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Geophysical Investigation of Road Failure along Lagos – Badagry Expressway Using Electrical Resistivity Imaging

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Abstract: Geophysical investigations of road failure using Two-dimensional (2D) electrical resistivity imaging was carried out along Lagos –Badagry expressway, Lagos State, Nigeria with a view to determining the subsurface geological structures that may pose danger to the highway. The study was conducted on five worrisome parts of the highway, namely: Iyana Isashi, Iyana Era, Agbara, Magbon and Oko Afo, using Constant Separation Traversing (Wenner array) to obtain three (3) profiles at each location. ABEM Terrameter SAS 1000 was used for the survey which displays apparent resistivity values digitally. The data was processed using RES2DINV software to produce 2D images of the study area. The subsurface images showed that the resistivity lies between 3.89 Ωm and 401 Ωm, indicating variation in soil matrix. It was observed that causes of road pavement failure on the studied road were as a result of a combination of clayey topsoil / sub-grade soils with resistivity ranging from 3.79 Ωm to 83.3 Ωm, water-logged sands due to ingress with characteristically low resistivity values and thin pavement, thereby unable to withstand pressure exerted on the road.
[Ogungbe, A. S, Afolabi, T O, Onori, E. O, Ogabi, C. O. **Geophysical Investigation of Road Failure along Lagos – Badagry Expressway Using Electrical Resistivity Imaging.** *J Am Sci* 2021;17(1):6-18]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). http://www.jofamericanscience.org. 2. doi:10.7537/marsjas170121.02.

Keywords: Road Failure, Electrical Resistivity, Geological structures, Imaging, Investigation

1.0 Introduction

Road failure is defined as the inability of a normal road to carry out its functional services by not providing a smooth running surface for operating vehicles (Akintorinwa et al, 2010). It occurs when an asphalt surface no longer holds its original shape and develops material stress which causes problems. Road failure problems include cracking, potholes, depressions, rutting, shoving, upheavals, and ravelling.

Flexible highway (i.e. good and well developed interconnectivity of roads) aids easy and smooth vehicular movement, and has been very useful for transportation of people, goods and services from one point to another, especially in developing countries where other means of transportation such as rail, underground tube, air, and water transportation systems have remained largely under developed. However, bad portions of road, many of which result from poor construction or being founded on incompetent sub-grade and sub-base materials had been found to do more harm than good. They have been responsible for many fatal accidents, wearing down of vehicles and waste of valuable time during traffic jams (Osinowo et. al, 2011).

According to Aigbedion (2007), road failure could be defined as a discontinuity in a road pavement resulting in cracks, potholes, bulges and depressions. A road pavement is supposed to be a continuous stretch of asphalt lay for a smooth ride or drive. Visible cracks, potholes, bulges and depressions may punctuate such smooth ride. The punctuation in smooth ride is generally regarded as road failure. According to the Federal Ministry of Works and Housing (FMW & H, 1992), failed roads are characterized by potholes, polishing / pavement surface wash, block and longitudinal cracks, drainage collapse, depressions, over flooding of the carriageway, gullies and trenches, rutting and rave.

Several factors are responsible for road failures, which include geological factor, geomorphological factor, geotechnical factor, road usage, construction practices, and maintenance (Adegoke and Agada, 1980; Ajayi, 1987). The geological factors influencing road failures include the nature of soils and the near surface geologic sequence, existence of geological structures such as fractures and faults, existence of ancient stream channels, presence of cavities and shear zones (Momoh et. al, 2008 and Adiat et. al., 2009).

The geomorphological factors are topography and surface/subsurface drainage system. Other factors considered by some researchers include: faulty design and poor road construction (Paul and Radnor, 1976, Abynayaka, 1977, World Bank, 1991, Federal

Ministry of Works and Housing (FMWH, 1995), Jain and Kumar, 1998). Poor Maintenance according to John and Gorden (1976), Oglesby and Garry (1978), TRRL (1991); and Traffic Effects and Human Impacts on the Roads according to American Association of State Highway and Transportation Officials (AASHTO, 1976), Anambra State Ministry of Works and Housing (ANSMWH, 1998), FMWH (1995) and Ibrahim (2011), bedrock depressions (Adeyemo and Omosuyi, 2012), presence of undetected linear features, such as fractures and rock boundaries and construction of roads on weathered layer (Ibitomi et al., 2014).

Road transportation is an important element in the physical development of any society as it controls the direction and extent of development. Furthermore, road plays a significant role in achieving national development and contributes to the overall performance and social functioning of the community. The present condition of most of the roads in the southwestern Nigeria has stimulated the interest of various stakeholders in the usage and maintenance of our highways. Rehabilitating the roadways has become a financial burden on the Federal, State, and Local Governments.

In spite of various rehabilitation efforts, several segments of our highways fail perpetually soon after commissioning. Such rehabilitation has become an annual ritual and a big financial burden on various tiers of Government. Some huge amount of money allocated towards rehabilitating and maintenance of roads throughout the country which were overlaid with asphaltic concrete in order to increase their strength could have been reduced if adequate geological and geophysical advice were sought prior to the construction of these roads.

The geophysical studies provide the geotechnical information required in the engineering design in order to enhance the strength and stability of highways. The applications of such geophysical investigations are used for the determination of depth to bedrock, structural mapping and evaluation of subsoil competence (Burland and Burbidge, 1981; Burger, 1992**).** The use of electrical resistivity imaging to address a wide variety of hydrological, environmental and geotechnical problems is increasingly becoming very popular.

Two dimensional (2D) electrical resistivity imaging is now being used to detect fractures and cavities in the subsurface, geotechnical investigations for buildings, roads, bridges and dams. The method can also be used for delineating archaeological features, locating surface utilities and for monitoring pollution seepage through the earth's subsurface. The method has been proven to be an effective tool for identifying anomalies and defining the complexity of the subsurface geology (Griffiths and Barker, 1993; Loke and Barker, 1996a; Giano et. al., 2000; Ugwu, 2012; Andrews et. al., 2013). The 2D electrical resistivity imaging in which the subsurface is assumed to be varying vertically down and laterally along the direction of profile but constant in the perpendicular direction has been used to investigate areas with moderately complex geology (Griffiths and Barker, 1993; Andrews et al., 2013).

Lagos has one of the largest and most extensive road networks in West Africa (Adeyemi and Oyeyemi, 2000) but roads in many parts of the state are generally in poor condition, causing damage to vehicles, contributing to hazardous traffic conditions, accidents and delay in travel time.

The Lagos - Badagry Expressway is the local name for the Nigerian section of the Trans–West African Coastal Highway whose failure bugs the mind of regular users since almost every section of the road has failed resulting to loss of lives and properties, human injuries (through accidents, etc.), difficulty in transporting goods through this route. It is one of the popular highways in Lagos State. The 60.3 km expressway (from Eric Moore in Surulere to Badagry) is synonymous with potholes, depressions and cracks on both sides of the road (Samuel, 2017).

