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Original Research Article

Evaluation of Soil Stabilization Techniques for Enhancing Pavement Performance along the Warri-Sapele Highway, Delta State, Nigeria

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Abstract: Road pavement failure is a significant challenge affecting transportation infrastructure in Nigeria, particularly in areas with weak or unstable subgrade soils. The Warri-Sapele Highway in Delta State has experienced persistent pavement deterioration, often attributed to poor soil conditions beneath the pavement structure. This study evaluates the effectiveness of selected soil stabilization techniques in improving the engineering properties of subgrade soils along the highway. Soil samples were collected from various failed pavement sections and subjected to laboratory tests, including Atterberg limits, compaction, and California Bearing Ratio (CBR) tests, both before and after stabilization using materials such as lime and cement. The results revealed that the native soils exhibited low strength and high plasticity, which contribute to pavement failure. However, after stabilization, significant improvements were observed in strength parameters and load-bearing capacity. The study recommends appropriate stabilization techniques tailored to local soil conditions to enhance pavement longevity and minimize road maintenance costs in the region.

Keywords: Soil Stabilization, Pavement Performance, Subgrade Improvement, Highway Engineering, Warri-Sapele Highway.

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INTRODUCTION

The performance and durability of road pavements are directly influenced by the characteristics of the subgrade soil upon which they are constructed. In Nigeria, premature pavement failure remains a major concern, particularly on highways traversing regions with problematic soil types. The Warri-Sapele Highway, a key transport corridor in Delta State, has suffered recurrent pavement damage, leading to increased maintenance costs, traffic disruptions, and safety hazards. One of the critical factors identified in pavement failure along this route is the inadequate strength and stability of the subgrade soils.

Soil stabilization is a proven geotechnical technique aimed at improving the physical and engineering properties of soils through the addition of stabilizing agents such as lime, cement, or other chemical additives. When appropriately applied, these methods can significantly enhance soil strength, reduce plasticity, and improve moisture resistance — all of which are essential for supporting pavement structures.

This study focuses on evaluating the effectiveness of different soil stabilization techniques for improving the subgrade quality along the Warri-Sapele Highway. Through field sampling, laboratory testing, and analysis of stabilization outcomes, the research aims to provide practical recommendations for improving pavement performance and reducing the incidence of failure in this critical transportation corridor.

Types and Causes of Road Failure

In Nigeria and other developing countries, the primary causes of road failure include overloading, inadequate maintenance, substandard design, and unsuitable subgrade soils. For instance, highways like Warri–Sapele–Benin and Benin–Asaba in Delta State have experienced major degradation due to excessive axle loads and heavy rainfall, resulting in fatigue cracking, potholes, and pavement collapse [16]. Ezeagu and Ezema (2022) found up to 30% failure rates within one year on FERMA-maintained roads like the Asaba–Illah route, primarily due to high traffic from heavy-duty vehicles. Despite adherence to FMW material guidelines, failure persisted, emphasizing poor implementation and a need for FERMA to revisit its design framework and

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funding mechanisms [17]. On the Onitsha–Enugu expressway, failure was attributed to insufficient maintenance, aging infrastructure, and government mismanagement [18]. Ebuzoeme (2015), using statistical tools, verified these findings and stressed the importance of comprehensive design and multi-stakeholder involvement, even though poor design was not the primary cause [19]. Afoloyan and Abidoye (2017) reviewed studies showing that failure is often due to poor geotechnical surveys, lack of supervision, inadequate drainage, and vehicle overloading. They recommended stronger designs, expert supervision, congestion management, and routine maintenance using trained personnel [20]. Emmanuel *et al*., (2021) assessed the Sagamu–Papalanto highway and found clay-rich soils (A-26, A-7, A-2-7), low CBR values (3–12%), and high plasticity, suggesting poor subgrade quality. Soil stabilization was recommended as a corrective strategy [21]. In Rajshahi City, Bangladesh, 25% of roads consistently fail due to weak asphalt, overloading, drainage issues, and neglect, increasing accident risks and vehicle operation costs [22]. Attubi and Onokata (2019) linked road congestion and accidents in Warri to poor construction, careless driving, and a lack of signage, advocating for structurally sound roads and clear signage to improve traffic safety [23].

Influence of Soil Properties on Road Pavement Failure

Subgrade soil's geotechnical and mineralogical traits significantly influence pavement durability, with numerous Nigerian and international studies linking unsuitable soils to early failure.

Ogundipe (2008) documented poor geotechnical features—like high plasticity and low CBR (5.45–36.64%)—on the Aramoko–Ilesha road, resulting in pavement failure [1]. Jegede (2004) similarly found poor strength and excess fines on the Okitipupa–Igbokoda route; although CBR reached 55%, poor drainage still led to damage [24]. Tse and Efobo (2016) observed that the Umuahia–Okigwe road failed due to clay-rich soils with expansive characteristics, such as montmorillonite and kaolinite, with soil types MI-MH and A-7-5 signifying high shrink-swell potential [25]. Ogunribido *et al*., (2015) reported that roads from Ogbagi to Arigidi Akoko failed from fine content excess, expansive soil behavior, poor compaction, and drainage issues. CBR values ranged from 14–31%, with plasticity index varying between 0 and 29.5% [26].

In the Niger Delta, Warmate and Dieokuma identified low-quality subgrade soils (A-2-4 to A-2-7) with CBR values near 10%, requiring soil capping, compaction above 95%, and effective drainage [27]. Wazoh *et al*., (2016) studied road conditions in Jos and concluded that even acceptable soils degrade under excessive traffic loading beyond design thresholds [28]

At the Enugu–Port Harcourt expressway, Osadebe *et al*., (2013) linked road failure to water infiltration into plastic shale subgrades, excessive loads, drainage problems, and a high water table—leading to cracking and base failures [29]. To address expensive and inconsistent soil surveys, Aitsebaomo *et al*., (2013) proposed a digital mapping initiative to aid engineers in accessing soil classification data for better design and planning [30].

Uge (2017) in Ethiopia identified extensive pavement failures shortly after construction, caused by expansive soils and a lack of proactive geotechnical planning, calling for advanced stabilization techniques beyond basic CBR assessments [31]. Mahmoud *et al*., (2012) evaluated the Gombi–Biu road and found subpar liquid limits and CBR values (5.1–31.1%), necessitating stabilization to meet pavement suitability standards [9]. Adeboje *et al*., (2017) demonstrated that adding pulverized palm kernel shell (PPKS) to lateritic soils notably improved strength metrics like CBR and unconfined compressive strength (UCS), while reducing moisture sensitivity [32]. Lastly, Sowemimo (2016) found that Herbert Macaulay Road in Lagos suffered from inadequate materials, poor compaction, heavy traffic, and insufficient lab and field tests, with CBR values well below acceptable thresholds (5.27–6.14%) [33].

