Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2023, 10(6):61-70**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Analysis of the Causes of Road Failures using Electrical Resistivity Tomography in Mgbelu Umunnekwu, Isiukwuato, Southeastern Nigeria

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Abstract The Mgbelu Umunnekwu Road is a secondary road which traverses the North and Southern parts of Isiukwuato LGA. The road enables farmers in the community to convey farm produce to markets for sale. However, the major failure of the road has exposed the community to several challenges including security risks. A major failed section of the road identified for the Analysis of the Causes of Road Failures in Mgbelu Umunnekwu Community is located between Latitude 5° 40' N and 5°50' N and Longitude 7° 22' E and 7° 34' E. Using the IGIS device, Wenner Array was deployed to carry out 3 levels of Electrical Resistivity Tomography profiling, while Geotechnical Analysis of soil samples was also conducted. The ERT had a profile length of 100m and an electrode spacing of 5m. Result of ERT survey in Mgbelu Umunnekwu Road at Oguduasa indicated the presence of clay, and alluvium (clay, silt and sand) materials from top soil to a depth of 2m at location 1, 4m in location 2 and 3.78m in location 3. Furthermore, the presence of unconsolidated shale traversed the soil to a depth of 10m. Considering the fact that clay, silt, sand and unconsolidated shale are unsustainable materials for road construction, their presence reduce the quality and strength of roads. It is therefore obvious from scientific procedures, experiments and investigations that the rock types upon which the road is built is a major factor besides others for the road failures, incisions and consequently landslides.

Keywords Road-Failure, Mgbelu-Umunnekwu, Resistivity Tomography, Ajali Formation

Introduction

Road is any wide way with specially prepared surface by which vehicles can move on, leading from one place to another and its network is considered very essential in the economies of many nations, especially the developing ones like Nigeria which require roads and highways for transportation of most goods and services. However, construction and maintenance of good roads and highway networks in the study area are often problematic and have resulted to economic setbacks. Studies on road failures have been widely carried out using geophysical and geotechnical methods [1]. Geophysical method involves the use of electrical resistivity and electromagnetic approaches which tries to evaluate the subsurface condition of roads to establish integrity of road and likely fault zones which could result to road failures [2]. Road failures are not primarily due to usage or design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behaviours of residual soils on which the roads are built and non-recognition of the influence of geology and geomorphology during the design and construction phases [3 & 4]. As such, these factors can be categorized as: geological, geomorphological, geotechnical, road usage, construction practices and maintenance [3].

For the past two decades, geophysics has proved quite relevant in highway site investigations [1]. Geophysical methods like electrical resistivity have been used in mapping subsurface geologic sequence and concealed geological structures [5]. Rehabilitating the road ways has become a financial burden on the federal, state and local governments, hence, there is a need to identify the causes of the road failures and find a means of solving or mitigating the problem.

Road Failure

Road failure could be defined as a discontinuity in a road pavement resulting to cracks, potholes, polishing/pavement surface wash, block and longitudinal cracks, drainage collapse, depression/ sinking of roadway, over flooding of the carriageway, gullies and trenches, rutting ravelling. All these are evident along Mgbelu Umunnekwu - Uturu Okigwe Road, few kilometres to Abia State University permanent site under study confirming its failure. Several factors are responsible for road failures which can be geological, geomorphological, geotechnical, road usage, construction practices and maintenance [3]. Principal causes of road failures include:

Absence of Quality Preliminary Geological Investigation: The basic tests required to be carried out on the subgrade are often times not done. The effect of this is either poor design as a result of the use of assumed geotechnical data or road construction without design [6 & 7]. This is meant to reveal the true nature of the subsurface and the component rock types to guide the construction activities as knowledge of the properties of subgrades is very important in designing a road construction.

Poor design of roads: A good road design should not only cater for the present traffic and drainage need but should project and forecast for the possible increase in traffic [7]. Due to inadequate projection, most roads today are overloaded and are failing because they were not designed to carry the traffic loads they are subjected to.

Use of sub-standard materials: Use of low-quality aggregate adversely affects the quality of the roads. These sometimes occur in the form of the improper grading of aggregates for subbase and poor subgrade soil. The use of extreme cohesive and expansive soil as sub grade soil results in prolonged consolidation and unnecessary settlement of the roadway [6]. The use of soil of low bearing capacity leads to the failure of the sub grade soil.

Poor supervision and workmanship: A good pavement design with good detailing without a good supervision by the designer (consultant) is equally useless as this could lead to road failure [7]. Supervision ensures that the road construction is rightly executed and that good equipment and materials are used. Quality control which includes laboratory and in-situ tests on the filling, subbase and base materials, determination of the thickness of pavement layers and so on are achieved during supervision.

