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Geological, Geophysical and Geotechnical Investigations of Road Failure along Keffi – Nasarawa Road, Northcentral, Nigeria

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ABSTRACT

Road failure remains a major infrastructural challenge in Nigeria, particularly along the Keffi–Nasarawa road, where persistent pavement deterioration has resulted in economic losses and safety risks. This study integrates geological, geophysical, and geotechnical investigations to evaluate the factors responsible for pavement failure along the route. Geological mapping revealed that the road traverses diverse lithologies, including schist, granite-gneiss, migmatite-gneiss with varying degrees of weathering. A geophysical survey employing electrical resistivity methods (Schlumberger array) comprised 35 Vertical Electrical Soundings (VES) with data processed using WinResist software,. The results identified four to five subsurface lithologic layers characterized by varying thicknesses and resistivity values: topsoil (1.0–1.5 m; 102–800 Ωm), clayey sand/lateritic clay (7–19 m; 90–400 Ωm), weathered bedrock (13–25 m; 150–376 Ωm), and fresh bedrock. These conductive subsurface zones indicate structurally weak layers that contribute to pavement instability. Geotechnical investigations on 24 soil samples conducted in accordance with British Standards 1377, included compaction, particle size distribution, Atterberg limits, and California Bearing Ratio (CBR) tests. Soaked CBR values ranging from 0.46% to 21.13% and unsoaked values from 0.93% to 52.4%, while plasticity indices ranged between 17.5 and 30. The failed sections are characterized by high plasticity , clay rich soils with low bearing capacity, poor drainage, and seasonal flooding, which collectively reduce subgrade strength and pavement stability. The failure is primarily attributed to weak, clay-rich subsoils (silty clay), poor drainage conditions, and seasonal flooding, which collectively reduce soil strength and pavement stability.

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INTRODUCTION

The Keffi-Nasarawa Road in Nigeria is only one of several places where road collapses are a serious issue. Road failures can result from geological, geophysical, and geotechnical conditions, which can be inconvenient for drivers and financially detrimental to the surrounding population (Osadebe and Omange, 2005).

Road pavement failure is a prevalent problem in Nigeria, particularly following development, a well-designed road pavement is expected to provide a smooth driving surface, but it can deteriorate over time, developing defects such as cracks, potholes, bulges, and depressions, ultimately leading to premature road failure. Roads have a significant impact on the socioeconomic advancement and development of any nation, influencing the allocation of resources, including money and human capital (Aigbedion, 2007).

Jonathan, et al. (2022), Investigation of the cause of flexible pavement failure along three selected roads in the Niger Delta region of Nigeria stated that lack of laboratory investigations of construction materials, poor quality of the construction materials, lack of maintenance culture, poor soil condition of the road, inadequate drainage system and overloading of road pavement are the major factors responsible for flexible pavement failure.

Jekaninfa and Osinowo, (2021), Geophysical and Geotechnical investigation of road pavement in part of Ibadan metropolis in Southwestern Nigeria stated that poor construction practices, lack of proper drains, and poor engineering properties of subgrade materials as the causes of road pavement failure

Ademila, (2021), combined geophysical and geotechnical investigation of pavement failure for the sustainable construction of Owo-Ikare highway, southwestern Nigeria revealed that the road pavement is constructed on poor clayey subgrade soil. Deep weathering, fractured bedrock, uneven bedrock topography with subsurface structures, water-saturated clayey subgrade, and unsuitability of the soil for subgrade and subbase road constructions are responsible for the instability of the road.

Adewale, et al. (2021), Geophysical Investigation of Road Pavement Instability: A Case Study of Moshood Abiola Polytechnic (Mapoly) – Onikolobo Road, Southwestern Nigeria revealed that the geo-electric layers generally identified are the topsoil, weathered layer, partly weathered/fractured basement and fresh bedrock. The failed and stable portions of the road are underlain by topsoil consisting of low-resistive and expansive clayey soil. The stability of the stable portions of the road can be attributed to their regular maintenance and good drainage channels

Thus, by examining geological, geophysical, and geotechnical elements, this study seeks to explore the fundamental causes of road failure along the Keffi-Nasarawa Road.

Geophysical studies, such as electrical resistivity imaging, will evaluate subsurface conditions for hidden geological risks, while geological investigations will concentrate on comprehending the geological formations and their impact on the stability of the road. Furthermore, by analyzing soil samples in a laboratory, a geotechnical study will assess the mechanical characteristics of the soil materials beneath the road.