The roads investigated in this study have protracted failure characteristics such as, potholes, cracks, depressions and water percolated channels. This failure becomes incessant despite previous rehabilitation efforts.

2.0 Materials And Methods

Description of the Study Area

The locations investigated are along Lagos-Badagry Expressway, Lagos Nigeria. Lagos-Badagry Express road connects to some part of Ogun State (Agbara and Igbesa). It also connects Lagos, Nigeria with Republics of Benin, Togo, Ivory Coast, Dakar, Senegal and Ghana. The expressway can be linked from Ikeja through Oshodi –Apapa expressway at Mile 2.

Scope of the Study

The study was conducted on five spoilt parts of the highway as shown in Figure 1.

Fig.1: Map showing the locations

Geological Setting of Study Area

The study area is along Lagos – Badagry expressway and islocated in Ojo and Badagry local governments, within Lagos west in the southwest part of Nigeria. The geological setting of the study area reveals that it lies solely within the extensive Dahomey basin, the basin extending almost from Accra to Lagos. The littoral and lagoon deposit of recent sediment underlies the area. The coastal belt varies from about 8 km near the Republic of Benin border to 24 km towards the eastern end of the Lagos Lagoon (Nton, 2001). The area consists of sediment of clay, unconsolidated sands and mud with a varying proportion of vegetable matter along the coastal areas while the alluvial deposit consists of coarse claying unsorted sand with clay lenses and occasional pebble beds (Alabi et. al., 2010). The study area falls into the ecological zone of wetland soils and lies on the coast where inland water empties into the Atlantic Ocean. It has a geologic origin of deltaic basis and tidal flats (Nton, 2001).

Physiography and Climate of the Study Area

Lagos State is located in the southwestern coast of Nigeria, approximately between latitudes $6^0 22'$N and $6^0 52'$N and longitudes $2^0 42'$E and $3^0 42'$E (Odumosu, et. al., 1999). It is bounded on the west by the Republic of Benin while the southern boundary of the state is formed by the 180km long Atlantic coastline. Its northern and eastern boundaries are shared with Ogun State. Lagos is the largest city in Nigeria and loosely classified into two main geographical areas – the "Island" and the "Mainland" and was the capital city of the country before it was replaced with Abuja on 12th December, 1991. Lagos remains the commercial nerve centre of Nigeria. The city is a typical example in the history of growth and development of urban areas in Nigeria. The main occupations of the people of the study area are farming and fishing.

Two main seasons exist in the study areas. These are rainy and dry seasons; rainy season exists between April to July (heavy rain season) and October to November (milder rain season) while a very brief dry season occurs in August and September, and long dry season spell occurs from December to March. The study area has wet equatorial climate with mean annual rainfall above 1800 mm and experiences an average annual temperature of 27^0C. Humidity is high in the rainy season and drops to its lowest level during December due to harmattan but generally high and rarely below 70% throughout the year. The vegetation cover is dominated by swamp forest, wetlands and tropical swamp forest comprising of fresh waters and mangrove. Generally, the pattern of relief in the study area reflects the coastal location of the state. Water is the most significant topographic feature in the study area located within Lagos State. Water and wetlands cover over 40% of the total land area within Lagos State and an additional 12% is subject to seasonal flooding (Iwugo et. al., 2003).

Data Acquisition Method

For field configurations in electrical resistivity method, the four electrodes were positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside, both current and potential electrodes were moved along a profile with constant spacing between electrodes. The whole spread is progressively moved. A minimum of one person was required to handle each of the electrodes with its connecting cable and an additional person who handled the recording equipment, thus making a five-man data collection crew for this survey. The electrode spread (Wenner array configuration) for data collection along the three profiles surveyed in each of the locations used electrode spacing of 10 m, 20 m, 30 m and 40 m. A total length of 200m was surveyed for each profile. During the field work, the ABEM Terrameter SAS 1000 was used. Three traverses parallel to the road segment were established at each location and had a length of 200 m each (Figure 2).

Fig.2: Profile Orientation along Road Segment

Data Processing

The raw field data were processed using RES2DINV for 2D resistivity method. This is a window based computer program that automatically determines a two-dimensional (2D) resistivity model for the subsurface data obtained from electrical survey. The forward modelling subroutine is used to calculate the apparent resistivity values. The inverse procedure is based on an iterative smoothness-constrained least-squares algorithm. This computer program uses a smoothness constrained non-linear least-squares optimization inversion technique to convert measured apparent resistivity values to true resistivity values and plot them in cross-sections. The inversion process removes geometrical effects from the pseudo section and produces an image of true depth and true formation resistivity. The program creates a resistivity cross-section, calculates the apparent resistivity for that cross-section, and compares the calculated apparent resistivity to the measured apparent resistivity. The iteration continues until a combined smoothness constrained objective function is minimized.

3.0 Results And Discussion

The electrical resistivity images of the earth's subsurface obtained in the study areas are presented in Figures 3-7.