Poor maintenance: One of the main problems of highway development in Nigeria is maintenance. The roads are rarely maintained and whenever maintenance is attempted it is not properly done. The effect of delayed maintenance is the spread of road defect to areas bounding the failed section [7].

Bad/ absence of drainage: Drainage is an important feature in determining the ability of any given road pavement to withstand the effects of traffic and environment. Poor drainage conditions on road pavement are of adverse effects and causes failures in different ways [7]. Good drainages provide a flow path for rain and storm water, thereby draining the road properly.

Overloading of roads: All road surfaces wear under the action of traffic, particularly during the very early life of the road. The action of traffic continues to wear the macro surface texture and thus gradually reduces the high-speed skidding resistance. According to [6], increase of traffic loads both in terms of numbers and axle loads due to increased economic and developmental activities in the country, leads to systematic deterioration of the facility because the overload is beyond what the roadway was designed to carry.

Inadequate penalties for road failure: Highway failures do not just happen. They are caused either by government agencies, the contractors or the road users. Adequate sanctions and penalties are not placed on agencies responsible for supervision and the contractor in cases of road failure [7].

With respect to the failed road at Umunnekwu, the geological and rock properties are the focus of investigation. Knowledge of these will aid rehabilitation efforts by authorities involved.

Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography (ERT) is a non-invasive method with unique features, relevant for understanding subterranean formations and for depth estimations of natural resources [8]. It has the striking advantage of measuring data in noisy environment [8]. It is a systematic combination of Vertical Resistivity Sounding (VES) and Horizontal Resistivity Profiling (HRP) using multi electrode system connected to multi-core cable. ERT operates on the principle of Ohms Law which states that the electric current I in a conducting wire is proportional to the potential difference V across it [9, 10, 11 & 12]. This is mathematically expressed as Voltage (V) = Current (I) x Resistance (R)

$$V = IR \quad (1)$$

Since resistance (R) is directly proportional to its length (l) and inversely proportional to the cross-sectional area (A), it follows that:

$$R = \rho \frac{l}{A} \quad (2)$$

$$\rho = \frac{RA}{l} \quad (3)$$

Resistivity values will be compared to standard values provided by [10] and [13] in table 1 below

Table 1: Resistivity Values of Rocks and Subsurface Materials ([10] and [13])

Resistivity (ohm-m)	Soil type/ Lithology
20 - 40	Clay-sand
40 – 60	Sand-clay
5 – 100	Clay
10 – 1000	Unconsolidated shale
20 – 2000	Consolidated shale
250 – 500, 2000 – 3400	Sand
100 - 10000	Saturated sand
150	Saturated sandy soil
500 – 10000	Limestone
200 – 8000	Sandstone
1 – 5	Leachate
100	Saturated gravel
250 – 1700	Top soil
30 – 215	Sand clay/ clay sand
300 – 3000	Slate
50 – 3000	Shale
25	Saturated sandstone
20	Saturated Clayey soil
10 – 800	Alluvium and sand
$50\text{-}10^7$	Limestone
15 – 30	Saturated landfill
30 – 100	unsaturated landfill
800 – 1500	Laterite

Statement of the Problem

The persistent and consistent failing of the Mgbelu Umunnekwu Road after several rehabilitation interventions leaves a lot to be desired. The road which is one of the major routes connecting the northern and southern parts of Isuikwuato through Mgbelu Umunnekwu Community has degenerated so much with breakages, bulges, and gully formations around the perimeter of the road. This has posed economic setback in terms of mobility-time management for business men and women, death traps as it has become accident hot spots and an active location for thieves/ marauders who waylay victims at such bad spots. In view of the foregoing, assessing and evaluating the anisotropic layers and intercalations of the subsurface becomes necessary to unravel possible causes of the road failures.

Aim and Objectives

The aim of this research is to analyse shallow subsurface factors responsible for road failures in Mgbelu Umunnekwu Community in Isiukwuato Area of Southeastern Nigeria. In order to achieve this,

a. Electrical Resistivity Tomography survey will be conducted in the study area to determine resistivity of rock materials.
b. Consequence of soil properties identified in (a) above will be determined to establish the causes of the road failures.

Location and geology of study area

The study area is Mgbelu Umunnekwu Community in Isiukwuato Area of Southeastern Nigeria. The community under study comprises Ugwuaba, Amaokwe Amaiyi (Pipeline Installation) and Oguduasaa villages. Isiukwuato LGA is situated in the northern part of Abia State, Southeastern Nigeria, and located between Latitude 5° 40' N and 5°50' N and Longitude 7° 22' E and 7° 34' E. It can be accessed from the northwest through Okigwe, from the southwest through Nunya section of the Port Harcourt, Enugu Expressway and from the south-east through Umuahia. Isuikwato has hilly landscape. According to the 2006 population census, the area is home to about 114,442 people.