Keffi-Nasarawa Road is an important roadway that connects the towns of Keffi and Nasarawa, located in Nasarawa State, Nigeria. It is roughly 39 kilometers long. This road is essential for enabling the movement of goods and commuters, but because it is a trade route between Nasarawa State and the adjacent Federal Capital Territory (FCT), Abuja, it frequently experiences heavy traffic congestion, especially during rush hours. Keffi-Nasarawa Road directly affects trade, business activity, and the general well-being of locals, it is imperative that the road's infrastructure be improved for the region's economic development.

In order to develop practical suggestions for road improvement, a thorough investigation into the elements causing the road's degradation is presently under process. This includes putting in place the appropriate geotechnical safeguards against geophysical and geological risks. The knowledge gathered from this study will be extremely helpful in shaping the design and upkeep of future road infrastructure. Significant road degradation, as seen by cracks, potholes, and pavement deterioration, has affected the Keffi-Nasarawa Road, leading to a high frequency of traffic accidents and transportation disruptions. In addition to impeding economic and mobility operations, these deteriorations put drivers' safety at risk. The aim of the research is to perform a thorough geological, geophysical, and geotechnical examination of the Keffi–Nasarawa route in order to unravel the root causes of road failures and provide suitable corrective actions.

The following selective objectives of this research are to: Produce the geological map, use geophysical surveys to ascertain the subsurface lithology, determine the connections between road failures and geology, make appropriate engineering recommendations for the design and upkeep of roads.

Road failure refers to the deterioration or degradation of a road's surface, structure, or foundation, leading to a reduction in its functional and safety performance (Federal Highway Administration (FHWA, 2019), including bad construction, poor maintenance, and environmental conditions, can lead to road collapses. According to the Federal Highway Administration (FHWA, 2019), Road failure can occur in several forms including Pavement Distress, Structural Failure, Drainage Issues, Settling or subsidence, Edge failure, Reflection cracking.

Location and Geology of the study area

The Keffi-Nasarawa Road is located within the Keffi local government area of Nasarawa State, Nigeria. A major highway connecting the towns of Keffi and Nasarawa

Keffi is a town located in the Keffi Local Government Area of Nasarawa State and is located about 50km southwest of Abuja. Geographically, Keffi is located on Latitude 8° 50′43″ N and Longitude 7° 52′37″ E on an elevation of 1050ft [320m] above sea level. It is known for its agricultural activities, with the production of crops such as rice, maize, and yams being prominent. The town also serves as a transportation hub for the movement of goods between Nasarawa State and other parts of the country.

Nasarawa, on the other hand, is located in the Nasarawa Local Government Area of Nasarawa State but is near to the Federal Capital Territory (FCT), Abuja. Geographically, Nasarawa is located on Latitude 8° 32′ N and Longitude 7° 42′ E. It is a rapidly growing suburban settlement and is known for its bustling economic activities. Many residents of Nasarawa commute daily to Abuja for work, making the Keffi-Nasarawa Road a crucial transportation route for them.

The study area is an extract of the Keffi sheet 208. The study area falls within the Basement complex of North Central Nigeria and is geographically located at the following coordinates A [8° 50′ 29″N, 7° 51′ 58″E], B [8° 49′ 29″N, 7° 53′ 48″E], C [8° 32′ 30″N, 7° 42′ 00″E], D [8° 31′ 28″N, 7° 44′ 00″E].