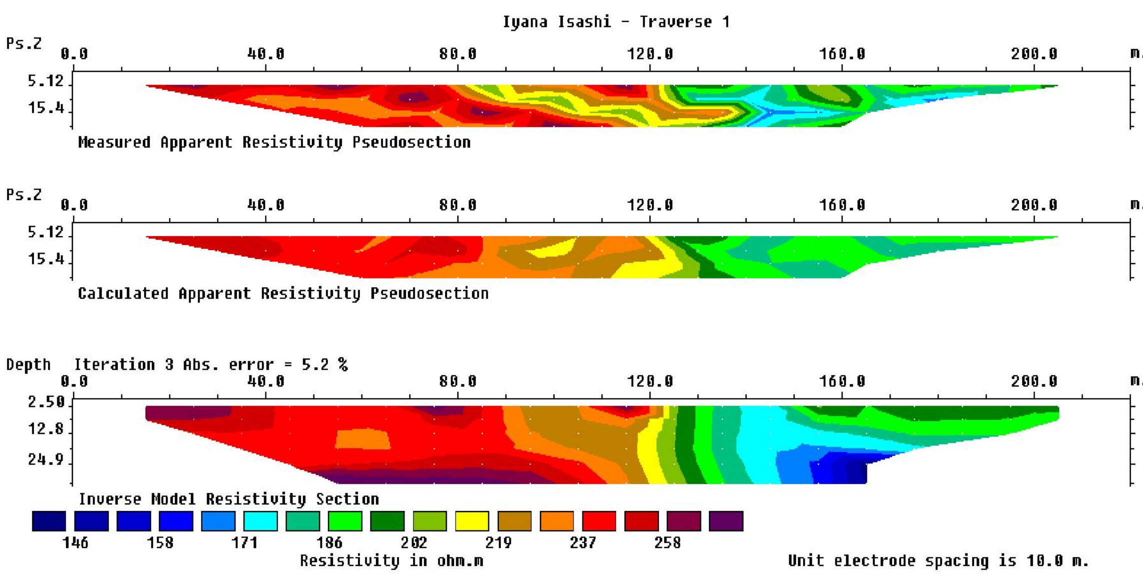

Fig. 3a: Result of 2D inversion of profile 1 at Iyana Isashi

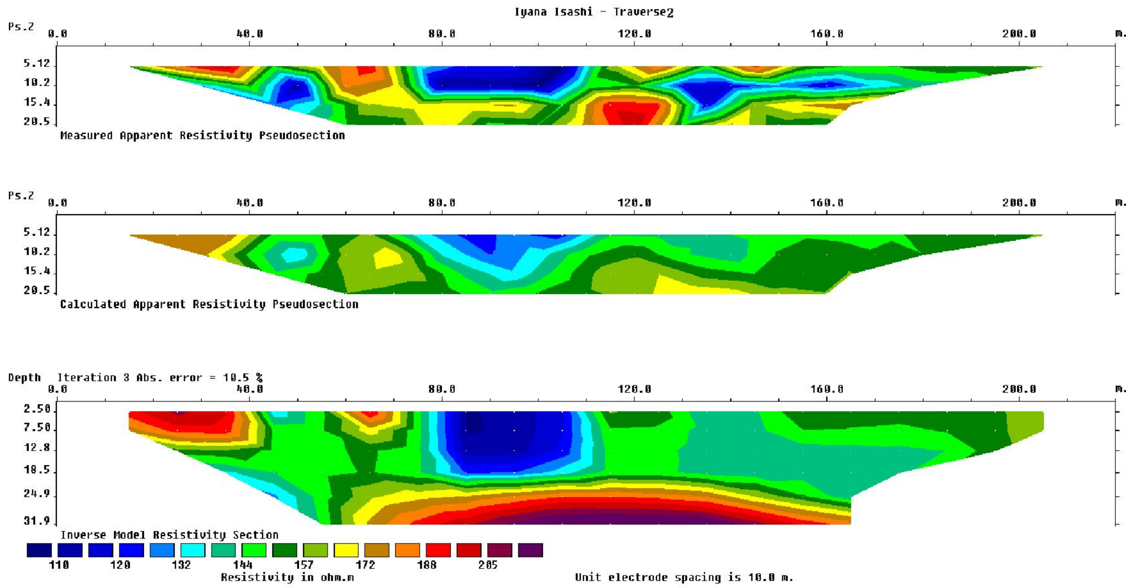

Fig. 3b: Result of 2D inversion of profile 2 at Iyana Isashi

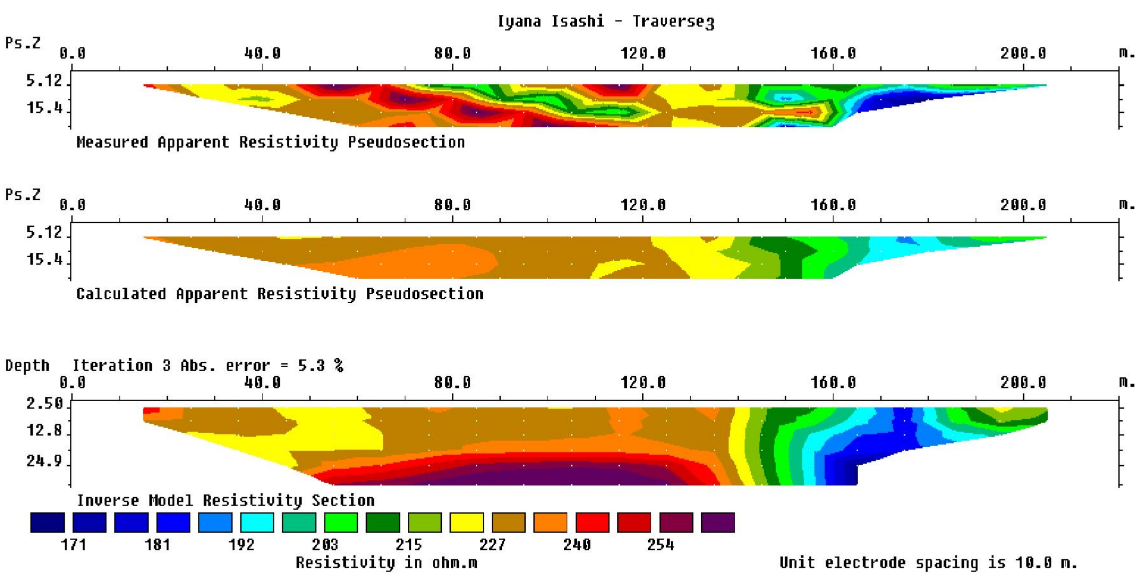

Fig. 3c: Result of 2D inversion of profile 3 at Iyana Isashi

Three profiles were established at Iyana Isashi, and the results are shown in Figure 3a-3c. For profile 1 (Figure 3a), the lateral extent is 200 m. At the lateral distance of 15 m to 120 m, to a depth of 24.9 m, a formation of clayey sand was observed with resistivity value ranging from 219 Ωm to 237 Ωm while clay settlement with resistivity slightly above 50 Ωm is confined within the sand from a depth of 2.5 m to 25 m at the lateral distance of 120 m to 160 m. At the lateral distance of 40 m to 90 m, to a depth of 30 m, a formation of sand was observed with resistivity value of 258 Ωm.

For profile 2 Figure (3b), at a lateral distance of 15 m to 40 m to the depth of 12.8 m from the surface, a formation of clayey sand was observed with resistivity value ranging from 188 Ωm to 205 Ωm. At the lateral distance of 80 m to 100 m to the depth of 18.5m from the surface, a formation of clay was observed with resistivity value ranging from 50 Ωm to 100Ωm. At the lateral distance 110 m to 200 m to a depth of 24 m from the surface, a formation of sand was observed with resistivity value ranging from 132 Ωm to 144 Ωm, while a formation of clayey sand was observed at the depth of 31.9 m with resistivity of 205 Ωm.

Figure 3c shows profile 3 at Iyana Isashi. At a distance of 60 m to 140 m to a depth of 24.9 m, clayey sand was observed with resistivity value ranging from 227 Ωm to 248Ωm, while a formation of clay content was observed at a lateral distance of 160 m to 180 m, to a depth of 30 m from the surface with the resistivity value of 100 Ωm. From lateral distance of 40 m to 140 m to a depth of 24 m to 30 m, a formation of clayey sand was observed with the resistivity value of 254 Ωm.