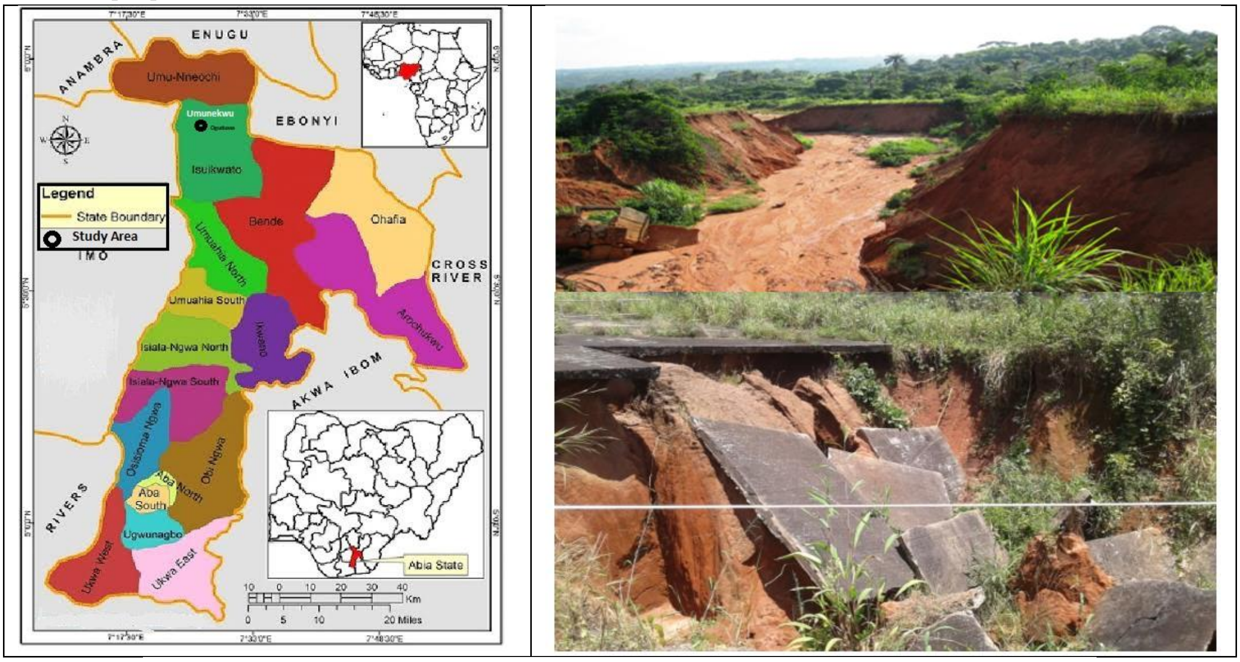

Figure 1: Map of Abia State showing Isuikwuato LGA and Umunnekwu (The Study Area)

Umunnekwu Mgbelu is underlain by the loose and friable Maastrichtian Ajali Formation. The Ajali Sandstone which consists of thick, friable, poorly sorted sandstone typically white in colour but sometimes iron-stained [14 & 15]. Its sandstone is often overlain by a considerable mass of red earth formed by weathering and ferruginisation [16]. Hence, there is an intercalation of mudstone and shale into the Ajali alluvium. This is a key factor defining the electrical properties of rocks in the community.