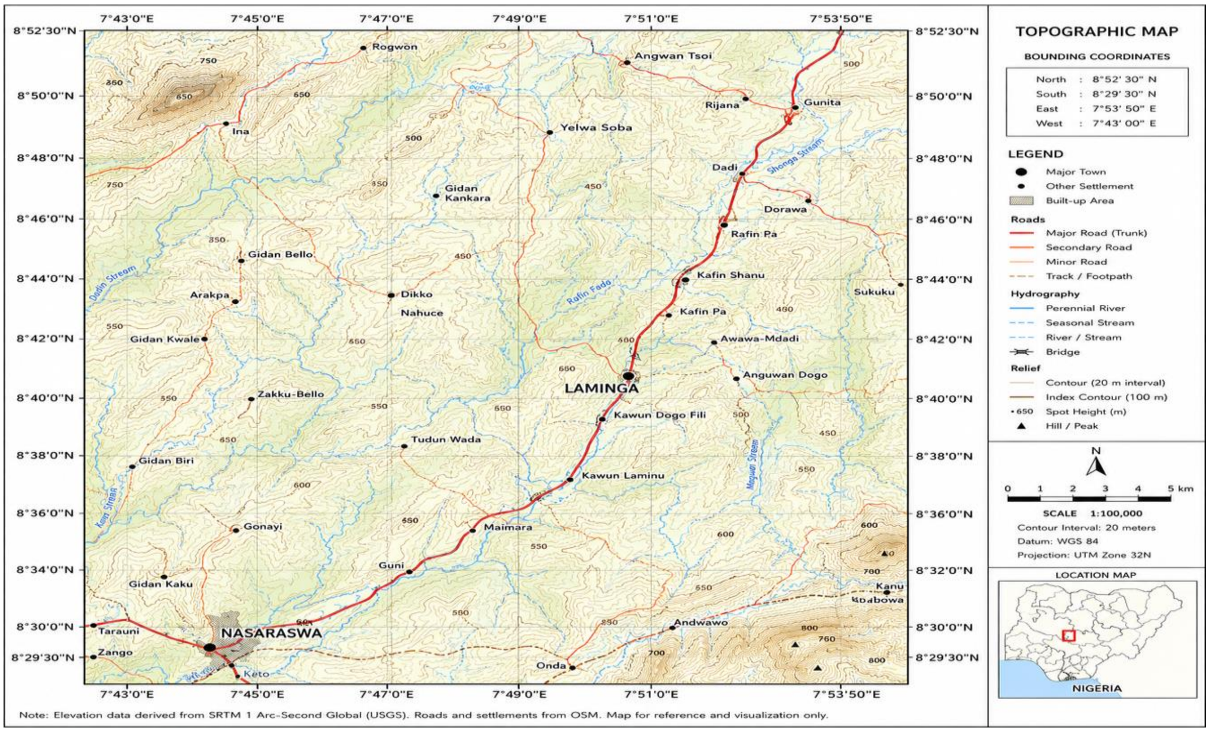


Figure 1: Extract Map of study area (NGSA Keffi sheet 208) (scale: 1:200,000)

Plate I: Alligator cracking

Plate II: Poor drainage

Plate III: Edge failure/detoriation

Plate IV: Stable part

Pavement Distress: This type of failure includes cracks, potholes, rutting, and uneven surfaces as seen in plate I.
Surface Deterioration: This type of failure involves wear and tear, oxidation, and damage from weather and traffic as seen in plate III.
Drainage Issues: This comprises water accumulation, erosion, or damage due to improper drainage as seen in plate II

MATERIALS AND METHODS

Geophysical electrical resistivity measurement via Vertical Electrical Sounding [VES] was carried out at thirty-five [35] stations along part of Keffi – Nasarawa road using the Schlumberger array. The station intervals was selected to provide adequate spatial coverage of the study corridor while targeting failed and stable pavement sections. The Schlumberger array utilizes four electrodes, arranged linearly with different inter-electrode spacing, the potential electrodes remains partially fixed at the center of the spread and the current electrodes expanded systematically about the center of the spread. The electrical resistivity method is an active geophysical method. It involves injecting of electrical current into the ground through a pair of electrodes. The procedure involves the measurement of the potential difference between the other two electrodes in the vicinity of the current flow. Calculate apparent resistivity by using the potential difference for the interpretation. The electrodes that introduce current into the ground are called Current electrodes and electrodes between which the potential difference is measured are called Potential electrodes The electrical sounding carried out was to determine the apparent resistivity of the subsurface layers as well as thickness of overburden.