MATERIALS AND METHOD

Study Area

The study was carried out in three separate locations—Okuovwori, Okolovu, and Akuekpara—situated along the Warri-Sapele Highway in Delta State, Nigeria. The roadway features a dual-lane design composed of a lateritic subbase, a soil-cement base layer, a surface-dressed median, and an asphalt concrete wearing surface. As illustrated in Figure 1, this important route links Warri and Sapele within Delta State. These locations are geographically positioned between Longitude 5° 47' 0" East and Latitude 5° 34' 25" North (Effurun) and Longitude 5° 42' 4" East and Latitude 5° 55' 7" North (Sapele), and lie at elevations ranging from 6 to 7.8 meters above mean sea level. Owing to its critical role in transportation, this roadway is considered one of the most essential federal routes in Delta State. Continuous vehicular movement, coupled with repeated high axle loading, has led to significant structural distress. The persistent mechanical stress has triggered various pavement failures, including fatigue (alligator) cracking, potholes, localized failures, and surface irregularities [17].

Parent Materials and Geological Formations

The primary geological materials underlying the area include sand, clay, and swamp deposits.

Vegetation

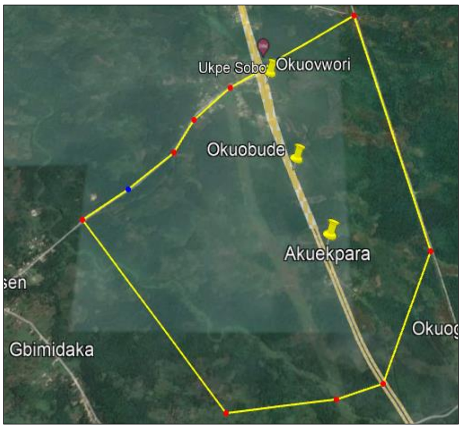

Figure 1: Location of project area

Vegetation details were not explicitly provided in the original, but may refer to the natural cover typical of Delta State's swampy or forested lowland terrain. Let me know if you'd like this section expanded.

The vegetation of the sample sites varied from economic palms such as Coconut (*Cocos nucifera* L), Oil palm (*Elaeis guineesis Jacquin*), Raphia palms such as *Raphia hookeri* (the wine palm), *Raphia vinifera* (the bamboo palm), *Raphia regalis* and arable crops such as cassava (*Manihot esculenta*), maize (*Zea mays)* and prominent weeds of the grass.

Field Study

The study involved soil investigations near a tarred road between Sapele and Warri. Auger borings were randomly conducted 5–10 meters from both sides of the road, while profile pits were dug 100 meters away to represent underlying parent materials. The physical condition of the road was also visually assessed for signs of failure and deterioration.

Soil samples from the profile pits were collected, preserved, and analyzed in the lab for pedological and geotechnical properties. The soils were then classified using both the USDA soil taxonomy (2022) and the AASHTO system. Physical and chemical lab results were used to assess soil suitability for road construction and predict potential road failure by comparing properties across different parent materials using standard guidelines.

Sample preparation: wet soil samples were air dried, crushed with wooden roller and passed through a 2mm plastic sieve and stored in polypropylene bottles for analysis.

Particle Size Determination

The particle sizes was determined using Hydrometer method of Bouyoucos (1951) as modified by Day (1965), and reported by Gee and Or (2002) [35].

- 51 g of air-dry or 50g of oven-dried soil into a soil shaking bottle
- 100ml of calgon was added and will be allowed to soak for 30 minutes.
- The mixture was stirred with a mechanical stirrer.
- The soil suspension was transferred into a sedimentation cylinder and was filled to mark with distilled H_2O.
- A plunger was inserted and was moved up and down to mix the content thoroughly, while the sediment was dislodged with their upward strokes of the plunger near the bottom, the hydrometer was lowered carefully into the suspension and readings was taken after 40 seconds (R40 sec.).
- The temperature reading was taken thereafter with a thermometer.
- The second reading came up in 120 minutes time, while the first (R40 sec.) reading calculate for % silt + clay, the second reading was calculated for % clay and subtracted from % silt clay and both subtracted from 100 to get % sand.

Selected Physical Properties Analysis

Atterbergs Limit Test (Barnes, 1995)**:**

1. Liquid Limit Test

Approximately 100g of dry soil was mixed with distilled water to form a uniform paste. A portion was placed in a liquid limit device cup, smoothed to ½ inch depth, and a groove was created using a standard tool. The device's crank was turned at two revolutions per second, and the number of blows required to close the groove over a ½ inch span was recorded. This process was repeated after remixing until consistent blow counts (10–40 blows) were achieved. About 10g of soil from near the groove was used for moisture content analysis. The test was repeated for four different moisture contents, and a graph of moisture content versus log of blows (flow curve) was plotted to determine the liquid limit at 25 blows [37].

2. Plastic Limit Test

Approximately 15g of moist soil was hand-rolled on a glass plate into 1/8 inch diameter threads. Rolling continued until the threads crumbled. The crumbled portions were tested for moisture content. This was repeated three times, and the average moisture content was taken as the plastic limit.

Calculations

a. Liquid Limit (w_l): Moisture content at 25 blows from flow curve
b. Plastic Limit (w_p): Average moisture content at thread crumbling
c. Plasticity Index (I_p): $I_p = w_l - w_p$

3. Compaction Test

The mold (without collar) was weighed, and 6 lbs of prepared soil (passed through No. 4 sieve) was layered into the mold in three layers. Each layer was compacted with 25 blows from a rammer dropped from one foot. After trimming the soil flush with the mold's top, the mold with compacted soil was weighed. About 100g of soil (sampled from various depths) was taken for moisture content determination. The remaining soil was remixed, and moisture content was increased by 3% increments for each subsequent trial. This process was repeated through five to six compaction runs to obtain a full compaction curve as the soil became wetter and stickier.

Calculation:

The dry density,

$\gamma d = W/V(1+w)$

In which W = total weight of moist compacted soil in cylinder,

V = volume of the mold,

w = moisture content of moist compacted soil.

California Bearing Ratio Test: [35]

This test was conducted on compacted soil in a CBR mould (150mm diameter, 175mm height), fitted with a detachable 50mm collar and a perforated base plate. Soil was compacted at optimum moisture content and dry density as determined by a compaction test. The sample, passing a 20mm IS sieve, weighed approximately 4.5–5.5 kg and was thoroughly mixed with water. A 50mm deep displacer disc was placed in the mould during compaction to yield a 125mm deep specimen.

Compaction was done in three layers using a 2.6 kg rammer, each layer receiving 56 evenly distributed blows. After trimming and removing the disc and base plate, the mould and compacted soil were weighed to determine bulk and dry densities.

A filter paper and perforated base plate were attached to the top, and surcharge weights (minimum two, each 2.5 kg = 7 cm pavement) were applied. The mould was then submerged in water for 96 hours (4 days) with constant water level, and expansion readings were taken daily using a dial gauge setup.

After soaking, the mould was removed, drained, and weighed. The surcharge weight was reapplied, and the mould placed under a CBR penetration test machine. The penetration piston was positioned with minimal load (≤4 kg), and gauges were zeroed. Load was applied at 1.25 mm/min, recording penetration at depths:
0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, and 12.5 mm.