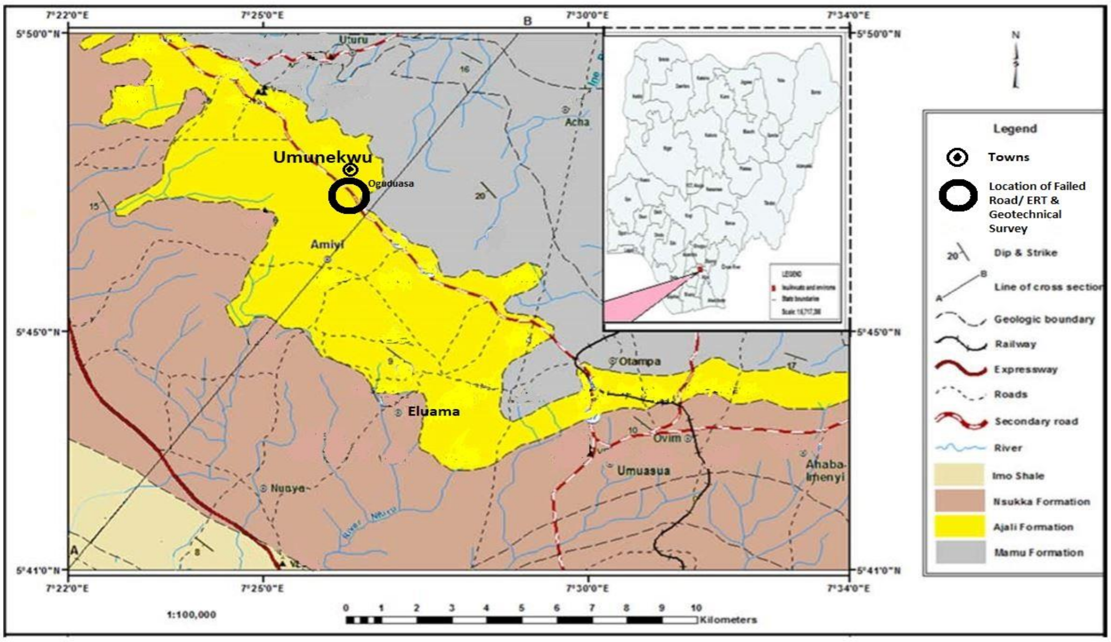

Figure 2: Geologic Map of Isuikwuato and the Study Area

Materials and Methods

Materials

The Integrated Geo-Instrument Services (IGIS) Device

This instrument with model Number: SSR-MP-ATS is a multi-electrode meter used to collect resistivity data. According to [10] & [17], the instrument design incorporates several innovative features and advanced techniques of digital circuitry to make it a reliable geophysical tool providing high quality data useful for geophysical applications. It has an excellent depth penetration with relatively low power inputs to a depth of 600m, utilizing the signal stacking up to 16 successive readings to achieve good signal enhancement.

Other materials include Handheld GPS and Digital Camera. The RES2DINV (ver 5.1) Computer Software was used for modelling, and analysis of ERT data, including Microsoft Word and Excel spreadsheet.

Methods

The ERT survey was conducted in 3 locations where the road failed using the Wenner electrode configuration, with each having a profile length of 100m and mid-point of 50m. The setup involved a systematic connection of the IGIS device with accessories using multi-core cables.

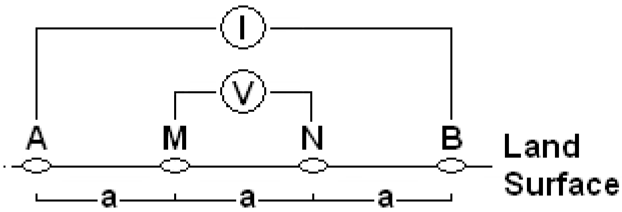

Figure 3: Wenner Configuration

Resistivity data were then recorded via complex combinations of current and potential electrode pairs to build up a pseudo cross-section of apparent resistivity beneath the survey line [10]. A total of 22 electrodes were plugged into the ground with an electrode spacing of 5m. In the meter is positioned relays which ensure the switching of those electrodes according to a sequence of readings predefined and stored in the internal memory of the equipment [10 & 18]. Recorded data were then analysed on a laptop computer preinstalled with

RES2DINV software for processing to produce two-dimensional sub surface images. The measured data were subjected to a least-square inversion process.

Results and Discussion

Result of ERT

The ERT conducted at the portions of the failed road in the study area produced 2-D images of the subsurface. 3 ERTs were executed using Wenner Electrode Configuration with the IGIS device. Standard resistivity values as presented in Table 2 will provide reference for interpretation of Least Square Inversion Models. The profile length was 100m with electrode spacing of 5m having an array mid-point of 50m. Presented below in table 2 is the ERT data for location 1.