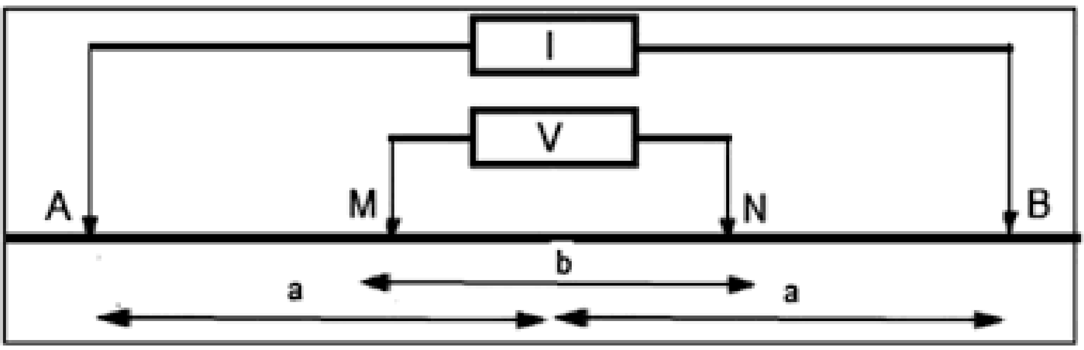


Figure 2: Schematic view of the Schlumberger array

Surface electrical resistivity surveying relies on the principle that the distribution of electrical potential in the ground around a circuit-carrying electrodes depends on the electrical resistivity and distribution of the surrounding soil and rocks. The purpose of direct current (DC) electrical survey is to determine the subsurface resistivity distribution of the ground. This then can be related to physical conditions of interest such as Lithology, porosity, the degree of water saturation, the presence or absence of voids in the rock, and conditions of the subsurface such as the Fracture zones, folds, lineation dykes and other zones of structural weakness, features in mineral prospecting, and water exploration prospecting.

The electrical resistivity data, despite their pitfalls, are valuable for determining the electrical characteristics of project sites, water table levels, locating contaminant planes, and measuring overburden thickness (Wightman *et al*. (2003).

Geotechnical Characterization of Soil in the Area

To evaluate the geotechnical performance of subgrade soils along Keffi-Nasarawa road, twenty-four (24) soil samples was collected at various depths and the following laboratory test was employed in analyzing the soils

i. Soil sampling: Twenty four - (24) soil sample were collected at various points along the road side for the disturbed samples. Samples were collected at depths ranging from 0.5m to 1m which corresponds to the pavement subgrade zone directly affected by traffic load and seasonal moisture variations for each sampling point using GPS to accurately locate sample points.

ii. Laboratory test: the following laboratory analysis were carried out using the British Standard (BS 1377) on the soil samples including
   a. Particle size distribution: is used to understand and characterize the size distribution of particles within a sample
   b. Consistency limit test: to evaluate the liquid limit, plastic limit, plasticity index
   c. Compaction: used to evaluate the compaction characteristics like maximum dry density and optimum moisture content
   d. California bearing ratio: used to evaluate the California bearing ratio values of the soil samples (soaked and un-soaked)

RESULTS AND DISCUSSION

Geological investigation

Based on field observation, major rock types seen underlying the study area are granitic gneiss, schist and Migmatite gneiss. Low-lying outcrops that generally trends in a NE – SW direction, mostly characterize the study area. The rock units occurs as a moderate low lying outcrops with structures such as joints and folds. Granite gneiss is seen in the northern part of the mapped area and generally trends in the NE-SW direction. The rock occurs as a moderate to low-lying outcrop in the study area and an NE trending direction, with structures such as; joints and folds. The schist covers the Northwestern portion of the mapped area, with a trend direction of NW-SE. The rock is a low-lying outcrop; it has a NE strike direction, with dark and shiny minerals. Some observed structural features that seen during the mapping exercise included joints and folds.