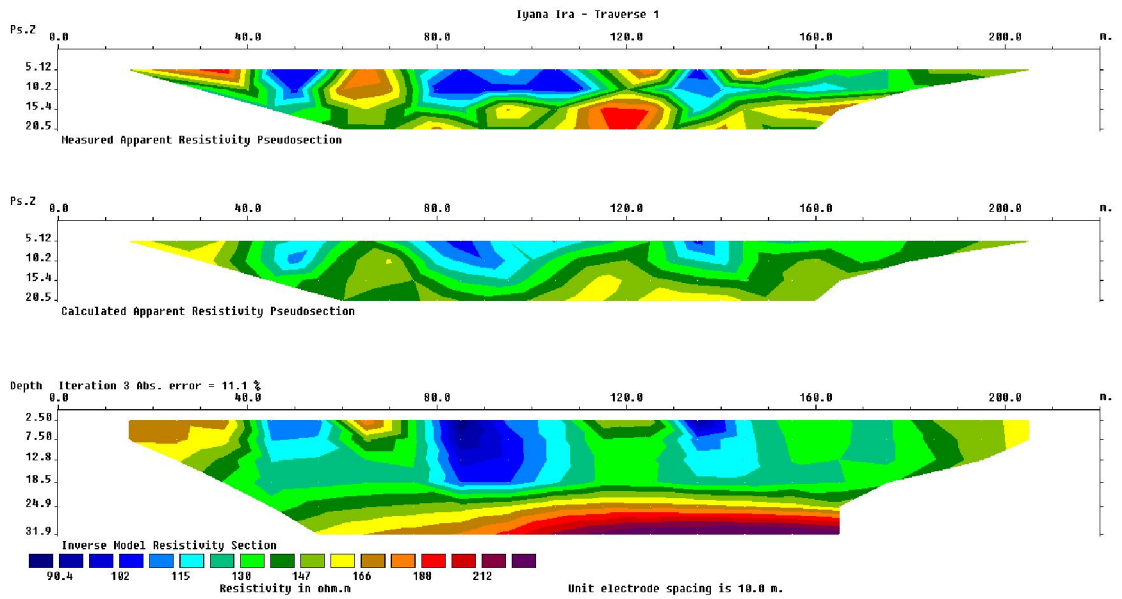

Fig. 4a: Result of 2D inversion of profile 1 at Iyana Era

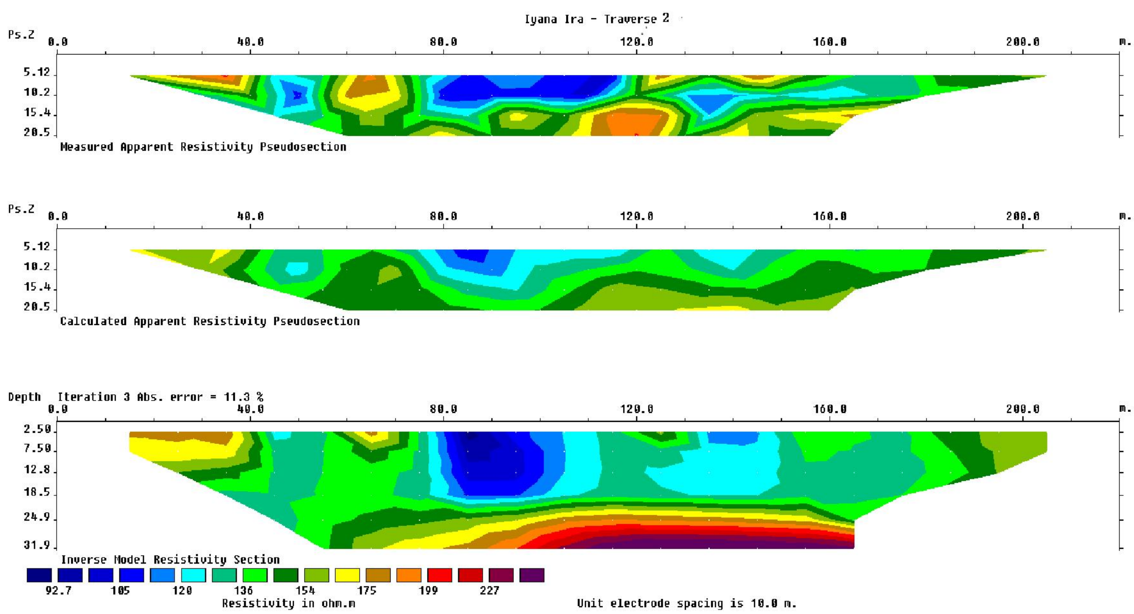

Fig. 4b: Result of 2D inversion of profile 2 at Iyana Era

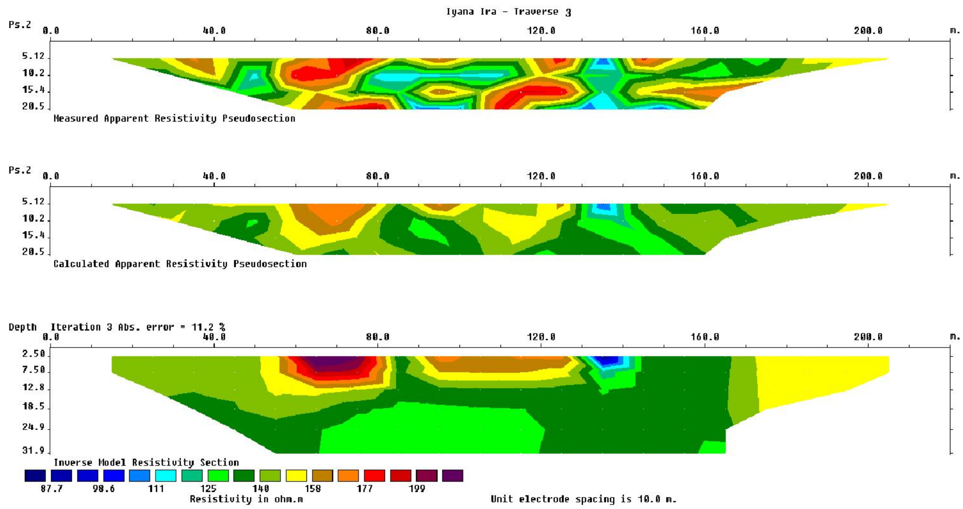

Fig. 4c: Result of 2D inversion of profile 3 at Iyana Era

Figure 4a is profile 1 at Iyana Era. It depicts low resistivity value of 92.4 Ωm at a lateral distance of 80 m to 100 m to a depth of 25 m from the surface, indicating clay formation, while a formation of sand with resistivity value ranging from 130 Ωm to 147 Ωm was observed between 40 m to 200 m along the profile to a depth of 24.9 m from the surface. A relatively low resistivity value ranging from 166 Ωm to 212 Ωm was also observed from 90 m to 160 m at 25 m to 31.9 m depth.

Figure 4b is profile 2 at Iyana Era. This profile is dominated by dry clay, mud and sand from 40 m to 200 m at depth about 31.9 m from the surface with the resistivity ranging from 136 Ωm to 154 Ωm, but clay sediment is formed within the sand and mud at 80 m to about 105 m, along the profile at depth 18.5 m from the surface with the resistivity ranging from 92.7 Ωm to 120 Ωm. At 15 m to 40 m and from 80 m to 170 m on the profile at depth 2.5 m to 7.5 m and 31.9 m from the surface are characterized by relatively low resistivity, ranging from 175 Ωm to 227 Ωm. This was observed to be clayey sand formation.

