under maintained roads. The consequent daily loss of human life and economically significant properties, should make road failure an alarming issue to the Nigerian Government. A proper geophysical investigation must be conducted on the road to examine the subsurface soil characteristics. **Objectives:** Consequently, this study investigate the causes of road failure along Kutigi Street to determine the geo-electric properties of the subsurface of the study area. **Methods:** The technique employed for this study was 2D Electrical Resistivity Wenner Array Method. Two profiles covering a distance of 300 meters each were established parallel to the road pavement along the stable and unstable sections of the road. Data were collected along the two profile using ABEM Terra meter SAS 4000. The observed field data were processed and inverted using 2-D modelling inversion algorithm (RES2DINV Software). **Results:** The results reveals the presence of low resistivity values at several portion of both profile A and Profile B. Resistivity values ranging from 9.25  $\Omega\text{m}$  – 115.30  $\Omega\text{m}$  to a depth of 11.25 m from the topsoil was observed along profile A and resistivity values ranging from 5.20  $\Omega\text{m}$  – 25.6  $\Omega\text{m}$  to a depth of 11.25 m from the topsoil was observed along profile B. **Conclusions:** The low resistivity values observed in both profiles comprises of expansive clay and sandy clay materials which has the tendency of absorbing water. These makes them swell and eventually collapse under imposed wheel load stress which leads to failure. Regions of the road with sandy and clayey materials should be excavated from the subsurface to a depth of 4 m – 6 m from the topsoil of the road and replaced with competent fill materials.

**Keywords:** 2D Electrical Resistivity, Wenner Array, Electrical Sounding, Geophysical Investigation.

### 1. INTRODUCTION

Failure is defined as an unacceptable difference between the expected design life and the observed performance [1]. Road failure can be defined as the inability of a road to provide the primary services for which it was constructed, as a result of discontinuity in the road pavement [2]. The overuse of these roads, movement of heavy duty vehicles is a factor contributing to the deterioration of the road and eventual failure. There is need to conduct a proper geophysical investigation to find relevant information about the subsurface soil characteristics [3]. Generally, it is observed that after the opening of a newly constructed road or well-maintained road, the road is very good in the terms of level of services. After sometimes with the use of traffic volume on the road and constantly changing weather, especially after heavy rainfall or during rainfall, the road quality becomes deteriorated. The deteriorated road shows uneven cracks, potholes and ruts. This problem is very much common in every road, hence the quality and level of services of the road dropped down drastically as the road users increase and maintenance overlooked.

Several research works have been carried out to investigate the causes of road failures in Nigeria. Momoh et al. (2008) conducted an investigation on highway failure on the basement complex of south western Nigeria, for the purpose of evaluating the geophysical factor responsible for the highway failure. Schlumberger Vertical Electrical Sounding (VES) and Dipole-dipole electrical resistivity, Magnetic and Very Low Frequency Electromagnetic (VLF-EM) methods were used along Ilesha – Owena highway with the purpose of detailing the subsurface geo-electric sequence, mapping of the subsurface structural features within the sub-grade soil and delineating the bedrock relief as a means of establishing the causes of highway pavement failures [4]. Along the failed segments, low resistivity clay enriched, water absorbing substratum and linear features suspected to be faults, fracture zones, joints and buried stream channel were delineated [4]. Oladapo et al. (2008) investigated road failures in the basement complex area of southern Nigeria using Electrical Resistivity Method involving Dipole-dipole and Wenner Vertical Electrical Sounding (VES) technique [5]. It was discovered that the failed segment of the road way are characterized by relatively low resistivity less than 200  $\Omega\text{m}$  with the stable zones having

