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Preliminary Investigation Of Road Failure In Parts Of Ogbia Local Government Area, Bayelsa State, Nigeria Using Electrical Resistivity Imaging

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Abstract
Road failure in parts of Bayelsa State Nigeria has been constituting nuisance to human and vehicular activities in the area. This study was designed to investigate the geologic features responsible for road failure in parts of Ogbia Local Government Area of Bayelsa State, Nigeria. Electrical resistivity method involving 2D imaging of the failed parts of Otuoke-Onuebum and Imiringi-Emeyal 2 Roads were conducted on four profiles normal to the strike of the affected parts. The data collected were tomographically inverted and the results predominantly showed that the failed portions of the roads are characterized with very low resistivities ranging from 0.094 Ωm to 173 Ωm. These results suggest that the formation underlying the failed portions of the roads are predominantly clays and peat, loam and mud. These suggest that clay volumetric variation due to variation in moisture content most likely caused the failure of some parts of the roads. The thicknesses of the clay formations range from 2 m to 8 m. Also, in the parts underlain by peat, loam and mud, the failure in those segments of the roads is attributed to the high moisture of the formations, which are easily compress by loads. The thicknesses of the peat, loam and mud formations range from 3 m to 10 m. It was recommended that excavation of clay and peat, loam and mud deposits be carried out and replaced with less expansive soil like sand on the affected parts of the road to minimize failure.
Keywords: *Road Failure, Ogbia Local Government Area, Resistivity Tomography, Clay, Peat, Loam, Mud.*

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I. Introduction

Road is one of the essential structures in trade and transportation system globally as it serves as thoroughfare for the movement of motorized and non-motorized objects, linking towns, local governments areas, states and countries. The social economic development of any state greatly depends on its road network. The deterioration and degradation of a road surface and its underlying layers is regarded as road failure. According to Onuoha and Onwuka (2014), road failure could be defined as a discontinuity in a road pavement resulting from cracks, potholes, bulges and depressions. Three causative factors of road failures are natural causes, anthropogenic activities, and failures occasioned by poor construction design (Obiora *et al*., 2021). Roads are built on the earth surface which is composed of geological materials; hence, geology plays very vital roles in road performance, stability and failures. Therefore, the soil on which a road is constructed affects its stability and longevity. Good roads are economically important because they serve in connecting farmers and fisherman predominantly in rural areas to the consumers mostly located in the urban and semi urban areas, where their agricultural produce is sold. Also, industrialization of localities takes place rapidly due to good access road networks. Since there is a very strong positive correlation between a country's economic development and the quality of its road network, a country's road network should be constructed in an efficient way in order to maximize economic and social benefits (Ighodaro, 2009). Field observations and interpretations by geophysicists have shown that road failures are not primarily due to usage and design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behaviour of residual soils on which the road are built (Ajayi, 1987). The nature of the soil or rock supporting road structure becomes an extremely undisputable issue of safety, road integrity and durability (National Cooperative Highway Research Program, NCHRP, 2006). Incessant failure of roads has become a common phenomenon in many parts of the world. As a result of potholes and degraded surfaces, travelling by roads is challenging and occasionally near impossible in many regions, especially during rainy seasons, leading to the recurrent rehabilitation and reconstruction of roads. These have constituted some financial burden to the various tiers of government.

Due to the roles good road networks play in social-economic development of countries, governments embark on roads construction and rehabilitation, since such investments enhance job creation as individuals and organizations seek to establish businesses within the vicinity of the roads, leading to town development and urbanization. It is imperative that adequate investigation should be carried out to discover undisputable factors leading to road failure. According to Studies (Oke *et al*., 2009), timely identification of features responsible for road failure ultimately enabled the relevant agencies to appreciate the causes of the failure with a view to providing remedial measures. Several factors are responsible for road failures and they include geological, geomorphological, geotechnical, road usage, specification of construction practices, and maintenance. Geological factors causing road failures are controlled by nature, which include physical, biological, chemical, mineralogical, weathering and erosional, hydrogeological processes, environmental and tectonic forces. Other conditions such as flood, old age, buried channels, water intrusion, stress from heavy vehicles, expansion and contraction from seasonal temperature changes, use of poor and substandard materials, inadequate maintenance, lack of drainage system and improper channeling of drainage system, and heavy traffic are also indisputable factors to road failures. Also, when the fundamentals of which roads are constructed are ignored or not taken into account, then the consequences of road failure are inevitable. High accident rates, longer travel times, higher cost for vehicle maintenance, high crime rates and detrimental influence on economic growth are among a few consequences of road failure that have been observed. These consequences have led to loss of lives and properties, underdevelopment, unemployment, loss of jobs and rise in crime rate at failed portions of the roads (Abdulazeez, 2024).