The maximum load and penetration were noted, and 20–30g of soil was sampled from the top 3cm for moisture content analysis.

Calculation

Expansion Ratio

1. Expansion Ratio – the expansion ratio was calculated as follows:
2. Expansion ratio = $d_f - d_i /h \times 100$
3. Where d_f = final dial gauge reading (mm); d_i = initial gauge reading (mm); h = initial height of specimen (mm)

4. **Load Penetration Curve**

A load vs. penetration graph was plotted. If the curve's initial portion was concave, a tangent at the point of greatest slope was drawn to correct the origin. Corrected load values were obtained for desired penetration values, and the CBR **(%)** was calculated accordingly.

C.B.R. = $P_T/P_S \times 100$

P_T = corrected test load corresponding to the chosen penetration from the load penetration curve;

P_S = Standard load for the same penetration as for P_T taken from the standard load.

RESULTS

Morphological Description of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

Table 1 presents the morphological features of Pedon 1**,** located at Okuovwori**,** derived from Sand, Clay, and Swamp parent material.

- **Topsoil (0–37 cm):** Very dark gray in color.
- **Subsoil Colors**:
  - 37–64 cm: Reddish yellow
  - 64–92 cm: Gray
  - 92–109 cm: Light brown
  - 109 cm and deeper: Gray
- **Soil Structure:** Moderately blocky with slight angularity.
- **Textural Classes by Depth**:
  - 0–37 cm: Sandy Clay Loam
  - 37–64 cm: Sandy Loam
  - 64–92 cm: Sandy Loam
  - 92–109 cm: Sandy Clay Loam
  - 109–125 cm: Sandy Loam
- **Horizon Boundaries**:
  - Layers 1–3: Diffuse and blended interfaces
  - Layers 4–6: Sharp and well-defined boundaries

Morphological Description of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

Table 2 provides the morphological data for Pedon 2**,** located at Okolovu**,** also underlain by Sand, Clay, and Swamp materials.

- **Topsoil Color**: Black
- **Subsoil Colors by Depth:**
  - 12–23 cm: Reddish yellow
  - 23–28 cm: Pinkish gray
  - 38–46 cm: Light gray
  - 46–152 cm: Strong brown
- **Soil Structure**: Ranges from fine and many to fine and very few structural elements

Table 1: Morphological Description/Classification of Pedon 1 (Sand, Clay and Swamp)

Geographical coordinates	N5.836207, E5.731114
Taxonomic Class	Typic Endoaquepts
Parent Material	Sand, clay and swamp
Physiographic Position	Terrace – Elevation: 16 m a.s.l.
Drainage	Poor
Vegetation/Landuse	Permanent crops – oil palm
Depth to water table	Deep (≥164cm)

Horizon	Depth (cm)	Description
A	0-37	Very dark gray (10YR4/3); sandy loam; non sticky, non-plastic; fine many single grain; medium few root size; smooth clear boundary; pH 5.06
Bw	37 -64	Reddish yellow(7.5YR6/8); Sandy Clay Loam; non sticky, non plastic; loose moist and dry; medium few root size; smooth clear boundary; pH 4.97.
Bw_2h	64 - 92	Light brown (7.5YR6/4); Sandy Loam; medium few root size; smooth diffuse boundary; pH 4.52.
Bw_3	92 - 109	Brown (7.5YR5/4); Brown; sticky, plastic; friable moist, soft dry; fine sub-angular blocky; medium few root size; smooth diffuse boundary; pH 4.43
Bw_4	109 -125	Gray (10.5YR6/1); Sandy loam; sticky, plastic; friable moist, soft dry; medium sub-angular blocky; very few fine root size; pH 4.34.

Table 2: Morphological Description/Classification of Pedon 2 (Sand, Clay and Swamp)

Horizon	Depth (cm)	Description
Ap	0 – 12	Black (10YR2/1); sandy loam; non sticky, non plastic; loose moist and dry; very fine many grain; medium few root size; smooth clear boundary; pH 5.87
A	12 – 23	Reddish yellow (5YR6/6); sandy loam; non sticky, non plastic; loose moist and dry; fine few grain; smooth clear boundary; pH 5.33
AB	23 – 38	Pinkish gray (7.5YR6/2); sandy loam; non sticky, non plastic; loose moist and dry; fine very few grain; smooth diffuse boundary; pH 4.01.
Bw	38 – 46	Light gray(10YR7/2); Sandy loam; non sticky, non-plastic; loose moist and dry, fine very few grain; wavy boundary; pH 4.2.
Bw_2	46 - 152	Strong brown (7.5YR5/6); Sandy clay loam; sticky, plastic; friable moist, soft dry; pH 4.1.

Geographical coordinates	**N 5.729985, E 5.752772**
Taxonomic Class	Aeric Endoaquepts
Parent Material	Sand, clay and swamp
Physiographic Position	Terrace– Elevation: 12 m asl.
Drainage	Poorly drained
Vegetation/Landuse	Fallow/Road
Depth to water table	Deep (≥150cm)

(12 cm) of the profile displays a sandy loam texture, which persists through 12 to 23 cm and also continues across 23 to 38 cm and 38 to 46 cm depths. However, from 46 to 152 cm, the soil texture transitions to sandy clay loam. The boundary separating the first and second layers appears wavy, while the transition between second and third layers is smooth and diffuse. The boundaries for layers three, four, and five are described as smooth and distinct.

Morphological Description of Pedon 3 (Akuekpara – Sand, Clay and Swamp)

Table 2 presents the morphological features of Pedon 3 located in Akuekpara, an area underlain by sand, clay, and swamp materials. The topsoil exhibits a very dark brown color, while the subsoil layers are brown (13–21 cm), gray (21–32 cm), light gray (32–43 cm), and brown again (43–63 cm). The topsoil texture is sandy loam, which continues through 13 to 21 cm. From 21 to 32 cm, the soil texture shifts to sandy clay loam, which persists down through 32 to 43 cm and 43 to 63 cm. The boundaries separating the first three layers are distinct, while those between layers three, four, and five are diffuse.

Physical-Chemical Properties of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

According to Table 4, the physical and chemical characteristics of Pedon 1, located at Okuovwori, show that soil pH ranges from 4.70 to 5.06. The organic carbon content lies between 2.14 g/kg and 9.08 g/kg, while total nitrogen varies from 0.16 g/kg to 1.58 g/kg. The concentration of available phosphorus ranges between 1.68 mg/kg and 7.98 mg/kg. Calcium levels were found between 0.24 and 1.92 cmol/kg, whereas magnesium content ranged from 0.06 to 1.17 cmol/kg. The potassium content was recorded between 0.11 and 0.27 cmol/kg, and sodium levels ranged from 0.02 to 0.13 cmol/kg. Regarding soil acidity, exchangeable acidity ranged from 0.14 to 1.22 cmol/kg, and the cation exchange capacity (CEC) fluctuated between 1.45 and 3.63 cmol/kg.