resistivity greater than 400  $\Omega\text{m}$  [5]. Adiat et al. (2009) used Electrical Resistivity and Electromagnetic methods to evaluate the subsurface integrity of a 3 km road from Igbara – Oke to Ibuji in south western Nigeria and also to investigate the causes of road pavement failure. Very Low Frequency Electromagnetic profiling and lateral resistivity profiling both at 10 m intervals and 21 Schlumberger Vertical Electrical Sounding (VES) were conducted [6]. The unstable segment of the road is accompanied by low resistivity of near surface materials and shallowness of the aquiferous zone on which the road pavement was founded [6]. Akintorinwa et al. (2010) carried out a research work titled geophysical investigation on road pavement failure in a basement complex terrain of south western Nigeria. The investigation was along Ilesa – Akure highway with the aim of establishing the causes of the road pavement failures [7]. Four failed segment and two stable segment as control were studied and subsoil on which the pavement was founded at the control stable segment have high resistivity value greater than 200  $\Omega\text{m}$  while the failed segment have a low resistivity value of less than 200  $\Omega\text{m}$  [7]. Osinowo et al. (2011) worked on integrated geophysical and geotechnical investigation of the fail portion of a road in the basement complex terrain, south western Nigeria. Very Low Frequency Electromagnetic and Electrical Resistivity method were used to map section of the road with anomalous electrical response and interpreted in terms of structures, lithology and water saturation [8]. These study implies that integrated geophysical and geotechnical investigation offers very useful approach for characterizing near surface earth which could be helpful in site preparation prior to conclusion [8]. Adeyemo and Omosuyi (2012) investigated the instability on road pavement along part of Akure – Owo express way. The geophysical survey comprises of ground magnetic profiling, Very Low Frequency Electromagnetic (VLF-EM) profiling and geo-electric sounding [9]. The study reveals low resistivity values obtained beneath the unstable segment which signifies clay and the instability of the road pavement is probably precipitated by presence of near surface bedrock depressions occupied by low resistivity weathered materials, typical of expansive clay and sandy clay, ruled as unstable construction material [9]. Jatto et al. (2014) worked on the geophysical investigation involving the Schlumberger Vertical Electrical Sounding (VES) and the magnetic method was carried out along stable and unstable sections of the Sarkin Pawa – Mangoro road in Niger state [10]. To investigate the factors responsible for the consistent pavement failures within the area, a profile with a total of 28 VES stations at a separation of 50 m was established parallel to the road pavement on each side of the road [10]. The geo-electric section along the stable segment of the parameter reveals generally resistive subsurface while the magnet profile shows a homogeneous subsurface devoid of geological substratum and near surface water table. The magnetic profile indicate predominately low magnetic linear features which is suspected to be a fault within the basement or an old stream channel which has been covered with sand [10].

### 1.1 Description of Study Area

The study area is located along Kutigi Street in the basement complex of Bosso Local Government Area of Minna, Niger State. It serves as a link road between Murtala Nyako road and Matasa Road. It is approximately about 558.31 m in length and located at latitude  $9^{\circ} 39' 05.11''$  N, longitude  $6^{\circ} 31' 03.4''$  E to latitude  $9^{\circ} 38' 52.8''$  N, longitude  $6^{\circ} 31' 16.7''$  E. The area comprises mostly of residential building and few trees on the road side.

### 1.2 Aim and Objective

The aim of this research work is to investigate the causes of road failure along Kutigi Street, using 2D Electrical resistivity imaging investigation.

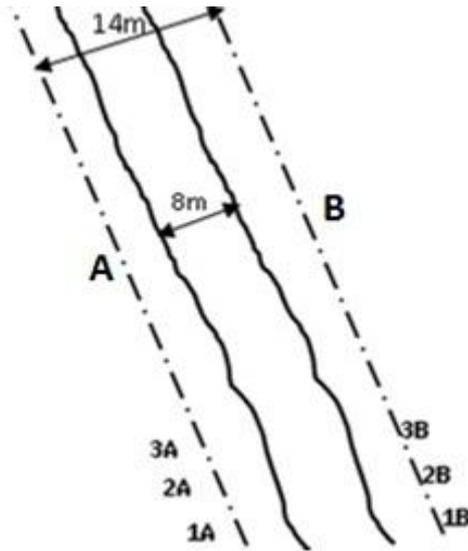
The objectives of the study are to:

- ✓ Determine the geo-electrical properties of the subsurface of the road in the study area.
- ✓ Delineate failed and stable region of the road pavement.
- ✓ Suggest solutions for the mitigation of the road failure problems on the road.