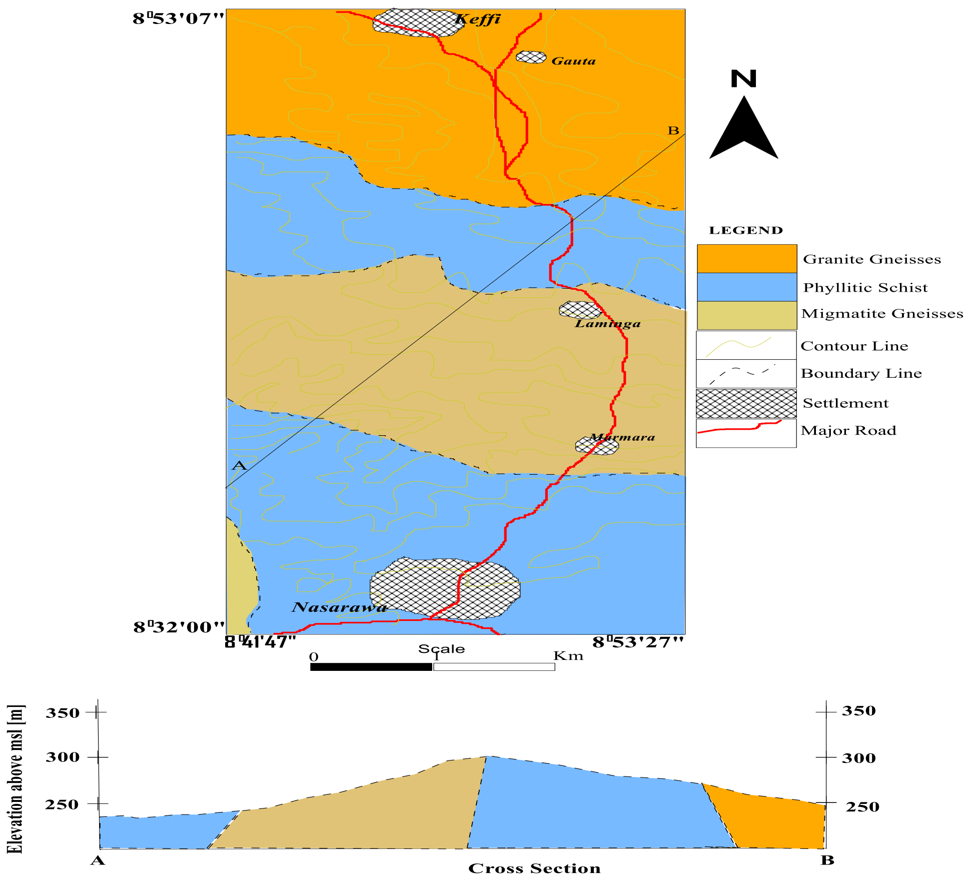
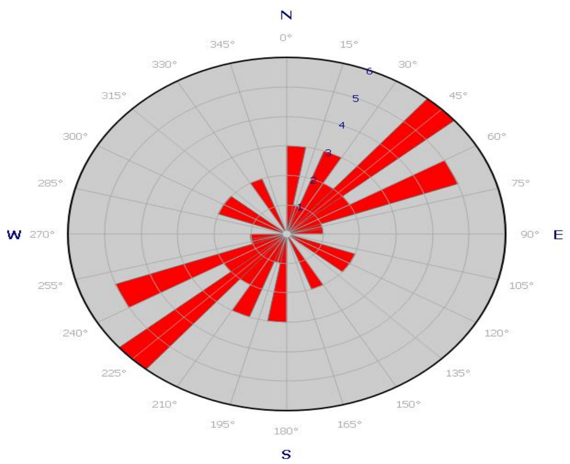
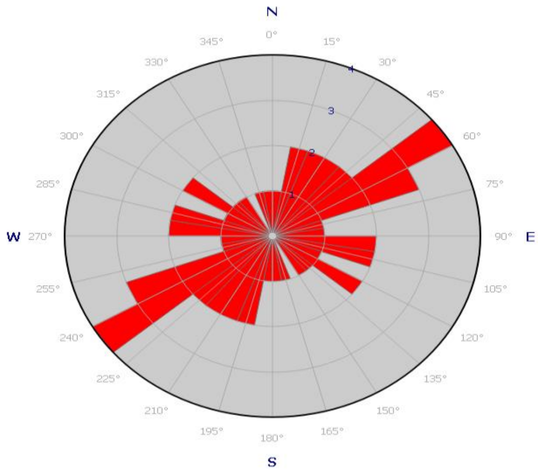


Figure 3: Geological map of the study area (source: Author's field report)



(a) Granite-gniess



(b) Schists

Figure 4: Rose diagram showing the orientation of joints in the study area

Geophysical Investigation

Geophysical investigation was carried out using the Allied Ohmega Resistivity Meter (Ohmega Ω model) along with a topographic map, Global Positioning System (GPS), electrode, current and potential electrode cables, crocodile clips, hammers, log-log data sheets.

The Electrical Resistivity method of the geophysical survey was conducted, using the Schlumberger array. This involved a Vertical Electrical Sounding (VES) using the Schlumberger array for every point or station that a VES reading was taken while spreading out the cables, The 35 VES station readings were plotted using Win Resist software, apparent resistivity (ρ_a) in ohm-m (Ωm) against AB/2 in meter (m) on the y and x-axis respectively. The produced curves were then sectioned into their characteristic layers and thicknesses to model the subsurface layers for further interpretation. Qualitative data were used to produce geo-electric sections using Surfer 12 software.