Table 2: ERT Data for Profile 1

k	Resistance at 5m	Apparent Resistivity	Resistance at 10m	Apparent Resistivity	Resistance at 15m	Apparent Resistivity	Resistance at 20m	Apparent Resistivity	Resistance at 25m	Apparent Resistivity	Resistance at 30m	Apparent Resistivity	Resistance at 35m	Apparent Resistivity
6.284	92.0853	2893.320126	31.2688	1964.931392	59.1472	5575.215072	36.5683	4595.903944	35.7003	5608.51713	31.5661	5950.841172	28.2911	6222.34453
6.284	95.2684	2993.333128	31.1127	1955.122068	56.2203	5299.325478	34.3558	4317.836944	33.3998	5247.10858	30.5451	5758.362252		
6.284	82.4767	2591.417914	41.7102	2621.068968	30.3899	2864.551974	33.1586	4167.372848	31.9084	5012.80964	29.9233	5641.140516		
6.284	69.6849	2189.499558	52.3076	3287.009584	23.48	2213.2248	32.6228	4100.033504	31.0894	4884.14474	26.7114	5035.633128		
6.284	66.0583	2075.551786	34.021	2137.87964	10.6026	999.401076	31.2032	3921.618176	30.8668	4849.17428				
6.284	62.4317	1961.604014	13.4125	842.8415	9.2504	871.942704	29.5829	3717.978872	29.0119	4557.76949				
6.284	29.6543	931.738106	16.085	1010.7814	8.8232	831.674832	28.2279	3547.682472	30.4211	4779.15481				
6.284	26.7199	839.539258	10.4361	655.804524	7.904	745.03104	27.6512	3475.202816						
6.284	26.2438	824.580196	13.6552	858.092768	14.2448	1342.714848	27.0744	3402.710592						
6.284	22.5249	707.732358	8.4002	527.868568	16.1351	1520.894526	29.6137	3721.849816						
6.284	18.806	590.88452	10.851	681.87684	20.8321	1963.633746								
6.284	13.7371	431.619682	10.8483	681.707172	25.529	2406.36354								
6.284	9.7307	305.738594	12.9564	814.180176	25.1123	2367.085398								
6.284	9.3076	292.444792	8.8176	554.097984										
6.284	10.5744	332.247648	11.3233	711.556172										
6.284	9.5359	299.617978	19.1689	1204.573676										
6.284	10.2407	321.762794												
6.284	14.5747	457.937074												
6.284	15.9754	501.947068												

The ERT conducted profiled a depth of 19.8m and a horizontal coverage of 100m across failed parts of the road. With reference to Table 2.1 showing resistivity values of rock materials culled from [10], it is obvious that rock composition beneath the surface along areas covered by profile 1 in Figure 4 below is a major factor to be considered.