Table 3: Morphological Description/Classification of Pedon 3 (sand, clay and swamp)

Horizon	Depth (cm)	Description
Ap	0 – 13	Very dark brown (10YR2/2); sandy loam; non sticky, non-plastic; loose moist and dry; medium few root size; smooth clear boundary; pH 4.01
AB	13 – 21	Brown (7.5YR6/1); sand loam; non sticky, non-plastic; loose moist and dry; smooth diffused boundary; pH 4.61
Bth	21 – 32	Gray (7.5YR6/1); sandy clay loam; non sticky, non-plastic; loose moist and dry; smooth diffuse boundary; pH 4.97.
Bt_2	32 – 43	Light gray(7.5YR7/1); Sandy clay loam; sticky, plastic; loose; smooth diffuse boundary; pH 5.06
Bt_3	43- 63	Brown (7.5YR5/4); Sandy clay loam; sticky, plastic; friable moist, soft dry; pH 5.78

Geographical coordinates	**N 5.760750, E 5.741545**
Taxonomic Class	Grossarenic Endoaqults
Parent Material	Sand, clay and swamp
Physiographic Position	Float– Elevation: 6 m asl.
Drainage	Poorly drained
Vegetation/Landuse	Fallow/Road
Depth to water table	Deep (≥63cm)

Table 4: Physio-chemical Properties of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Depth	Layer	pH	Org.C	Tot.N	Avail.P	Ca	Mg	K	Na	EA	ECEC	Sand	Silt	Clay	Texture	BS
(cm)		(1:1)	(g/kg)	(g/kg)	(mg/kg)	← (cmol/kg) →						← (g/kg) →				(%)
0-37	1	5.06	9.08	1.58	7.98	1.92	1.17	0.27	0.13	0.14	3.63	730	120	150	SL	96.14
37 – 64	2	4.97	3.29	0.63	1.68	1.68	1.02	0.11	0.04	0.59	3.45	770	20	210	SCL	82.88
64 – 92	3	4.52	5.81	0.41	3.56	0.24	0.08	0.11	0.04	1.22	1.69	690	140	170	SL	27.87
92 – 109	4	4.43	3.29	0.24	3.39	0.28	0.06	0.11	0.02	0.98	1.45	550	280	170	SL	32.56
109 - 125	5	4.70	2.13	0.16	2.98	0.66	0.40	0.16	0.04	1.14	2.41	710	80	210	SCL	52.66

Physical-chemical Properties of Pedon 3 (Akuekpara – Sand, Clay, and Swamp)

Table 4 presents the outcomes of the physico-chemical analysis conducted at Akuekpara (sand, clay, and swamp): The pH values ranged between 4.01 and 5.06. Organic carbon content varied from 4.07 g/kg to 7.55 g/kg. Total Nitrogen levels were observed within the span of 0.29 to 0.54 g/kg. Available Phosphorus showed fluctuations ranging from 1.60 to 10.92 mg/kg, while Calcium concentrations fell within 0.46 to 0.64 cmol/kg, indicating a general decrease with depth. Magnesium levels were between 0.17 and 0.66 cmol/kg, and Potassium content remained constant at 0.11 cmol/kg. Sodium concentrations were recorded within the range of 0.02 to 0.06 cmol/kg. Exchangeable acidity values were found between 0.24 and 0.88 cmol/kg. Additionally, the Exchangeable Cation Exchange Capacity (ECEC) varied from 0.85 to 2.12 cmol/kg. Sand content was consistent at 710 g/kg, whereas Silt and Clay ranged from 40 to 140 g/kg and 150 to 190 g/kg respectively. The soil texture was classified from sandy loam to sandy clay loam.

Physical Properties of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

This table displays the results of physical property tests at Okuovwori. The sieve analysis revealed that the percentage passing through sieve #10 ranged from 96.7% to 100%; sieve #40 ranged between 57.1% and 93.2%, and sieve #200 ranged from 27.6% to 34.6%. The Atterberg limits showed that the liquid limit ranged from 45.79% to 53.25%, the plastic limit varied from 0 to 46.24%, and the plasticity index spanned from 0 to 14.49%. Compaction tests indicated that the maximum dry density ranged from 1.06 g/cm³ to 1.40 g/cm³, while the optimum moisture content was between 5.30% and 8.50%. California Bearing Ratio (CBR) tests under different conditions provided a range of values for the unsoaked bottom with varying granular composition.

Table 5: Physio-chemical Properties of Pedon 2 (Okolovu– Sand, Clay and Swamp)

Depth	Layer	pH	Org.C	Tot.N	Avail.P	Ca	Mg	K	Na	EA	ECEC	Sand	Silt	Clay	Texture	BS
(cm)		(1:1)	(g/kg)	(g/kg)	(mg/kg)	(cmol/kg)						(g/kg)				(%)
0-12	1	5.87	17.05	2.47	4.39	1.44	0.88	0.33	0.17	0.1	2.92	810	80	150	SL	96.57
12 – 23	2	5.33	14.58	1.22	4.30	0.46	0.28	0.16	0.11	0.1	2.57	710	200	210	SL	90.99
23 – 38	3	4.02	12.78	0.91	4.81	0.18	0.02	0.11	0.04	1.16	2.70	530	280	170	SL	23.50
38 – 46	4	4.52	2.71	0.19	3.89	0.24	0.00	0.11	0.02	0.9	2.73	590	260	170	SL	29.14
46 - 152	5	4.34	2.32	0.17	3.14	0.15	0.02	0.11	0.02	2.66	2.96	550	220	210	SCL	10.17

Table 6: Physio-chemical Properties of Pedon 3 (Akuekpara -Sand, Clay and Swamp)

Depth	Layer	pH	Org.C	Tot.N	Avail.P	Ca	Mg	K	Na	EA	ECEC	Sand	Silt	Clay	Texture	BS
(cm)		(1:1)	(g/kg)	(g/kg)	(mg/kg)	(cmol/kg)						(g/kg)				(%)
0-13	1	4.01	7.55	0.54	3.14	0.17	0.02	0.11	0.02	0.83	1.15	710	140	150	SL	27.70
13 – 21	2	4.61	4.07	0.29	1.60	0.66	0.40	0.11	0.06	0.88	2.12	770	40	190	LS	58.40
21 – 32	3	4.97	6.30	0.45	5.57	0.28	0.02	0.11	0.02	0.43	0.85	710	120	170	SCL	49.65
32 – 63	4	5.06	4.26	0.30	10.92	0.46	0.03	0.11	0.02	0.24	0.86	710	140	150	SCL	72.13

Physical Properties of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

Table 7 displays the results of the physical properties at Okuovwori. The sieve analysis showed that the percentage passing through sieve #10 ranged from 96.7% to 100%; through sieve #40, it ranged from 57.1% to 93.2%; and through sieve #200, values fell between 27.6% and 34.6%. Atterberg limits indicated that the liquid limit ranged from 45.79% to 53.25%, the plastic limit spanned from 0 to 46.24%, and the plasticity index varied between 0 and 14.49%. Compaction tests revealed maximum dry density values ranging from 1.06 g/cm³ to 1.40 g/cm³, while the optimum moisture content was between 5.30% and 8.50%. For California Bearing Ratio (CBR) under different conditions, a range of results was noted. At the unsoaked bottom condition with a 2.5 mm penetration, the CBR values ranged from 26.43% to 33.12%. When the granularity was increased to 5.0 mm under the same unsoaked condition, CBR values increased to a range of 27.13% to 36.28%. However, under soaked bottom conditions, outcomes differed. At 2.5 mm granularity, CBR values ranged from 17.26% to 35.76%, while at 5.0 mm, they spanned from 23.29% to 37.48%. Focusing on the top conditions, unsoaked samples produced distinctive results. At 2.5 mm granularity, the CBR ranged from 20.07% to 30.31%, and increased to between 22.79% and 34.69% at 5.0 mm granularity. Under soaked top conditions, values declined significantly. A 2.5 mm penetration produced CBR values between 9.57% and 13.46%, which further decreased to 8.44% to 13.31% with a granularity of 5.0 mm.