Table 1: VES Coordinates and elevations

VES Points	Latitudes [Northing]	Longitudes [Easting]	Elevation [M]
1	8º 48’ 46’’	7º 52’ 08’’	311
2	8 48 08	7 51 38	306
3	8 47 36.7	7 51 2304	299
4	8 47 02	7 51 00	290
5	8 46 15.8	7 50 38.5	281
6	8 45 34.1	7 50 16.4	278
7	8 44 47	7 50 09.1	254
8	8 44 05.1	7 50 04.4	248
9	8 42 51.3	7 49 15.7	265
10	8 42 09	7 48 52.6	273
11	8 41 29.4	7 48 47.2	261
12	8 40 19.9	7 48 31.9	259
13	8 39 44.4	7 48 15.2	267
14	8 39 09	7 47 55	273
15	8 38 13.2	7 47 24.2	248
16	8 37 43.4	7 47 06.6	321
17	8 37 09.4	7 46 37	234
18	8 36 19.6	7 45 48.1	224
19	8 35 42.5	7 45 17	215
20	8 34 48	7 44 27	205
21	8 34 09.4	7 43 59.8	192
22	8 34 20	7 43 35	198
23	8 35 15	7 44 05	231
24	8 36 25	7 44 58	238
25	8 37 35	7 45 40	258
26	8 38 56	7 46 10	245
27	8 39 58	7 46 57	257
28	8 41 20	7 47 15	267
29	8 42 49	7 48 01	310
30	8 44 05	7 49 02	265
31	8 45 15	7 49 46	255

32	8 46 20	7 49 59	260
33	8 47 35	7 50 30	269
34	8 48 33	7 51 02	299
35	8 49 26	7 51 30	333