## 2. MATERIALS AND METHODS

The materials used include ABEM Terra meter SAS 4000, measuring tape, masking tape, hammers electric, cable steel electrode, RES2DINV software, Global Positioning Satellite (GPS). A transverse parallel to the road pavement

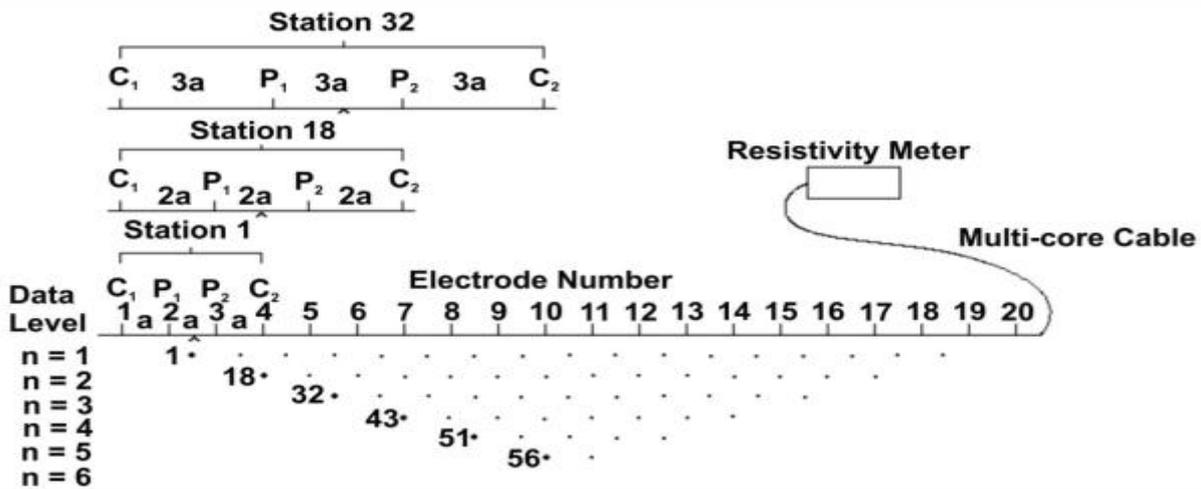
encapsulating both the stable and unstable portion of the road pavement of about 300 m in length was evaluated to delineate the geo-electric properties of the portion of the road in the study area.



**Figure 1:** The Location of the Study Area showing Profile A and Profile B.

In Figure 2, current was injected into the ground via electrodes  $C_1$  and  $C_2$  and the potential drop is measured between electrodes  $P_1$  and  $P_2$ .

Firstly the electrodes ( $C_1, P_1, P_2, C_2$ ) were spaced equally at an interval of  $a = 7.5$  m and the electrodes 1, 2, 3, 4 are used for the first measurement in order of  $C_1, P_1, P_2, C_2$  respectively. The second measurement follow regular pattern but in this instance, the electrodes to be measured are 2, 3, 4, 5 with  $C_1, P_1, P_2, C_2$  in respective order as shown in figure 2. These patterns was used to the position of electrode 39, 40, 41, 42 in similar order as the previous measurement. However after taking the measurement at  $a = 7.5$ , the subsequent step follows the same pattern and procedure as the first step for 2a, 3a, 4a, 5a, 6a, 7a, 8a, 9a and 10a.