Physical Properties of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

Table 8 presents the physical property results at Okolovu (sand, clay, and swamp). The sieve analysis showed that the percentage passing through sieve #10 ranged from 79.1% to 100%; for sieve #40, it ranged between 59.4% and 99.3%; and for sieve #200, between 18.5% and 52.9%. In terms of Atterberg limits, the liquid limit ranged from 52.18% to 56.45%, the plastic limit spanned from 0% to 14.69%, while the plasticity index varied between 0% and 11.76% across the different layers. Compaction results showed that the maximum dry density ranged from 1.22 g/cm³ to 1.36 g/cm³, with optimum moisture content between 6.90% and 9.20%. For the California Bearing Ratio (CBR), unsoaked bottom conditions at 2.5 mm penetration showed values between 27.92%.

Table 7: Physical Properties of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearing Ratio							
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	Bottom				Top			
									Un-soaked		Soaked		Un-soaked		Soaked	
									2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm
0 -37	96.7	87.1	27.6	53.25	NP	NP	1.06	5.30	26.43	27.13	17.26	23.29	20.07	22.79	9.57	8.44
37 -64	100	93.2	30. 0	52.43	46.24	6.19	1.18	6.40	30.56	35.19	25.19	25.36	30.31	23.64	13.21	11.01
64 - 92	100	89.3	31.9	51.01	NP	NP	1.32	7.70	33.12	36.28	29.32	27.48	23.29	24.60	13.46	13.31
92 – 109	100	84.3	33.5	49.86	44.37	9.49	1.38	7.00	23.95	30.27	35.76	26.58	20.56	25.51	9.00	6.29
109 - 125	98.7	57.1	34.6	45.79	41.31	4.48	1.40	8.50	30.56	32.35	32.25	29.54	21.30	28.69	10.25	9.47

Physical Properties of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

Table 8 outlines the physical properties observed at Okolovu (sand, clay, and swamp). Sieve analysis results revealed that the percentage passing through sieve #10 ranged from 79.1% to 100%, sieve #40 showed values between 59.4% and 99.3%, and sieve #200 ranged from 18.5% to 52.9%.

Regarding Atterberg limits, the liquid limit varied from 52.18% to 56.45%, the plastic limit ranged from 0% to 14.69%, and the plasticity index spanned from 0% to 11.76%, depending on the soil layer. Compaction tests indicated maximum dry density values between 1.22 g/cm³ and 1.36 g/cm³, while optimum moisture content ranged from 6.90% to 9.20%.

California Bearing Ratio (CBR) values under various conditions were also recorded. For the unsoaked bottom at 2.5 mm penetration, CBR ranged from 27.92% to 37.99%, while at 5.0 mm penetration, the range was 12.60% to 31.62%. Under soaked bottom conditions, 2.5 mm penetration yielded values from 10.15% to 25.35%, and 5.0 mm penetration ranged from 12.87% to 16.44%.

For the top layers, unsoaked samples with 2.5 mm penetration produced CBR values ranging from 21.72% to 26.19%, and from 16.42% to 28.44% at 5.0 mm. Under soaked top conditions, 2.5 mm penetration gave values between 6.44% and 14.20%, while 5.0 mm penetration ranged from 12.89% to 18.41%.

Physical Properties of Pedon 3 (Akuekpara – Sand, Clay, and Swamp)

Table 9 presents the physical property data for Akuekpara – sand, clay, and swamp. According to the sieve analysis, percentage passing through sieve #10 ranged from 98.7% to 100%, sieve #40 from 73% to 99%, and sieve #200 from 38.6% to 53.4%.

Atterberg limit results showed liquid limits ranging from 55.90% to 60.88%, while all layers were identified as non-plastic in terms of both plastic limit and plasticity index. In compaction tests, the maximum dry density values ranged from 1.36 g/cm³ to 1.48 g/cm³, and optimum moisture content was between 4.50% and 7.00%. For the California Bearing Ratio (CBR), the unsoaked bottom layer at 2.5 mm penetration produced values between 17.09% and 29.23%, while 5.0 mm penetration ranged from 23.15% to 32.09%. In soaked bottom conditions, 2.5 mm penetration values ranged from 29.85% to 36.83%, and 5.0 mm ranged from 20.60% to 31.18%. For the top layer, unsoaked samples with 2.5 mm penetration yielded CBR values from 5.83% to 15.11%, increasing to 12.11% to 23.62% at 5.0 mm. Under soaked top conditions, CBR values ranged from 3.14% to 9.27% for 2.5 mm penetration, and from 9.08% to 15.02% for 5.0 mm penetration.

AASHTO Classification of Pedon 1 (Okuovwori – Sand, Clay, and Swamp)

Table 10 presents the results of the AASHTO soil classification for Okuovwori, covering the sand, clay, and swamp zones. The dominant soil types ranged from silty or clay-rich mixtures of gravel and sand to clay-dominated subsoils. The overall evaluation of the soil's suitability as a sub-grade spanned from fair to poor in some instances, while other layers were classified as excellent to good. Group index values were recorded within a narrow range of 0 to 1 cm. Group classifications varied between A-2-6 and A-6, with corresponding final classifications falling between A-2-6(0) and A-6(1).

AASHTO Classification of Pedon 2 (Okolovu – Sand, Clay, and Swamp)

According to Table 11, the AASHTO classification outcomes for the Okolovu soil profile—which includes sand, clay, and swamp—revealed a range of primary materials, from silty or clayey gravel and sand mixtures to clay-rich textures. The soils' performance as a sub-grade material ranged from poor in some cases to excellent in others. Group index values were within the range of 0 to 3 cm. The soils were classified under groups A-3 to A-2-6, and the final classification results ranged from A-3(0) to A-2-6(0).

AASHTO Classification of Pedon 3 (Akuekpara – Sand, Clay, and Swamp)

As shown in Table 12, the AASHTO classification for the Akuekpara soil profile—comprising sand, clay, and swamp—indicated that silty soils were the dominant material across all layers. The general assessment of the soils as a sub-grade material was rated from fair to poor. The group index remained constant at 0 cm. Soils were classified as A-4, with a consistent final classification of A-4(0) across all layers.