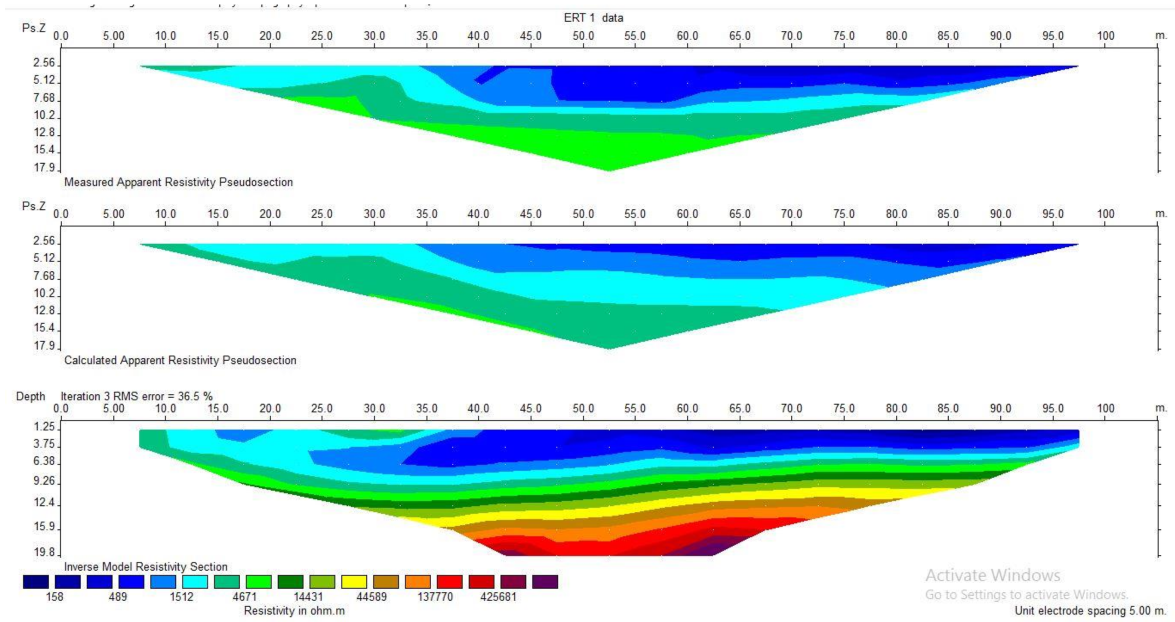

Figure 4: ERT Model for Profile 1

The least resistivity value is in the neighbourhood of 158ohm-meter. Topsoil from points 60m to 95m along the horizontal profile contains clay material to a depth of 2m. looking further at the model, it is clear that there exist a sand clay and clay sand mixture, whose resistivity is between 158 to 489ohm-meter. It deeps to about 6m traversing points 48m to beyond 95m along the horizontal profile. Resistivity values up to 1000ohm-m is indicative of sand and unconsolidated shale. This is found at between points around 33m to beyond 95m along the horizontal profile to a depth of 6.38m. Between 1000 to 1500ohm-metre is characteristic of laterite and consolidated shale, including areas from 24m to beyond 95m along the profile, reaching to the surface at between 15m to 20m and 37m to 40m. It could be seen that between 1512ohm-meter and 3000ohm-meter, layers of shale/ slate materials are present. They arc the surface at between 10m to 35m along the horizontal profile and below lower resistivity materials traversing 25m to beyond 100m points on the profile length. Regions with resistivity values ranging 4671ohm-meter and above are higher resistivity materials such as sandstone and saturated sand to a depth of around 9.26m. It can therefore being seen that from the model, the failed part of the road as profiled consists of unsustainable road materials to a depth of slightly above 9m.

Analysis of data in Table 3 below produced the model in Figure 5. The least resistivity values in Figure 5 (profile 2) below are between 260 to 789, which represent clay, alluvium and sand materials. This can be found at the beginning of the profile up to 25m and deepens to about 4m.

Table 3: ERT Data for Profile 2

k	Resistance at 5m	Apparent Resistivity	Resistance at 10m	Apparent Resistivity	Resistance at 15m	Apparent Resistivity	Resistance at 20m	Apparent Resistivity	Resistance at 25m	Apparent Resistivity	Resistance at 30m	Apparent Resistivity	Resistance at 35m	Apparent Resistivity
6.284	17.8667	561.3717	59.0019	3707.679	41.0402	3868.449	52.5808	6608.355	49.4023	7761.101	37.8142	7128.733	32.0625	7051.826
6.284	35.843	1126.187	69.1101	4342.879	44.7811	4221.066	53.2921	6697.751	47.1938	7414.146	37.437	7057.623		
6.284	44.7082	1404.732	68.9991	4335.903	58.3559	5500.627	54.0034	6787.147	45.9846	7224.181	37.0597	6986.495		
6.284	52.3029	1643.357	68.8842	4328.683	62.1181	5855.252	52.899	6648.346	45.1212	7088.541	37.4885	7067.332		
6.284	68.3742	2148.317	68.2319	4287.693	62.0762	5851.303	53.304	6699.247	45.5134	7150.155				
6.284	73.9497	2323.5	68.4213	4299.594	60.0358	5658.975	53.709	6750.147	45.9055	7211.754				
6.284	79.5252	2498.682	67.687	4253.451	63.0704	5945.016	56.437	7093.002	47.7042	7494.33				
6.284	76.4562	2402.254	70.4211	4425.262	65.251	6150.559	57.5104	7227.907						
6.284	77.6018	2438.249	69.3179	4355.937	67.2609	6340.012	58.5837	7362.799						
6.284	78.7474	2474.243	70.1143	4405.983	70.3851	6634.5	59.2242	7443.297						
6.284	78.5621	2468.421	76.8192	4827.319	67.9698	6406.833								
6.284	87.7119	2755.908	76.2019	4788.527	65.5545	6179.167								
6.284	95.5229	3001.33	75.3918	4737.621	59.2994	5589.561								
6.284	98.3511	3090.192	66.9566	4207.553										
6.284	94.9927	2984.671	58.5214	3677.485										
6.284	91.6342	2879.147	60.6072	3808.556										
6.284	91.4261	2872.608												
6.284	97.7742	3072.065												
6.284	97.1421	3052.205												

Noticeable presence of unconsolidated shale and laterite can also be seen in the region with resistivity values in the neighbourhood of 1000 to 1500ohm-meter stretching from 0.00 to 25m below the alluvium and clay materials, and from 25m to 60m at the ground surface.