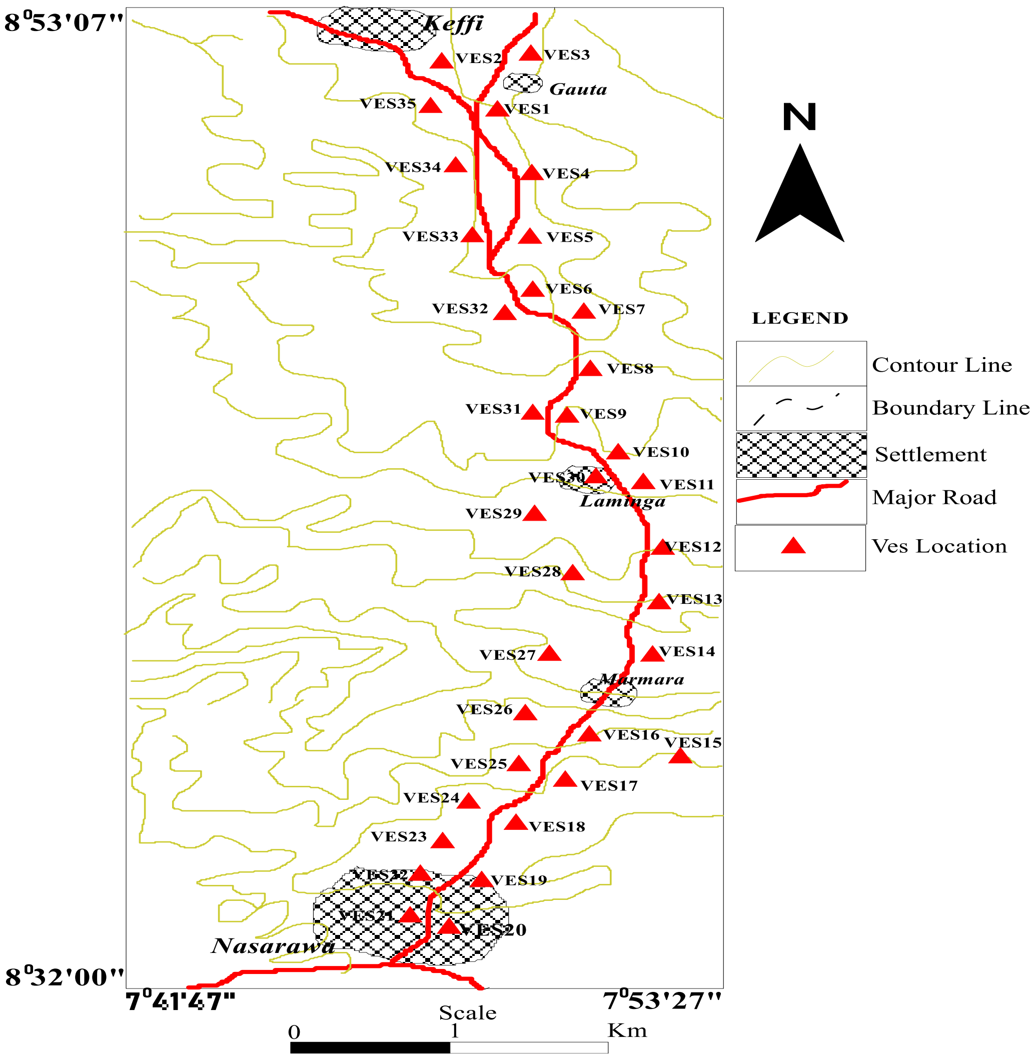


Figure 5: Vertical Electric Sounding sample point (source: Author's field report)

Table 2: Summary table of VES along Keffi-Nasarawa road

S/No	Layer No	Layer resistivity(Ωm)	Layer thickness(m)	Suggested/inferred layer (lithology)
1	1	80 – 1204	0.9 - 2.0	Topsoil, sand, sandy clay, and clayey soil, mud-clay
2	2	58 - 944	0.8 - 3.5	Sand, clayey soil, sandy clay, and laterite
3	3	59 - 435	2.5 – 15	Overburden formation
4	4	78 – 789	8-30	Weathered/ Fractured basement
5	5	201-1023	Infinity	Fresh basement

Table 2 above shows that the subsurface is heterogeneous throughout the Keffi-Nasarawa Highway. The electrical resistivity methods revealed four to five geo-electric layers in the study area and their lithology are clayey sand, sandy clay, sand, and clay/peat. These geo-materials preferred for construction purposes are sand clay, mud clay, and sandy clay because of their high shear strength and low compressibility potential (Terzaghi, et al. (1996), Das, B.M. (2013).

These geologic formations were found at a thickness range of about 0.8 m – 30 m across the study area. Different curve types is obtained which range from HA, HKH, KHA, and HK, and the curve type characterizes an area dominated with water retaining geo-materials

Based on the investigation with a view to understanding the near-surface geo-engineering characteristic for subsurface studies and road construction integrating geology and geophysical investigation (1-D survey), five main lithology's were identified which are; Topsoil, Laterite, overburden, weathered/ fractured basement, and fresh basement.

Table 3: Summary table of geophysical survey

Lithology	Section	Thickness [m]	Resistivity [ohms-m]	Composition	Geology	Remarks
Topsoil	Failed	0.9 – 1.3	80 – 849	Clay, mud clay	Schist	Corresponds to aquiferous zone, poor drainage, clayey materials
	Stable	1.4 – 2	280 – 1204	Sandy materials	Granite gneiss, Migmatite	Competent formation
Laterite	Failed	0.8 – 2.8	58 – 200	Clay, mud clay	Schist	Water saturated zone, poor drainage
	Stable	2.8 – 4.4	210 – 944	Lateritic sand	Biotite granite, Migmatite	Results from weathering of parent rock
Overburden	Failed	2.5 – 8	59 – 120	Clay, Mud clay	Schist, granite	Weathered formation, clayey soil, poor drainage
	Stable	9 – 15	121 – 435	Lateritic sand	Granite, Migmatite	Lateritic sand competent enough to bear the structure
Weathered/ fractured formation	Failed	8 – 17	78 – 250		Schist, granite	Water saturated weathered formation, presence of geological structures
	Stable	18 – 31	300 – 789		Granite, Migmatite	Competent formation, Absence of geological structures