Ogbia is a Local Government Area situated between two major cities in Bayelsa State, Yenagoa and Nembe. The villages in the area are predominantly agrarian societies and fishermen. Plantain, cassava, yam, sweet potatoes, palm oil and varieties of vegetables are largely produced in the area to meet food demand of the state and environs. Recently, conveying the farm produce to the cities where they are mostly consumed has met serious setback due to deteriorating roads in the area. This has led to high cost of food in parts of Bayelsa State and environs.

Bayelsa State Government has constantly embarked on road construction, reconstruction and maintenance in the area. Most roads in the area fail shortly after construction, reconstruction and maintenance. Otuoke – Onuebum and Imiringi - Emeyal 2 Roads are the major roads in the area that have consistently failed shortly after reconstruction and maintenance. There is need to carryout geophysical investigation to determine structures underlying the failed portions of the roads. This study is aimed at delineation of geologic features responsible for the frequent collapse of these major roads.

II. The Study Area

The study area is located in Ogbia Local Government in Bayelsa State, Nigeria (Figure 1). Ogbia Local Government Area lies within longitudes 6°16`00``E and 6°45`00``E and latitudes 4°39`00``N and latitudes 4°52`00``N. Ogbia Local government has an area of about 695 km² and a population of over 179,926 (Uzoekwe and Iniaghie, 2024). The area is predominately Ijaw, with the Ijaw languages being widely spoken. Being in the Niger Delta Region, the study area has a riverine and estuarine setting, with bodies of water within the place preventing the development of significant road infrastructure. Many communities within the study area are surround by water. Bayelsa State experiences equatorial climate, with two distinct seasons, dry and rainy seasons. The dry season is dominant from the month of November to February, while the rainy season starts from March to October (Etu-Efeotor and Odigi, 1983). However, during the dry season, rainfall is sometimes experienced. The average annual rainfall is between 3,000 - 3,500 mm, which is mostly accompanied by lightening, thunderstorm and torrential rain (Etu-Efeotor and Odigi, 1983). The average daily temperature is between 26°C - 28°C, with a relative humidity of 70 - 90% during the wet season and 50% in the dry season (Etu-Efeotor and Odigi, 1983). Evapotranspiration is 1000mm, leaving an effective rainfall of 2000mm with a relative humidity of about 70% (Nwankwola and Ngah, 2014). The inhabitants of the communities are mainly fishermen and farmers. The data used for this study were collected along profiles laid perpendicular to the strike of the anomalous parts of the roads under investigation. Figures 2 and 3 shows some failed parts of Otuoke –Onuebum and Imiringi – Emeyal 2 Roads in Ogbia Local government respectively. Figure 4 shows the profiles, AB and CD where data were collected along Otuoke – Onuebum Road. Similarly, Figure 5 shows the profiles, MN and QR where data were collected along Imiringi – Emeyal 2 Road.

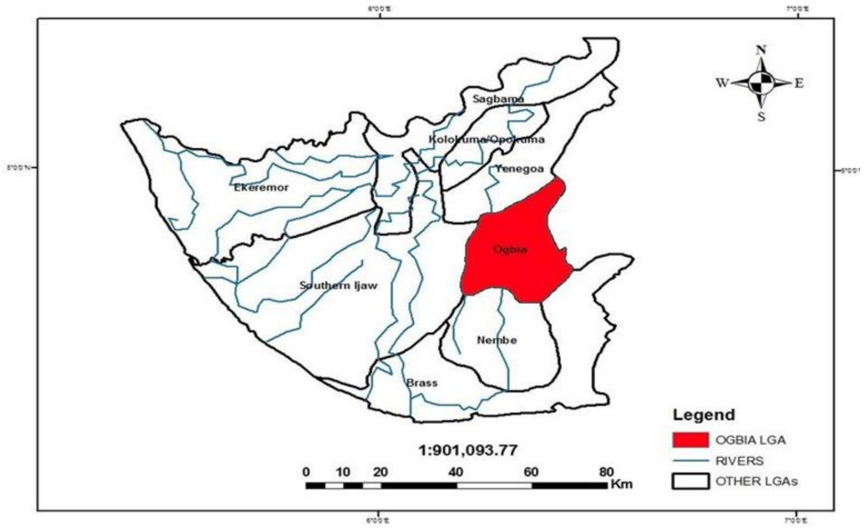

Figure 1: Map of Bayelsa State showing the boundary of Ogbia Local Government Area (adopted from Ezenwaka and Living-Jamala, 2024).