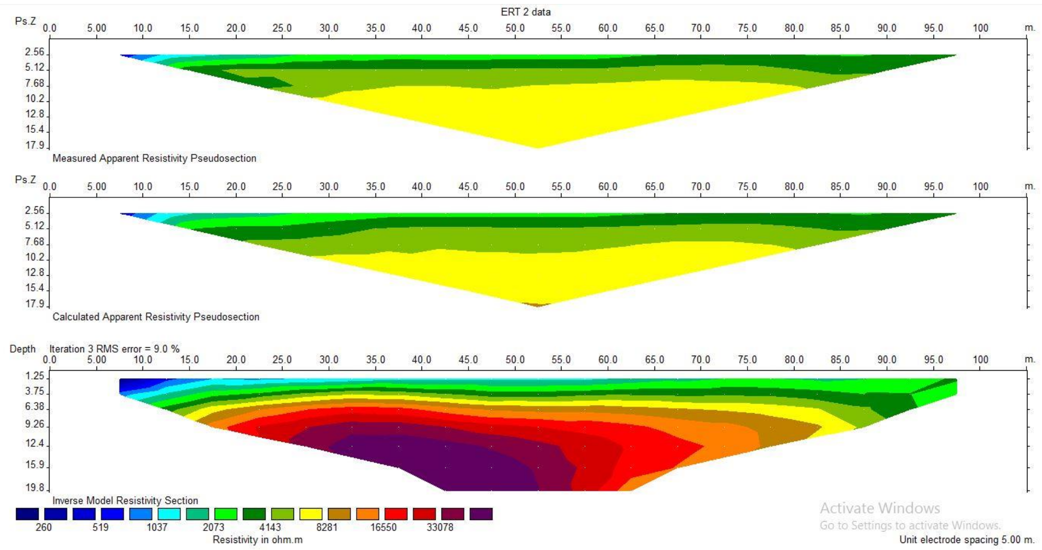

Figure 5: ERT Model for Profile 2

Layers of consolidated shale and sand can be observed traversing the profile from one end to the other with resistivity values between 1500 to 3400ohm-meter up to 5500ohm-meter which has penetrated a depth of 9.26m (showing visibly at the surface between 60m to 95m along the horizontal profile). Below the consolidated shale and sand, varying types of sandstone can be seen with higher resistivity values, deepening down to about 19.8m. Analysis of data in Table 4 produced the Least Square Inversion Model in Figure 6. Least square inversion model for ERT at the third location of failed road presents a consistent and evenly distributed clay, and alluvium materials at the ground surface to a depth of 3.75m as seen in Figure 6.

Table 4: ERT Data for Profile 3

k	Resistance at 5m	Apparent Resistivity	Resistance at 10m	Apparent Resistivity	Resistance at 15m	Apparent Resistivity	Resistance at 20m	Apparent Resistivity	Resistance at 25m	Apparent Resistivity	Resistance at 30m	Apparent Resistivity	Resistance at 35m	Apparent Resistivity
6.284	66.1739	2079.184	39.8011	2501.101	40.8296	3848.598	42.0182	5280.847	34.9046	5483.513	32.3289	6094.644	31.7345	6979.686
6.284	41.4281	1301.671	39.4734	2480.508	41.5173	3913.421	41.9422	5271.296	36.4111	5720.184	33.6659	6346.695		
6.284	40.0894	1259.609	39.7064	2495.15	43.3764	4088.659	41.8662	5261.744	37.0762	5824.671	35.8811	6764.305		
6.284	37.6578	1183.208	39.8754	2505.77	46.8834	4419.229	41.3146	5192.419	37.7412	5929.143	36.1803	6820.71		
6.284	35.0421	1101.023	42.4766	2669.23	46.5113	4384.155	40.7079	5116.169	37.4419	5882.122				
6.284	37.4209	1175.765	46.8254	2942.508	46.2552	4360.015	40.5358	5094.539	37.1426	5835.102				
6.284	37.0387	1163.756	46.7694	2938.989	42.253	3982.768	42.1631	5299.058	37.1797	5840.931				
6.284	44.056	1384.24	46.9295	2949.05	43.5574	4105.721	42.5946	5353.289						
6.284	45.3845	1425.981	47.9431	3012.744	41.2948	3892.448	43.0261	5407.52						
6.284	46.713	1467.722	48.9812	3077.979	39.0321	3679.166	43.1106	5418.14						
6.284	47.8489	1503.412	50.0193	3143.213	40.8973	3854.979								
6.284	48.7397	1531.401	48.375	3039.885	42.7624	4030.784								
6.284	55.7373	1751.266	46.7307	2936.557	42.8693	4040.86								
6.284	53.9909	1696.394	42.9325	2697.878										
6.284	48.9792	1538.926	41.6211	2615.47										
6.284	49.0595	1541.449	42.778	2688.17										
6.284	51.5706	1620.348												
6.284	60.3784	1897.089												
6.284	69.1862	2173.83												

Next in the sequence is the traversing layers of consolidated shale and sand which extends to about 10m deep. Layers of sandstone from the deeper part of the profile up to 19.8m.