Figure 4c is profile 3 at Iyana Era. At 15 m to 165 m along the profile from the surface up to 31.9 m depth is characterized by low resistivity, varying from 125 Ωm to 140 Ωm. Confined within this sandy clay formation, are clay formation with low resistivity value of 87.7 Ωm to 100 Ωm at lateral distance of 120 m to 130 m to a depth of 7.5 m from the surface and sandy and clayey sand with resistivity values ranging from 177 Ωm to 199 Ωm at 55; 158 Ωm at 90 m to 125 m respectively.

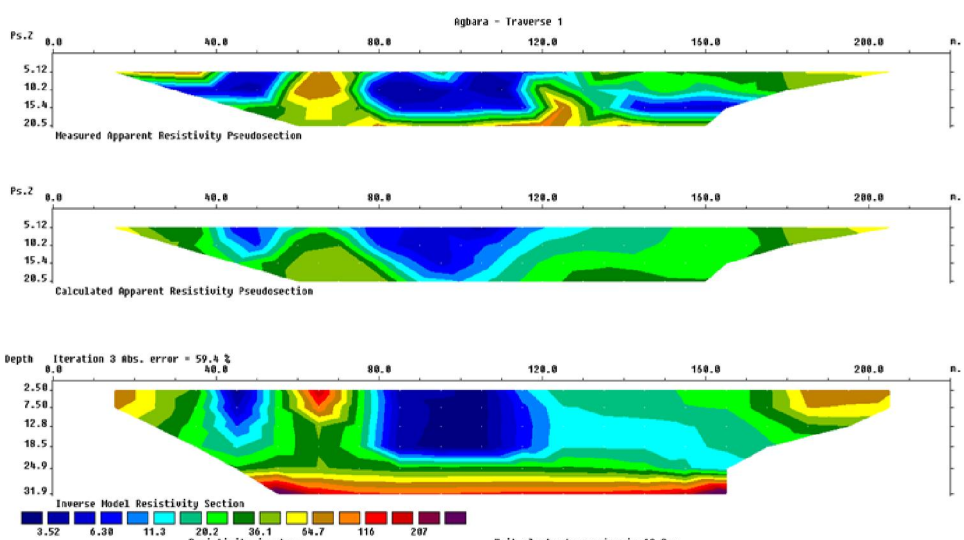

Fig. 5a: Result of 2D inversion of profile 1 at Agbara

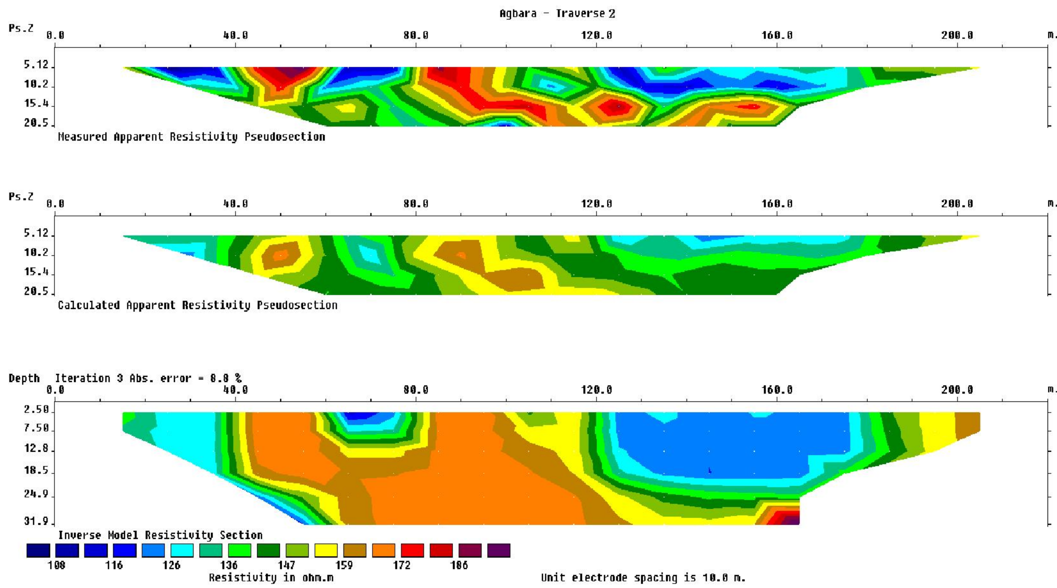

Fig. 5b: Result of 2D inversion of profile 2 at Agbara

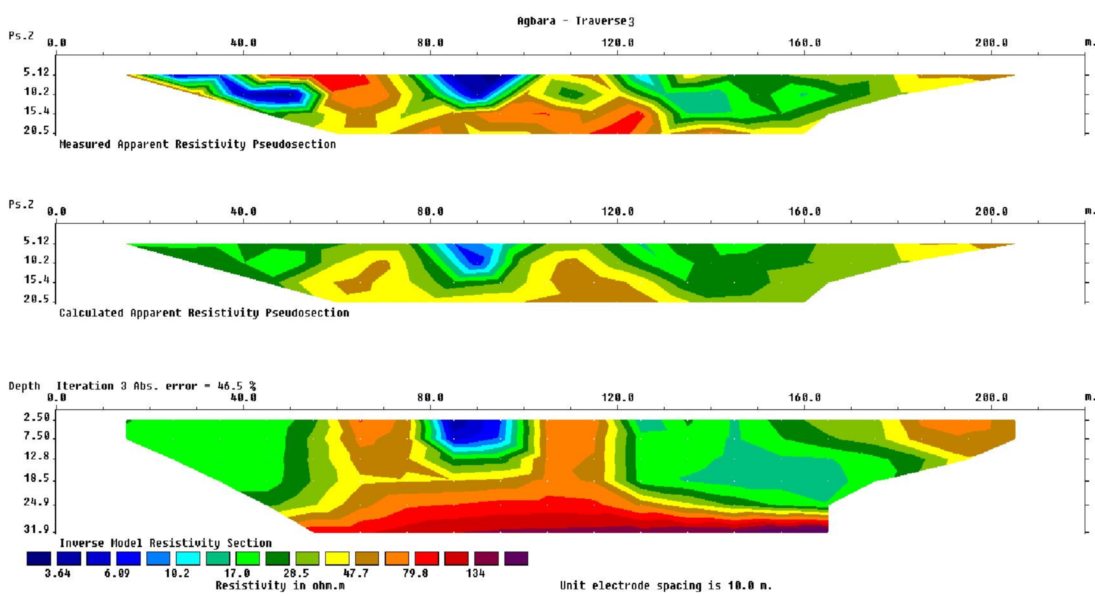

Fig. 5c: Result of 2D inversion of profile 3 at Agbara

For profile 1 at Agbara (Figure 5a), there is low resistivity ranging from 3.52 Ωm to 11.3 Ωm at lateral distance of 80m to 120m to a depth of 24.9m from the surface. This was observed to be peat mixed with clay. A large formation of clayey sand is observed at the depth of 30 m to 31.9 m with resistivity from 116 Ωm to 287 Ωm, from 40 m to 160 m spread along the profile. Above this formation is a layer of relatively low resistivity.