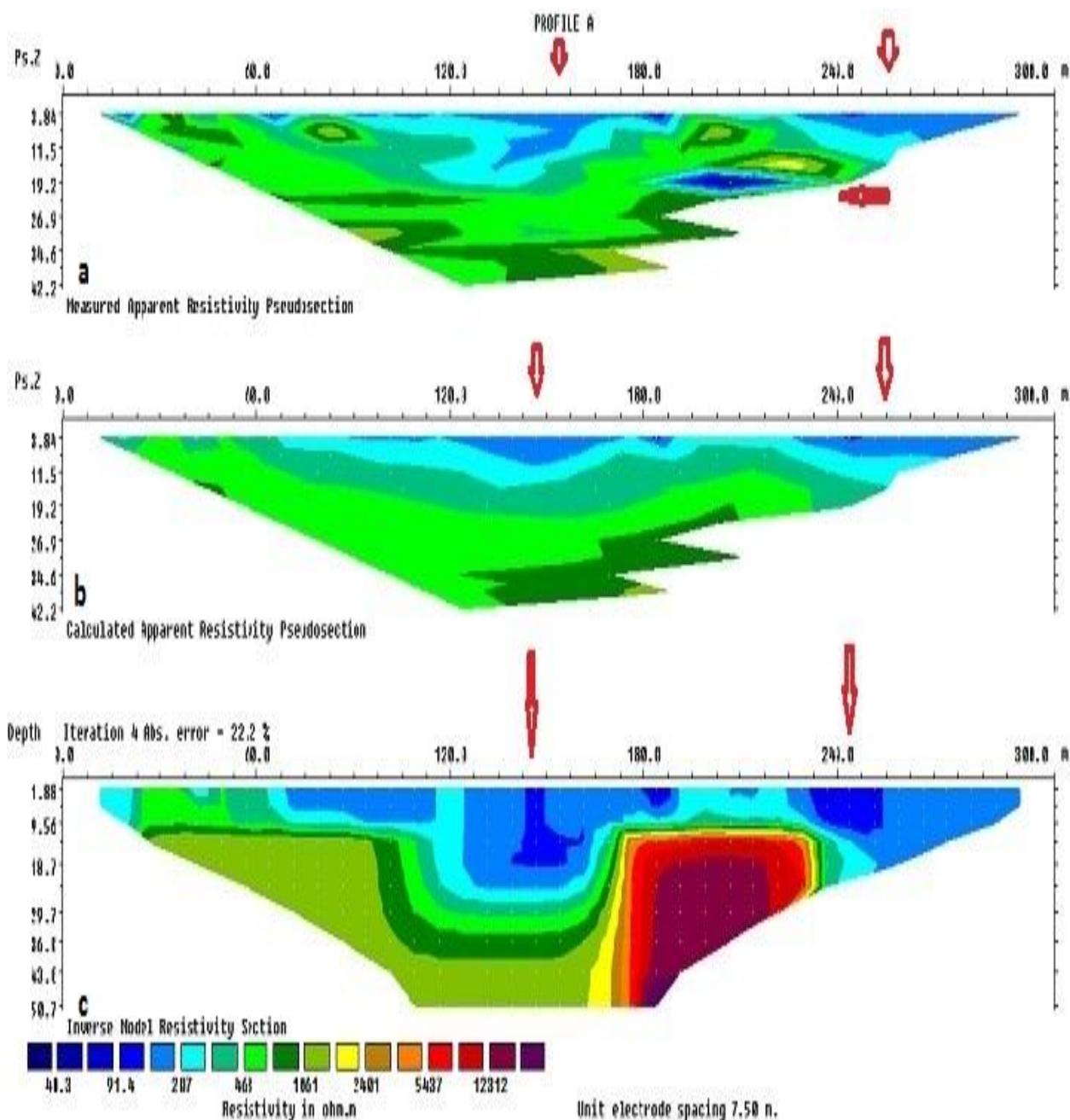
**Figure 2:** Sketch of the Electrodes for 2D Electrical Resistivity [11].

Electrical Resistivity Imaging (ERI) is a geo-electrical method used to obtain high resolution 2D image of the earth surface. The ERI was carried out during the field work, using Wenner array electrical configuration. The data collected from the field was imputed into the software RES2DINV to generate 2D resistivity image of the earth subsurface under investigation. The result obtain were plotted in form of a pseudo-section which gives an approximate picture of the subsurface characteristics. These values obtained are used to obtain qualitative interpretation of the profiles. Near subsurface resistivity variation at shallow depth of electrode spacing of 7.5 m is aimed at investigating the lateral depth variation in the electrical properties of the profiles subsurface. Expanding the Wenner array spacing to 15.0 m, 22.5 m,

30.0 m, 37.5 m, 45.0 m, 52.5 m, 60.0 m, 67.5 m, 75.0 m, and 82.5 m characterized its sensitivity for vertical variation in the subsurface resistivity below the center of the array.