Figure 2: Image of failed portion of Otuoke – Onuebum road.

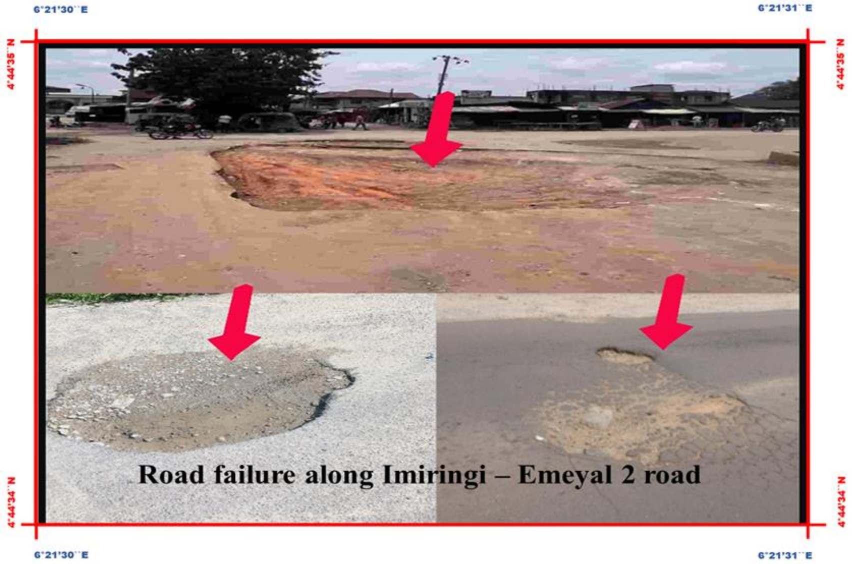

Figure 3: Image of failed portion of Imiringi – Emeyal 2 road

Figure 4: Google map of the study area showing Profiles where Data were collected along Otuoke - Onuebum Road.

Figure 5: Google map of the study area showing the Profiles where Data were collected along Imirigi - Emeyal Road.

The Study area is located in the Niger Delta Area. The Niger Delta Basin, occupying a total area of about 300,000km², is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the Western Coast of Nigeria (Tuttle *et al.*, 1999) and partly extends to Cameroon, Equatorial Guinea and Sao Tome and Principle. Oceanic basement rock of pre-rift time period and basaltic in composition is the oldest rock in the basin. Also, closer to the coast is the Precambrian continental basement. This basin was formed in the Tertiary period from the interplay between subsidence and deposition arising from a succession of transgressions and regressions of the sea (Hospers, 1965). It was formed by a failed rift junction during separation of the South American plate and the African plate, as well as the opening of the South Atlanic.

The sediment fill of the basin has a depth between 9 -12km (Fatoke, 2010) and it is composed of several different geologic formations that indicate how the basin was formed, as well as the regional and large scale tectonics of the area. The formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries. Three Litho-stratigraphic units are distinguishable in the Tertiary Niger Delta (Short and Stauble, 1967). The basal Akata Formation of about 7000m in thickness, which is predominantly marine pro-delta shale, is overlain by about 3700m thick paralic sand/shale sequence of the Agbada Formation (Tuttle *el. al*., 1999). The Akata Formation is the source rock in the sedimentary basin. The topmost section is the Continental upper deltaic plain sands – the Benin Formation, estimated to be 2000m in thickness (Tuttle *et al*., 1999). This thickness is of lateritic red earth formed by weathering of older sequences. The Benin Formation is a stratigraphic unit that was laid down during the end of Tertiary and Quaternary period (Doust and Omatsola, 1990). The Benin Formation is predominantly sandy with minor insertion of clays and mudstones. The sands and sandstone are coarse grained, commonly very pebbly to very fined grained. A separate member of the Benin Formation, Afam Clay Member, is recognized in the Port Harcourt Area which is interpreted to be in Miocene sediments (Short and Stauble, 1967). These Formations are underlain by various types of Quaternary deposits. According to Osakuni and Abam (2004), these Quaternary sediments are largely alluvial and hydromorphic soils and Lacustrine sediments of Pleistocene age.

The depositional pattern which accompanied the accumulation of sediments during the formation of the delta, rise to structural traps (growth faults and roll-over anticlines) in the Agbada Formation (Nwankwola and Ngah, 2014). Virtually all the hydrocarbon accumulations in the Niger Delta occur in the sands and sandstone of the Agbada Formation where they are trapped by the rollover anticlines related to growth fault development (Ekweozor and Daukoru, 1994).