Figure 5b is profile 2 at Agbara. From of 120 m to 180 m spread and to a depth of 24.9 m from the surface, is a relatively low resistivity with value ranging from 110 Ωm to 116 Ωm. This could be as a result of clay compacted. From 40 m to 100 m lateral spread, is a zone of resistivity ranging from 159 Ωm to 186 Ωm. This was observed to be sandy clay formation. Confined within this zone, is a local zone of relatively low resistivity of 110 Ωm to 116 Ωm at 60 m to 80 m spread and to a depth of 7.5 m from the surface.

For profile 3 at Agbara (Figure 5c), the spread from 60 m to 120 m, from the surface to 18.5 m depth was characterized by resistivity in the range of 47.7 Ωm to 79.8 Ωm. This was observed to spread from

40m to 160 m from 34.9 m depth to 31.9 m with resistivity from 79.8 Ωm to 134 Ωm, indicating sandy clay. Within this zone, is a zone of low resistivity ranging from 3.44 Ωm to 18.2 Ωm, from 80 m to 100 m spread and to a depth of 18.5 m from the surface. This was observed to be peat mixed with clay. From 120m spread up to 180 m and to a depth of 24.9 m from the surface, is a zone of relatively low resistivity of 17.8 Ωm to 22.5 Ωm. This was also observed at 15 m to 55 m along the profile.