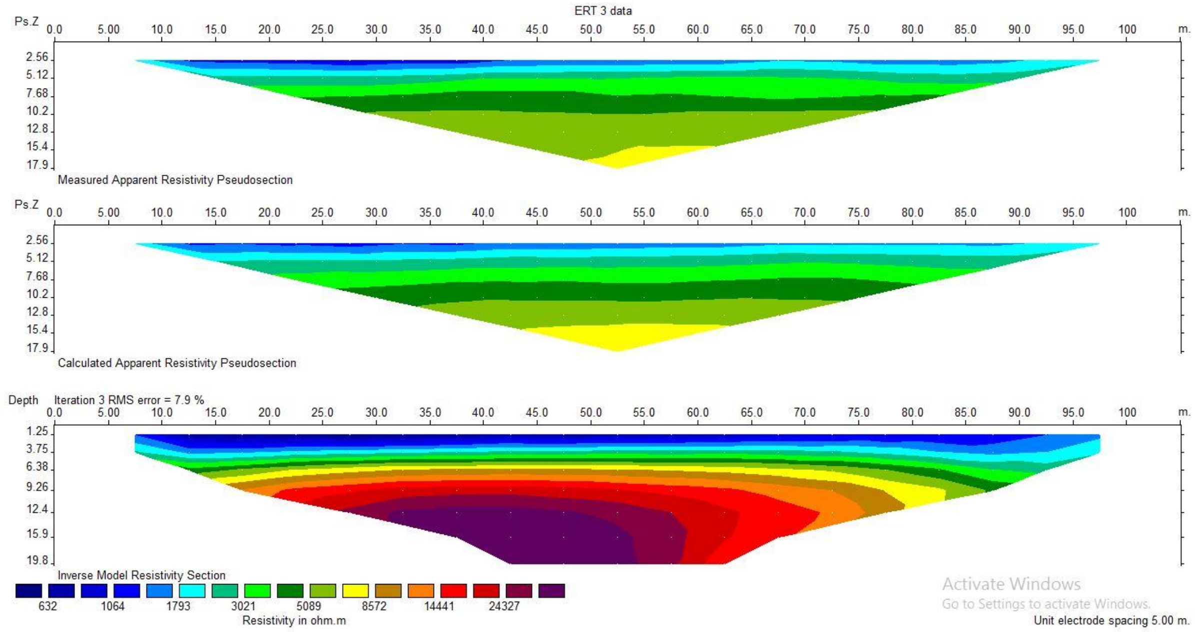

Figure 6: ERT Model for Profile 3

Discussion

The ERT at locations 1, 2 & 3 along the failed road with a profile length of 100m penetrated a depth of 19.8m. Top soil from points 60m to 95m along the horizontal profile at location 1 contains clay material to a depth of 2m. Meanwhile at location 2, clay, alluvium and sand materials dominate the top soil upon which the road was constructed to about 4m depth. Below the clay/alluvium/sand layer is an unconsolidated shale layer in location 2. Looking further at the model, it is clear that there exist a sand clay and clay sand mixture with resistivity between 158 to 489ohm-meter. The presence of unconsolidated shale extends to about 1000 & 1500 ohm-meter. The presence of consolidated shale extends to about 10m deep. It can therefore be seen that from the ERT models, the failed part of the road as profiled consists of unsustainable road materials to a depth of slightly above 9m.

The presence of clay, alluvium (clay, silt and sand) and shale are major factors responsible for failures of the roads because of their ability to absorb water and increase in volume, causing expansion. When the water dries, they reduce in volume and contract. The contraction and expansion cause cracks on the road and breakages on the road [19].

Conclusion and Recommendation

Conclusion

The outcome of ERT along the Mgbelu Umunnekwu road at Oguduasa indicated the presence of clay, and alluvium (clay, silt and sand) materials from top soil to a depth of 2m at location 1, 4m in location 2 and 3.78m in location 3. Furthermore, the presence of unconsolidated shale traversed the soil to a depth of 10m. This implies that the total average depth of unsustainable road materials beneath the constructed road is 10m.

Considering the fact that clay, silt, sand and unconsolidated shale are unsustainable materials for road construction, their presence reduces the quality and strength of roads. This is due to their ability to absorb water and increase in volume, causing continuous expansion and contraction under heavy vehicular weight. The contraction and expansion cause cracks and breakages on the road. It is therefore obvious from scientific procedures, experiments and investigations that the rock types upon which the road is built are major factors besides others for the road failures, incisions and consequently landslides.

Recommendation

Sequel to this research outcome that the rock type consisting of clay, alluvium and unconsolidated shale underlay the Mgbelu Umunnekwu Road at Oguduasa, it is therefore recommended that:

a. Remediation work at the failed portions of the Mgbelu Umunnekwu Road at Oguduasa should prioritize removal of topsoil to a depth of not less than 10m. Removed topsoil should be replaced systematically with sustainable materials/ rocks such as gravel, granite materials, etc.
b. Construction of roads should compulsorily be preceded by proper geophysical procedures to understudy the soil and subsurface characteristics of the area under consideration.
c. Standard concrete side drains and or tunnels across the road are also recommended for proper draining of water.

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