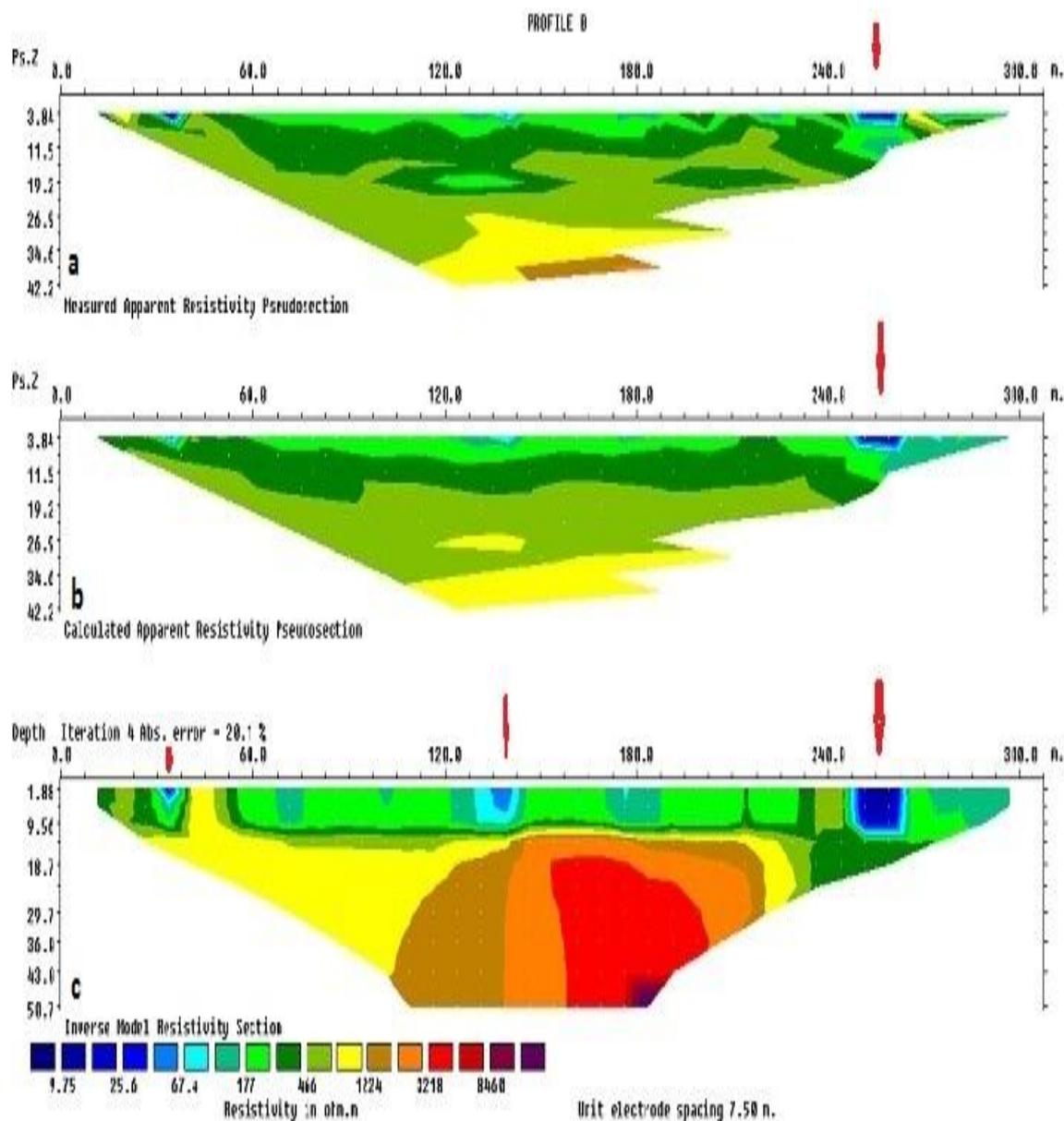
### 3. RESULTS

Profile A covers a lateral extent of 300 m, from latitude 0.9° 39.011' N and longitude 06° 31.133' E to latitude 0.9° 38.897' N and longitude 06° 31.252' E. The surface elevation are 300 m and 285 m at the starting and ending points along the road respectively.



**Figure 3:** Pseudo-section plots showing (a) measured apparent resistivity of profile A (b) calculated apparent resistivity of profile A (c) inverse model resistivity section of profile A.

Profile B covers a lateral extent of 300 m, from latitude 0.9° 39.014' N and longitude 06° 31.135' E to latitude 0.9° 38.901' N and longitude 06° 31.255' E. The surface elevation are 305 m and 285 m at the starting and ending points along the road respectively.



**Figure 4:** Pseudo-section Plot showing (a) measured apparent resistivity of profile B (b) calculated apparent resistivity of profile B (c) inverse model resistivity Section of profile B.

## 4. DISCUSSION

Figure 3(a) represents the Pseudo-section from the apparent resistivity measurement along profile A. It shows a low resistivity value ranging from  $9.75 \Omega\text{m}$  –  $91.40 \Omega\text{m}$ , between two major regions at distances ranging from  $120 \text{ m}$  –  $190 \text{ m}$  and  $225 \text{ m}$  –  $300 \text{ m}$  along the transverse to a depth of  $3.84 \text{ m}$  –  $19.20 \text{ m}$  and  $3.84 \text{ m}$  –  $11.50 \text{ m}$  respectively. Figure 3(b) is a Pseudo-section generated from the calculated apparent resistivity values showing relatively low resistivity values in two region along the traverse similar to the position of the result obtained in figure 3(a).