III. Materials And Method

The geophysical technique employed in this investigation is the Electrical Resistivity Tomography (ERT) utilizing combined Wenner-Schlumberger array configurations. The 2D ERT data were collected with a locally designed Terrameter. For each profile, the ERT data were collected using Wenner Array. Traversing along a profile with a given value of electrode spacing probed the subsurface resistivity variation along the profile horizontally. The procedure was repeated severally along the same profile using higher electrode spacing for different spreads and these resulted to the measurement of the horizontal variation in resistivity at different depths. In order to probe deeper and ensure data redundancy in the study, data were also collected along each profile using Schlumberger array. For each profile, the centre of spread for each VES station was located at the failed portion of the roads. The data collected were processed and tomographically inverted.

IV. Results And Discussion

The interpreted results of the geophysical investigation are presented in Figures 6 - 9. The ERT results provided two-dimensional subsurface resistivity models that reveal the lateral and vertical variations in electrical properties of the earth underlying the failed portions of the roads. These models delineated zones of low resistivities that likely correspond to areas of increased soil moisture, weathering, or erosion - factors that can impact road construction and stability.

The resistivities associated with the failed portions of the roads range from 30Ωm to 77Ωm and 0.094Ωm to 173Ωm. These resistivity ranges encompass the ranges for clay and peat, loam and mud. These suggest that clay volumetric variation due to variation in moisture content most likely caused the failure of the roads. Also, failure of the roads in the parts underlain by peat, loam and mud is attributed to the high moisture of the formation, which are easily compress by loads.

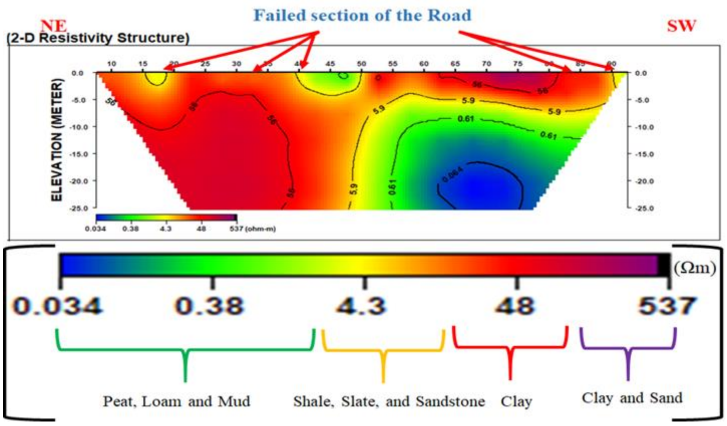

Figure 6: 2D Electrical Resistivity Tomogram for Profile AB.

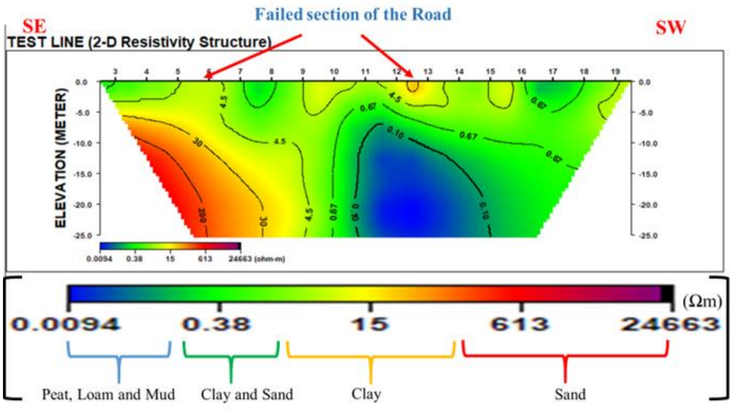

Figure 7: 2D Electrical Resistivity Tomogram for Profile CD

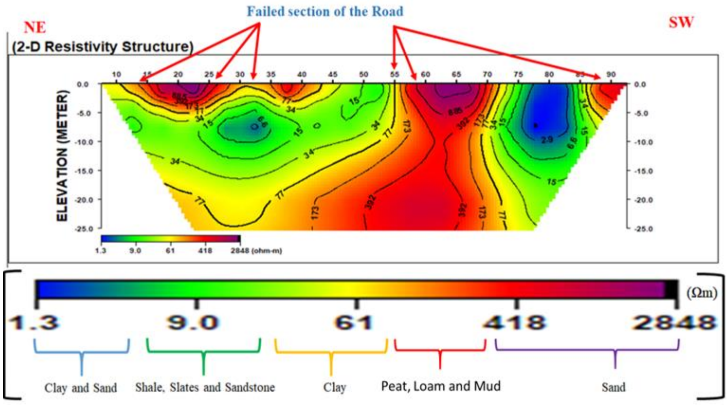

Figure 8: 2D Electrical Resistivity Tomogram for Profile MN.