Table 8: Physical Properties of Pedon 2 (Okolovu – Sand, Clay and Swamp)

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearing Ratio							
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm³)	Optimum Moisture Content (%)	Bottom				Top			
									Un-soaked		Soaked		Un-soaked		Soaked	
									2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm
0-12	79.1	59.4	18.5	52.18	NP	NP	1.36	6.90	29.32	19.87	10.15	16.44	25.19	28.44	14.20	18.41
12-23	99.3	76.9	34.7	52.76	NP	NP	1.34	8.40	27.92	12.60	13.72	14.26	25.88	23.18	13.13	17.48
23-38	100	98.1	68.7	52.56	44.46	8.10	1.28	7.20	30.80	29.68	20.39	15.59	21.72	19.95	9.20	15.89

38-46	100	98.7	69.7	54.32	44.51	9.81	1.27	8.90	37.99	31.62	25.35	12.87	23.64	17.43	6.44	14.27
46 -152	100	99.3	72.9	56.45	44.69	11.76	1.22	7.80	31.72	20.55	17.84	14.52	26.19	16.42	8.07	12.85

Table 9: Physical Properties of Pedon 3 (Akuekpara – Sand, Clay and Swamp)

Depth	Sieve Analysis % Passing			Atterberg Limit			Compaction		California Bearing Ratio							
(cm)	#10 1.18 mm	#40 0.425 mm	#200 0.075 mm	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Maximum Dry Density (g/cm^3)	Optimum Moisture Content (%)	Bottom				Top			
									Un-soaked		Soaked		Un-soaked		Soaked	
									2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm	2.5 mm	5.0mm
0-13	100	97.4	44.7	55.90	NP	NP	1.36	7.00	17.09	32.09	36.83	31.18	15.11	23.62	9.27	15.02
13 -21	100	96.8	45.4	59.00	NP	NP	1.37	6.40	17.43	28.19	35.26	27.53	7.02	17.78	6.55	12.36
21-32	100	94	43.4	60.62	NP	NP	1.42	5.20	24.68	26.08	32.25	24.17	5.83	12.11	4.68	11.90
32-63	98.7	73	38.6	60.88	NP	NP	1.48	4.50	29.23	23.15	29.85	20.60	6.01	18.66	3.14	9.08

Table 10: AASHTO Classification of Pedon 1 (Okuovwori – Sand, Clay and Swamp)

Depth	Layer	Significant Constituent materials	Genral Ratings as Subgrade	Group Index	Group Classification	Final Classification
(cm)				(cm)		
0-37	1	Silty or clayey gravel and sand	Excellent to Good	0	A-2-6	A-2-6(0)
37-64	2	Silty or clayey gravel and sand	Excellent to Good	0	A-2-6	A-2-6(0)
64 -92	3	Fine sand	Fair to poor	0	A-4	A-4 (0)
92-109	4	Silty soils	Fair to poor	0	A-4	A-4(0)
109-125	5	Clayey soils	Fair to poor	1	A-6	A-6 (1)

Table 11: AASHTO Classification of Pedon 2 (Okolovu-Sand, Clay and Swamp)

Depth	Layer	Significant Constituent materials	General Ratings as Subgrade	Group Index	Group Classification	Final Classification
(cm)				(cm)		
0-12	1	Silty or clayey gravel and sand	Excellent to good	0	A-2-4	A-2-4(0)
12-23	2	Silty or clayey gravel and sand	Excellent to good	0	A-2-4	A-2-4(0)
23-38	3	Silty soils	Fair to poor	3	A-4	A-4(3)
38-46	4	Silty soils	Fair to poor	0	A-4	A-4(0)
46-152	5	Silty or clayey gravel and sand	Excellent to good	0	A-2-6	A-2-6(0)

Table 12: AASHTO Classification of Pedon 3 (Akuekpara -Sand, Clay and Swamp)

Depth	Layer	Significant Constituent materials	General Ratings as Subgrade	Group Index	Group Classification	Final Classification
(cm)				(cm)		
0-13	1	Silty soils	Fair to Poor	0	A-4	A-4(0)
13-21	2	Silty soils	Fair to Poor	0	A-4	A-4(0)
21-32	3	Silty soils	Fair to Poor	0	A-4	A-4(0)
32-43	4	Silty soils	Fair to Poor	0	A-4	A-4(0)
43-63	5	Silty soils	Fair to poor	0	A-4	A-4(0)

DISCUSSION

The soil samples collected from profile trenches in sand, clay, and swamp parent materials revealed distinct physical and chemical properties. A slight increase in acidity was observed, typical of soils derived from alkaline parent material. This may be attributed to the downward movement of finer particles and alkaline cations through leaching.

The variation in particle sizes significantly influenced the textural classification of the soils. Across all profiles, the dominant textures were light sandy loam and sandy clay loam, mainly due to eluvial and illuvial deposition processes—highlighting the influence of toposequence in transporting and sorting soil particles.

Organic carbon and total nitrogen contents generally decreased with depth across all locations. Organic matter levels, as inferred from organic carbon, were low (2–22 g/kg), likely due to the flat topography which promotes water drainage and aerobic microbial activity. These conditions favor decomposition and may explain the elevated nitrate levels in some soils (Orhue *et al*., 2016).

Nitrogen content declined significantly with depth at all sites, while phosphorus levels decreased with depth in Okuovwori and Okolovu. Conversely, in Akuekpara, phosphorus increased in deeper layers—possibly due to organic matter mineralization. Variability in phosphorus content can also be linked to land use, fertilization, and tillage practices (Bünemann *et al*., 2006).

Topsoil in Okuovwori and Okolovu had higher exchangeable base contents, which declined with depth. These values were below the critical threshold of 2.5 cmol/kg (Obigbesan and Akinrinde, 2000), indicating low fertility. In contrast, Akuekpara showed increasing exchangeable base levels with depth, aligning with rising pH and base saturation.

Exchange acidity patterns varied unpredictably across soil layers, influenced by the underlying parent materials. Effective cation exchange capacity (ECEC) also varied, with higher values near the surface and declining with depth, likely due to the soils' moderately acidic pH. Since ECEC is pH-sensitive (Brady & Weil, 2012), this decline is consistent with increasing acidity. Infrastructure development, such as road construction, can impact key soil properties like base saturation, clay content, and pH (Iwara *et al*., 2013).

Higher total nitrogen was observed in surface layers at sites with greater organic carbon content. This nutrient diminished with depth due to leaching. Similarly, in Okuovwori and Okolovu, available phosphorus was highest at the surface—corresponding with organic matter concentration—and declined in deeper layers. Akuekpara exhibited an opposite trend, with available phosphorus increasing at depth.

Particle Size Distribution

Sieve analysis (particle size distribution) revealed the gradation of soil particles. According to Federal Ministry of Works and Housing (1997) standards, for road construction, at least 35% of the soil sample should pass through a No. 200 sieve.