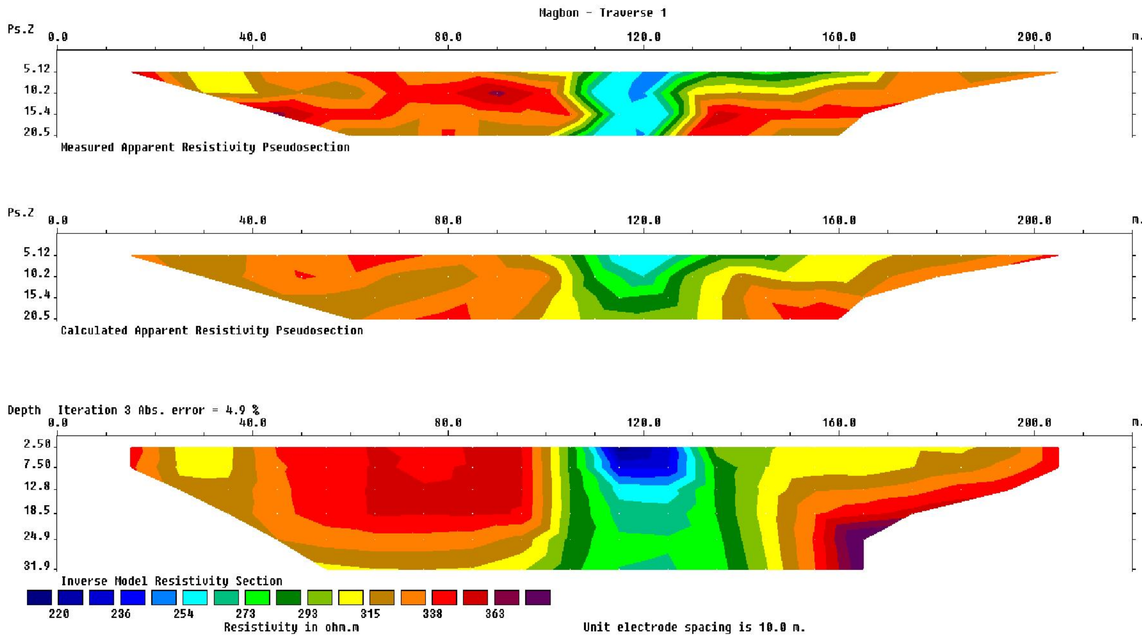

Fig. 6a: Result of 2D inversion of profile 1 at Magbon

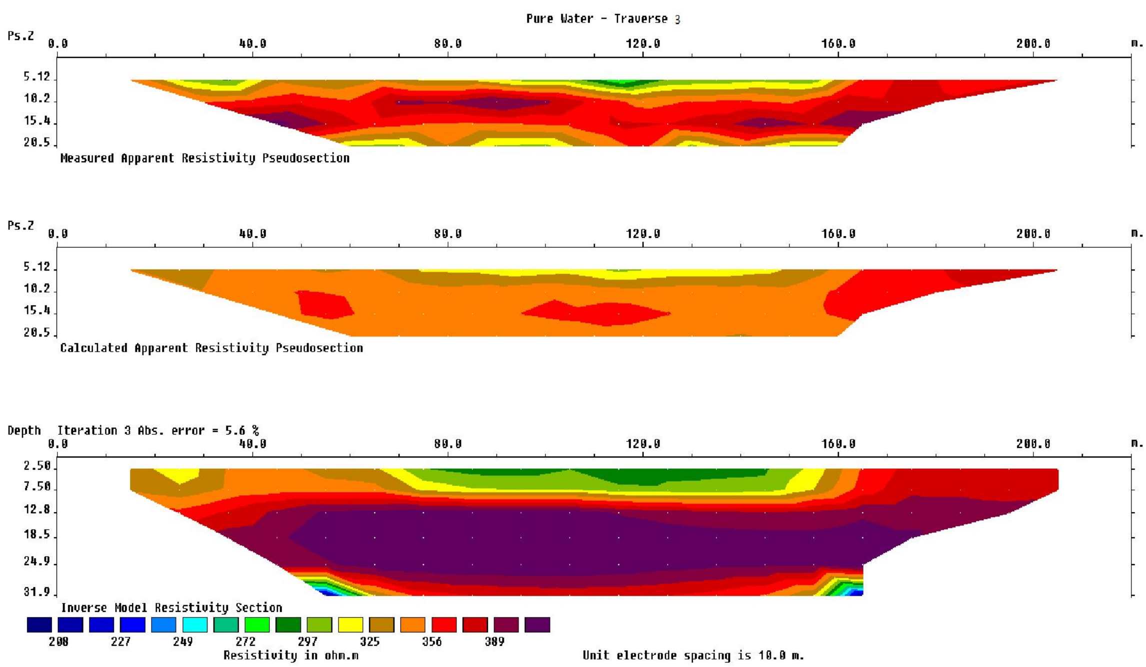

Fig. 6b: Result of 2D inversion of profile 2 at Magbon

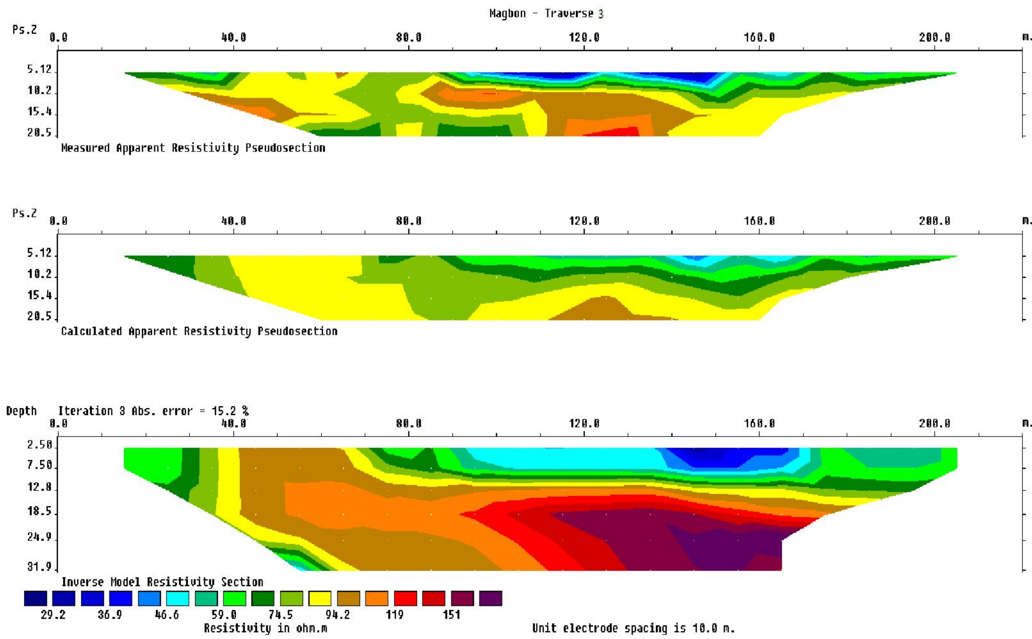

Fig. 6c: Result of 2D inversion of profile 3 at Magbon

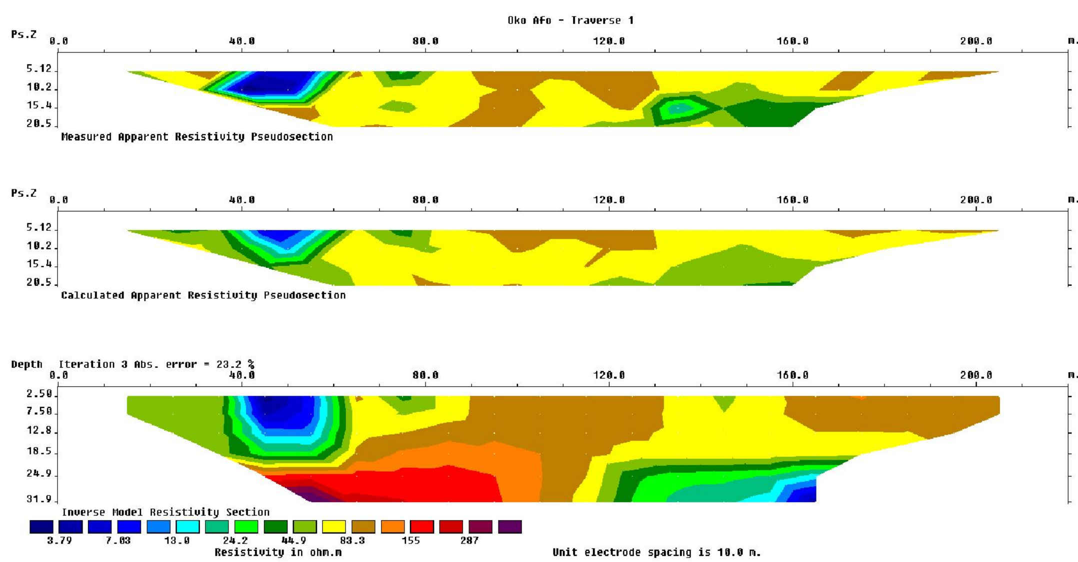

Fig. 7a: Result of 2D inversion of profile 1 at Oko Afo

Figure 6a shows profile 1 at Magbon. It shows resistivity value ranging from 328 Ωm to 363 Ωm from the surface up to 31.9 m depth from 15 m to 100 m spread along the profile. This implies sand formation. Localized within this formation, is a zone of relatively low resistivity at 25 m to 38 m along the profile up to a depth of 10 m from the surface. This was also observed from 145 m to 180 m along the profile. At 105 m to 145 m from the surface up to 31.9 m depth, is a zone of resistivity from 254Ω to 292 Ωm and confined within this is a zone of relatively low resistivity from the surface up to 12.8 m depth at 110 m to 130 m.

Figure 6b shows profile 2 at Magbon. A large section of the profile is characterized by resistivity ranging between 325 Ωm to 389 Ωm from 15 m to 200 m spread and to a depth of 7.5 m to 31.9 m. This implies sand formation. Within this formation, is a zone of relatively low resistivity varying between 208 Ωm and 297 Ωm at the surface from 70 m to 150 m spread along the profile and to a depth of 7.5 m from the surface. This clayey sand formation was also observed at 31.9 m depth at a spread of 50 m and 160 m.

For profile 3 at Magbon (Figure 6c), the spread from 70 m to 200 m, from the surface to 12.5 m depth was characterized by resistivity in the range of 29.2 Ωm to 74.5 Ωm. This was also observed at 15m to 30 m along the profile to a depth of 12.5 m. This is as a result of clay settlements. Below this formation, is a zone of resistivity ranging from 119 Ωm to 151 Ωm at 12 m depth to 31.9 m, spreading from 90 m to 120 m along the profile. This was as a result of sandy clay formation. From 40 m to 65 m along the profile, there is also a zone characterized by relatively low resistivity of 94.2 Ωm.