Figure 3(c) is the inverse model which reveals the resistivity sections along the transverse. Two distinctive zones were observed with low resistivity values along profile A. At a distance between  $122.5 \text{ m}$  –  $130.0 \text{ m}$  along profile A, low resistivity values ranging from  $19.25 \Omega\text{m}$  –  $107.0 \Omega\text{m}$  to a depth of  $19.2 \text{ m}$  from the top soil were observed. Also at distances between  $232.50 \text{ m}$  –  $252.50 \text{ m}$ , low resistivity values ranging from  $9.25 \Omega\text{m}$  –  $115.30 \Omega\text{m}$  to a depth of  $11.50 \text{ m}$  from the surface of the profile was observed.

Figure 4(a) is a Pseudo-section from the apparent resistivity measurement along profile B. It shows a low resistivity value ranging from  $25.60 \Omega\text{m}$  –  $67.40 \Omega\text{m}$ , between distances of  $247.50 \text{ m}$  –  $262.50 \text{ m}$  along the profile to a depth of  $7.50 \text{ m}$  from the surface of the profile. Figure 4(b) represents a Pseudo-section established from the calculated apparent resistivity values showing relatively low resistivity values in the same region along the traverse similar to the position of the result obtained in figure 4(a).

Figure 4(c) represents the inverse model showing resistivity sections along the profile B. Several zones along the profile exhibit slightly low resistivity values with most area along the profile having resistivity greater than 200  $\Omega\text{m}$ . Three distinctive zone with very low resistivity values were observed at a distances ranging from 30.0 m – 37.50 m, 135 m – 142.50 m and 247.50 m – 277.50 m to a depth of 3.84 m, 9.54 m and 11.25 respectively.

Low resistivity values, less than 200  $\Omega\text{m}$  observed in regions of both profiles comprises of expansive clay and sandy clay materials which have the tendency of absorbing water [6]. These makes them to swell and eventually collapse under imposed wheel load stress which leads to failure. The stable regions of the road have considerable high resistivity value greater than 200  $\Omega\text{m}$ , mostly laterite materials [6].

## 5. CONCLUSION

Geo-electrical attributes of the road subsurface along Kutigi Street were examined to ascertain the causes of its failure. In profile A Figure 3(c), low resistivity values were observed ranging from 9.25  $\Omega\text{m}$  – 115.30  $\Omega\text{m}$  to a depth of 11.25 m from the topsoil along the profile. In profile B, low resistivity values were observed in Figure 4(c) ranging from 5.20  $\Omega\text{m}$  – 25.6  $\Omega\text{m}$  to a depth of 11.25 m from the topsoil along the profile.

Low resistivity values below 200  $\Omega\text{m}$  was obtained in some regions of profile A and B, which indicates the presence of expansive clay and sandy clay material beneath the subsurface of the road pavement. These clay materials are unsuitable as subgrade materials for road pavement, as it consistently expand and contract under varying weather condition. The frequent expansion and contraction of these subgrade material leads to cracks on the road pavement and eventual failure of the road. Also slightly high resistivity values greater 200  $\Omega\text{m}$  were observed along the profile A and B indicating the presence of laterite material which is good subgrade material for road pavement.

Other contributing factors such as inadequate drainage system, lack of maintenance, thin pavement coating of the road, and poor construction materials are factors resulting to eventual failure of the road. Regions of the road with sandy and clayey materials should be excavated from the subsurface to a depth of 4 m – 6 m from the top soil of the road and replaced with competent fill materials.

Adequate drainage system should be provided for the road to avoid the long time suspension of water on road pavement as this weakens the molecular force holding the particles of the pavement together.

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**Cite this article: Peter, J.E., Rafiu, A.A., Udensi, E.E., Salako, K.A., Alhassan, U.D., and Adetona, A.A.** 2D ELECTRICAL RESISTIVITY IMAGING INVESTIGATION ON CAUSES OF ROAD FAILURE ALONG KUTIGI STREET, MINNA, NORTH CENTRAL, NIGERIA. *Am. J. innov. res. appl. sci.*. 2018; 6(5): 221-226.

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