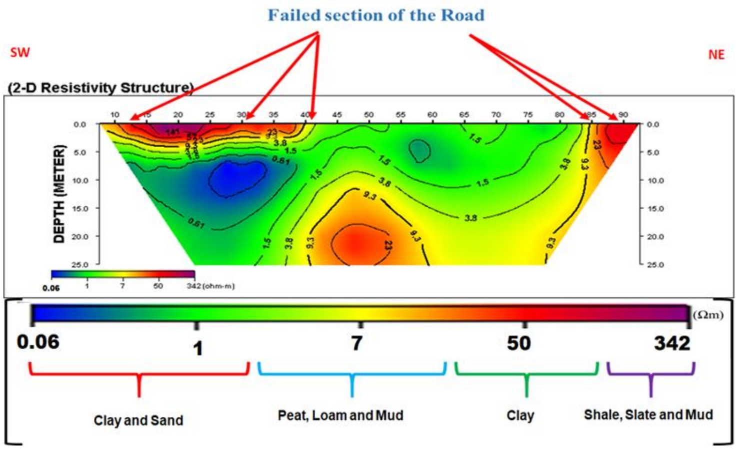

Figure 9: 2D Electrical Resistivity Tomogram for Profile QR

The most extensive feature in the tomogram is the Clay formation. This formation was delineated at shallow depth and has resistivity range of about 4.5 to 77Ωm and thickness of about 2 to 8m. The formation is easily saturated with water. The expansive and contractive nature of this clay-rich layer due to change in moisture content can potentially cause distortion and instability on infrastructures such as roads. Soils with free swell values of 100% or more are associated to clay which could swell considerably when wetted (Gibbs and Holtz, 1956). The dispersive and expansive-contractive behavior of the clay-rich zone is most likely a major factor contributing to the road failure on this section of the study area.

Also, peat, loam and mud formation was delineated at shallow depth and has resistivity range of about 0.094 to 173Ωm and thickness range of about 3 to 10m. The failure in this segment of the road is attributed to the high moisture of the peat, loam and mud which is easily compress by load. This formation is naturally consisting of dead organic materials. The characteristics of peat soil are high water content, low shear strength and high compressibility (Huat *et al*., 2014).

Sand formation underlying the stable parts of the road has a resistivity range of about 885 to 2848Ωm and thickness range of about 8 to 16m. Sand formations are typically characterized by relatively high electrical resistivity due to their low water content and large pore spaces. The segments of the roads overlying the sand formation are very stable and devoid of cracks, potholes, bulges and depressions. Also, the resistivity value of this formation shows that the soil is not vulnerable to volumetric changes on contact with water which results to its capability to sustain imposed wheel stress.

In general, the interpreted results have shown that the low resistivities associated with the formations underlying the failed road portions were attributed to the presence of high moisture content in the soil subsurface. The comparison of the resistivities of the adjacent formations underlying the stable parts of the roads shows that the formations underlying the stable parts are more resistive to current flow than the failed segments. Roads constructed over areas of clay and peat, loam and mud formations are generally subjected to later settlement due to the volumetric changes caused by swelling/shrinking and low shear strength of the subsurface as a result of high moisture contents. The combination of these characteristics makes it challenging for the soil to conduct water away from its surface, leading to poor water infiltration and subsequently contributing to road failure.

V. Conclusion

The purpose of this study was to provides a preliminary overview into the subsurface nature and potential factors causing road failure in parts of Ogbia Local Government Area, Bayelsa State. The geophysical investigation involving 2D imaging determined the variations of the subsurface soils that most likely caused road failure along Otuoke–Onuebum and Imiringi - Emeyal 2 Roads. The results show that the formation underlying the failed portions of the roads are predominantly clays and peat, loam and mud. These result show that the instability associated with some parts of the roads are due to the following.

i. clay volumetric variation due to variation in moisture content most likely caused the failure of some parts of the roads.
ii. high moisture content of peat, loam and mud facilitated compression of some failed portions of the roads due to loads.

Road construction and rehabilitation work along Imiringi - Emeyal 2 and Otuoke-Onuebum Roads do not stand the test of time; it is therefore recommended that clay, peat, loam and mud deposits as well as highly weathered geologic materials existing beneath the roads should be excavated and replaced with more competent material like sand before laying the asphalt.

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