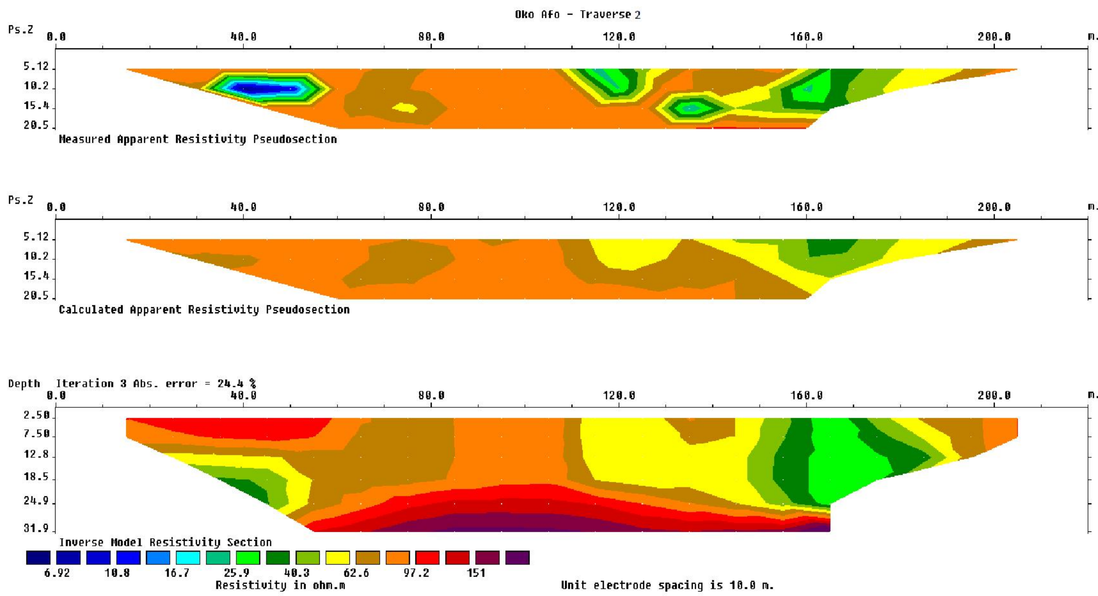

Fig. 7b: Result of 2D inversion of profile 2 at Oko Afo

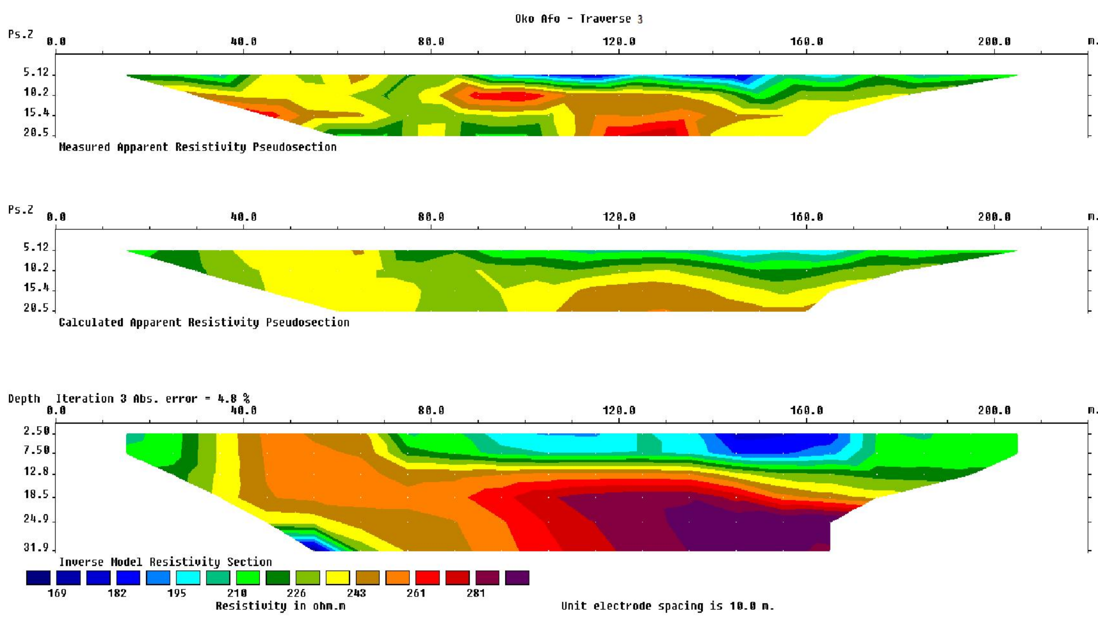

Fig. 7c: Result of 2D inversion of profile 3 at Oko Afo

Figure 7a is profile 1 at Oko Afo. In this profile, is a zone of low resistivity ranging from 3.79 Ωm to 7.83 Ωm, from 40 m to 60 m spread and to a depth of 15 m from the surface. This was observed to be peat mixed with clay. Below this is a zone of resistivity from 155 Ωm to 287 Ωm from a depth of 24.9 m to 31.9 m. This clayey sand formation was observed to have spread from 40 m to 90 m along the profile.

From 90 m to 130 m along the profile and to a depth of 18.5 m, is a zone of resistivity of 83.3Ωm. This clay formation was also observed to have spread narrowly to 31.9 m depth. The same trend was observed from 160 m to 200 m along the profile to a depth of 12.8 m.

Figure 7b is profile 2 at Oko Afo. Most part of this profile is characterized by relatively low resistivity, ranging from 97.2 Ωm to 151 Ωm and was observed to be sandy clay formation. This has spread from 15 m to 110 m along the profile and was observed to have stretched to 160 m along the profile from 24.9 m to 31.9 m depth. In this profile, there is also a zone of low resistivity ranging from 6.92 Ωm to 40.3 Ωm, from 150 m to 175 m spread and to a depth of 24.9 m from the surface. This was observed to be clay settlements. From 110 m to 150 m along the profile and to a depth of 18.5 m, is a zone of resistivity of 62.6 Ωm.

Figure 7c is profile 3 at Oko Afo. The spread from 70 m to 200 m, from the surface to 7.5 m depth was characterized by resistivity in the range of 169 Ωm to 226 Ωm. This sandy clay formation was also observed at 15m to 30 m along the profile to a depth of 12 m. Below this formation is a zone of resistivity ranging from 261 Ωm to 281 Ωm at 12 m depth to 31.9 m, spreading from 90 m to 160 m along the profile. This was as a result of clayey sand formation. From 40 m to 65 m along the profile, there is also a zone characterized by relatively low resistivity of 243 Ωm.

4.0 Conclusion

The average value of apparent resistivity of the entire study locations is 231.92 Ωm. This value characteristically placed the studied areas in a sedimentary basin which is in agreement with the general geology of the area. Wet soils and fresh groundwater have even lower resistivity values. Clayey soil normally has a lower resistivity value than sandy soil. This is because the resistivity of a particular rock or soil sample depends on a number of factors such as the porosity, the degree of water saturation and the concentration of dissolved salts.

In this work, geophysical Investigation of Lagos -Badagry highway has been carried out as a means of establishing the geological factors that may have influenced the constant failure of the highway. Results from geophysical survey conducted identify the possible causes of the expressway failure in the studied areas to include the following:

Poor sub graded materials, water lodge sand as well as very thin asphalt coating of the surface resulted in major cracks which was unable to withstand heavy traffic plying this particular road.

In addition, the physically obvious road failure witnessed along the profiles are not generally as a result of the above factors alone but others like poor (none) drainage pattern for runoff at the two sides of the road pavement.

It is evidently clear from the findings that the presence of clay soil has contributed to road failure witnessed on the road. This clay has the ability of absorbing water which makes them swell and fail under the action of stress (movement of heavy vehicles).

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1/21/2021