- Okuovwori and Okolovu: These samples did not meet the 35% passing requirement and are therefore unsuitable for road construction.
- Akuekpara: This sample met the criteria, with more than 35% passing the No. 200 sieve, making it suitable for use in road construction.

Here is a paraphrased and summarized version of the given text, while retaining your original section headings and structure**:**

Plasticity

According to the Federal Ministry of Works and Housing (1997), materials used for sub-base and base layers in road construction should have a liquid limit of 50% or less. However, the soil samples from Okuovwori (51.01–59.86%)**,** Okolovu (52.18–56.45%)**,** and Akuekpara (50.62–55.90%) all exceeded this threshold**,** rendering them unsuitable for use as subgrade, sub-base, or base materials**.**

Additionally, the plasticity index (PI) for all samples exceeded the Ministry's recommended maximum of 20% for subgrade materials. Soils with PI values under 25% typically show low to medium swelling potential (Ola, 2008), but the studied samples exceed that, increasing the risk of volume change and instability.

High liquid limits also indicate high compressibility, which can lead to structural failure of road sections if drainage is inadequate (Olubanjo *et al*., 2018). Although resurfacing may seem like a solution, it does not address the long-term deterioration of the underlying subsoil. Over time, applied loads can induce plastic deformation in weak soils (Adeyemi, 2002). Soils with high liquid limits often have lower load-bearing **capacities.** According to Cassagrande (1947), plasticity correlates with compressibility: low, medium, and high plasticity soils typically reflect similar compressibility behavior**.**

Compaction

The Federal Ministry of Works and Housing (1997) recommends a Maximum Dry Density (MDD) range of 1.50–1.78 g/cm³ and Optimum Moisture Content (OMC) of 8.56–12.02% for road construction materials.

The studied soils from Okuovwori, Okolovu, and Akuekpara fell below these thresholds, indicating low bearing capacity. These materials require proper compaction and stabilization to enhance their strength, reduce voids, and limit permeability. According to Olofinyo *et al*., (2019), soils must be compacted beyond MDD and OMC to ensure they can withstand loads and resist water infiltration.

Low MDD is a limiting factor, especially under increased axial loads from heavy-duty vehicles, which were not originally considered in design (Wazoh *et al*., 2016). This mismatch can further compromise road performance over time.

California Bearing Ratio (CBR)

CBR tests were conducted to evaluate soil strength across the study sites. The Federal Ministry of Works and Housing (1997) provides benchmarks:

- **Subgrade**: minimum 10%
- **Sub-base:** minimum 30%
- **Base:** up to 80%

***Okuovwori**:*

- **Unsoaked, bottom, 5.0mm**: 27.13%–36.28%
- **Soaked, bottom, 5.0mm**: 23.29%–29.54%
- **Unsoaked, top, 5.0mm**: 22.79%–28.69%
- **Soaked, top, 2.5mm:** 9.00%–13.46%

***Okolovu**:*

a. **Unsoaked, bottom, 5.0mm**: 12.60%–31.62%
b. **Soaked, bottom, 2.5mm:** 13.72%–25.35%
c. Unsoaked, top, 5.0mm: 16.42%–28.44%
d. **Soaked, top, 2.5mm:** 6.44%–14.20%

Akuekpara:

a. **Unsoaked, bottom, 2.5mm**: 17.09%–29.23%
b. **Unsoaked, bottom, 5.0mm**: 23.15%–32.09%
c. **Soaked, bottom, 2.5mm**: 29.85%–36.83%
d. **Soaked, bottom, 5.0mm**: 20.60%–31.18%
e. **Unsoaked, top, 2.5mm**: 5.83%–15.11%
f. **Unsoaked, top, 5.0mm:** 12.11%–23.62%
g. **Soaked, top, 2.5mm:** 3.14%–9.27%
h. **Soaked, top, 5.0mm:** 9.08%–15.02%

In summary, none of the soils met the 80% CBR threshold for base material, but many samples qualified as good sub-base or subgrade materials. These values also align with standards from the Asphalt Institute (1962), categorizing the soils as fair to good for road construction purposes.

CONCLUSION

The study reveals that variability in soil properties significantly influences road performance and structural integrity. The key objective was to investigate the underlying soil-related causes of road degradation, particularly in areas where soils fail to meet the standard construction specifications set by the Federal Ministry of Works and Housing**.**

Findings indicate that if substandard soils like those identified in this research are used in road construction without proper treatment or stabilization, it could lead to recurrent road failure, hindering the transportation of agricultural products and affecting the economic viability of farming communities in the region.

This research emphasizes the importance of understanding soil behavior when designing and constructing roads. Soil types respond differently under stress, and areas with weak soils demand reinforcement strategies. As such, soil improvement techniques like stabilization should be considered essential to ensure road durability. The AASHTO classifications derived from this study can inform targeted interventions, ensuring that road infrastructure is both sustainable and cost-effective.

Recommendations

1. Use of this study as a reference to distinguish between durable parent materials suitable for construction and those that require soil strength enhancement.
2. Involvement of soil scientists in road construction projects for accurate evaluation and interpretation of soil characteristics.
3. Pre-treatment and stabilization of soils should be implemented to bring them in line with the Federal Ministry of Works and Housing's specifications, enhancing long-term road performance.
4. A culture of regular maintenance should be promoted and adopted to extend the lifespan of roads and reduce long-term repair costs.

AASHTO Classification

The soil samples were classified under the AASHTO soil classification system as follows:

1. **A-2-6 and A-2-4**: Silty or clayey sands and gravels — considered excellent to good for sub-base materials.

2. **A-4 and A-6**: Silty and clayey soils — rated as fair to poor for subgrade materials.

This classification confirms that granular soils are better suited for road construction than clayey types, which exhibit lower performance under traffic loading.

REFERENCES

- Ogundipe, O.M. (2008). Road pavement failure caused by poor soil properties along Aramoko-Ilesa highway, Nigeria. *Journal of engineering and applied sciences.* 3(3): 239-241
- Sharad, S. A., Gupta, A. K., (2014). Pavement Deterioration and its Causes: *Civil, J.J. Magdumcollege of Engineering Shivaji University, India 2014.*
- Aigbedion, I. (2007). Geophysical investigation of road failure using electromagnetic profiles along Opoji, Uwenlenbo and Illeh in Ekpoma –Nigeria. *Middle-East Journal of Scientific Research.* 2 (3-4):111-115.
- Adiat, K.A.N., Adelusi, A.O. and Ayuk, M.A. (2009): “Relevance of Geophysics in Road Failures Investigation in a Typical Basement Complex of South Western Nigeria”. *Pacific Journal of Science and Technology*. 5(1): pp.528-539.
- Adegoke, A., Anthony, W.C., &Agada, O. A (1980). Geotechnical characteristics of some residual soils and their implications on road design in Nigeria. *TechnicalLecture.* Lagos, Nigeria. 1 – 16.
- Mesida, E. A., (1987). The Relationship between the Geology and the Lateritic Engineering Soils in the Northern Environs of Akure, *Nigeria. Bulletin of the international Association of Engineering Geology(35).* Pp 65-69.
- Ajayi, L. A. (1987). Thought on Road Failures in Nigeria. *The Nigerian Engineer, 22*(1),10 – 17.
- Ajani, A. R., (2006). Causes Of Premature Failures on Nigeria Highways A Training Course In Tunisia.
- Mahmood, H., Belel, Z. A., F.and Abba, H. A. (2012). Road Pavement Failure Induced by Poor Soil Properties along Gombe –BIU highway, Nigeria. Journal of Engineering and Applied Science 4(22). Pp1-5
- Ibrahim, k. (2011). Nigerian Roads ned N70 Billion for Repairs Annually. Daily TimesArticle , May 30, http ://daily times.com.ng.
- Federal Road Safety Corps, (FRSC) (2011). Report on Road Traffic CrashesMaintenance. *Annual Report*.
- Omer G. O., Ahmed M. E. and Awad E. M. M.(2014): “Failure Investigation for Recently Constructed Road in Khartoum State”. *Journal of Geological Resource and Engineering 2 (2014).* pp 20-31.
- Elyas, M. T. M. (1991). Use of DCP for Design/sSructural Evaluation of Roads and Airfields. Master of Science Thesis University of Khartoum, Khartoum, Sudan
- Dawson. A. R., Cheung. L. (2002): “The effects of particle and mix characteristics on the performance of some granular materials”. *Transportation Research Record: Journal of the Transportation Research Board.*pp 90-98.
- Zumrawi. M.M.E. (2013): “Pavement design for roads on expansive clay subgrades*”. University of Khartoum Engineering Journal 3 (1).* Pp 51-57.
- Ezeagu, C.A., Ibeabuchi, C.I. and Mezie, E.O. (2020): “Empirical Post-Mortem Analysis and Healing Approach of Flexible and Rigid Pavement Failures InAnambra State”. *Journal of Inventive Engineering and Technology (JIET), 1(2).*
- Ezeagu, C.A. and Ezema, N.M. (2022): “Deterioration and Failure Rates of Maintained Roads in Nigeria”. *Saudi J CivEng, 6(4).* pp 64-71.
- Onuoha, D. C., Onwuka, S. U. and Obienusi, E. A. (2014): “Evaluating the Causes of the Road Failure of Onitsha-Enugu Expressway, Southeastern Nigeria”. *Civil and Environmental Research Vol.6, No.8, 2014 www.iiste.org.* ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online).
- Ebuzoeme, O. D. (2015). Evaluating the Significance of Poor Road Design as a Factor of Road Failure: A Study of Onitsha-Enugu Expressway, South-eastern Nigeria. *Civil and Environmental Research, 7(2).*
- Afolayan, O. D. and Abidoye, A. O. (2017). Causes of Failure on Nigerian Roads: A Review. *J. of Advancement in Engineering and Technology Volume 5 / Issue 4.* ISSN: 2348-2931.
- Emmanuel, U. O., Igwe, O. and Ukah B. U. (2021). An Investigation Into The Cause Of Road Failure Along Sagamu-Papalanto Highway Southwestern Nigeria. *Geoenvironmental Disasters (2021) 8:3. (2021) 8:3.*
- Imran, M. A., Rabbany, H.M.A., Islam M. T. and Sharon M.M.H. (2015). Assessment on the Road Pavement Failure and Maintenance of Rajshahi City. *International Conference on Recent Innovation in Civil Engineering for Sustainable Development*. Pp 787 -791.
- Attubi, A.O and Onokata, P.C. (2019). The Effects of Traffic Congestion on Road Accidents In Niger-Delta: The Case Of Warri Metropolis. *Journal of The Social and Management Sciences. Delta State University, Abraka Vol. 1, No. 1.*
- Jegede, G. (2004). Highway pavement failure induced by poor geotechnical properties along a section of F209 Okitipupa-Igbokoda highway, Southwestern Nigeria. *Ife Journal of Science,* 6(1): 41-44.
- Tan, H.K. (2002). Soil sampling, preparation, and analysis. *Soil pH measurement*. pp. 96–113. (Marcel Dekker: New York).
- Ogunribido, T. H., Mohammed M. Z. and Adesuyi A. R. (2015). Effect of Engineering Properties of Soil on Pavement Failures in Ogbagi - Akoko Area, Southwestern, Nigeria. *Journal of Environment and*

Earth Science www.iiste.org. ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online) Vol.5, No.4, 2015.

- *World Bank (1991): Nigeria Highway Sector Study Journal, Vol. II, No.2.*
- Wazoh, H. N., Daku, S. S and Samuel, F.G. (2016). Investigative Study of Possible Causes of Failure of a Section Of Road In Jos- Plateau, North - Central Nigeria. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*. ISSN: 2458-925XVol. 2 Issue 11, November - 2016
- Osadebe, C.C., Fakeye, A.M., Matawal, D.S. and Aitsebaomo, F.O. (2013). Road Pavement Failure: A Case Study of Enugu-Port Harcourt Expressway. *Proceedings of National Conference On Road Pavement Failure In Nigeria, Abuja, 7th–9th May 2013: Book of Abstract*. Pp 7-8.
- Aitsebaomo, O. F., Matawal, D. S., Omange, G. N. and Osadebe, C. C. (2013). Digitised Subgrade Soils Map as a Tool for The Design, Construction and Maintenance of Nigerian Roads. *Proceedings Of National Conference on Road Pavement Failure in Nigeria, Abuja, 7th–9th May 2013: The Abstract.* Pp 10-11.
- Uge, B. U. (2017). Performance, Problems and Remedial Measures for Roads Constructed on Expansive Soil in Ethiopia – A Review. *Civil and Environmental Research www.iiste.org.* ISSN 2224-5790 (Paper) ISSN 2225-0514 (Online) Vol.9, No.5, 2017
- Adeboje, A., Kupolati, W., Sadiku, E., Ndambuki, J., Kambole, C. and Ogunleye, O. (2017). Stabilization of lateritic soil with pulverized palm kernel shell (PPKS) for road construction. *African Journal of Science, Technology, Innovation and Development,* Vol. 9, No. 1. pp 55–60.
- Sowemimo A.D. (2016). Structural Failure of Roads in Lagos, Nigeria. (Case Study Herbert Macaulay Road/Sabo to Moshalashi Bus-Stop). Pp 1-86.
- Hendershort, W.H., Lalande, H., and Duquette, M., (1993). Soil reaction and exchangeable acidity, In: Soil sampling and methods of soil analysis, (Carter M.R., Ed.), Canadian Soc.Soil Sci. Lewis Publishers, London,141-145.
- Simon, A.B., Giesecke, J. and Bidlo, G. (1973). Use of lateritic soil for road construction in North Dahomey. *Engineering Geology* 7:197-218. https://doi.org/10.1016/0013-7952(73)90031-8.
- Flaschka, H.A. (1964). EDTA Titrations: an introduction to theory and practice second edition. Pp 296.
- Anderson, J.M. and Ingram, J.S.L. (1993). Tropical Soil Biology and Fertility*; A Handbook of Method of Analysis* 38-39.

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