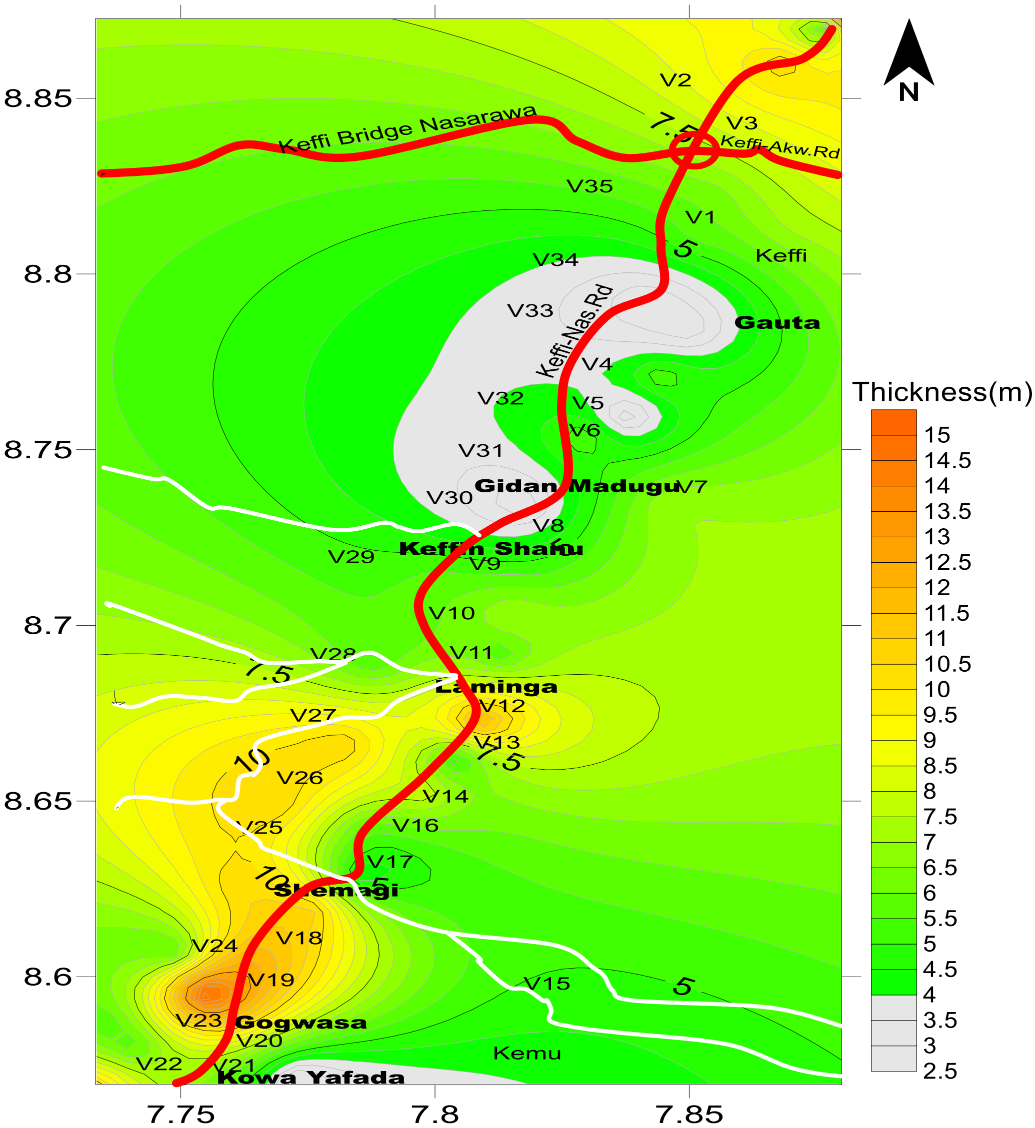


Figure 6: Iso-thickness overburden map of the study area

From the interpretation of the data conducted at the geo-electric layer, two zones were delineated, Zone-1 covers an area with a relatively low thickness value (<8 m), and Zone-2 is characterized by moderate to high thickness (9-13m). The boundary between the two shallow zones with contrasting geo-electrical behavior trends in the E-W direction.

The resistivity of the clayey weathered layer varies from 59–120 Ohm-m with thickness in the range of 2.5-8 m. The thickness and resistivity of the underlying thick overburdens suggest laterite as a result of the type of pre-existing parent rock (granite-gneiss, Migmatite) in the sounding location along the Keffi-Nasarawa road. Thus, the geological condition of an area is a key factor for the stability of roads.

The geo-electric layer (Overburden) thickness contour map shows the variation of thickness along the Keffi-Nasarawa highway, the low thickness values are represented by gray-green color between 2.5-8.0m while moderate – high thickness values 9 – 15.0 m range from yellow–red. Comparatively, the pavement failure along the Keffi-Nasarawa highway can be attributed to several factors, including the presence of water-saturated zones beneath the surface, weathered formations, and the existence of clayey soil that becomes saturated. Other factors, such as poor drainage patterns, also contribute to the failure. On the other hand, the stability of another section of the highway can be attributed to the presence of a competent layer with a thick lateritic layer and a resistive topmost layer. Additionally, the type of pre-existing parent rock (granite and Migmatite) along the Keffi-Nasarawa highway plays a role in its stability.

Geotechnical Investigation

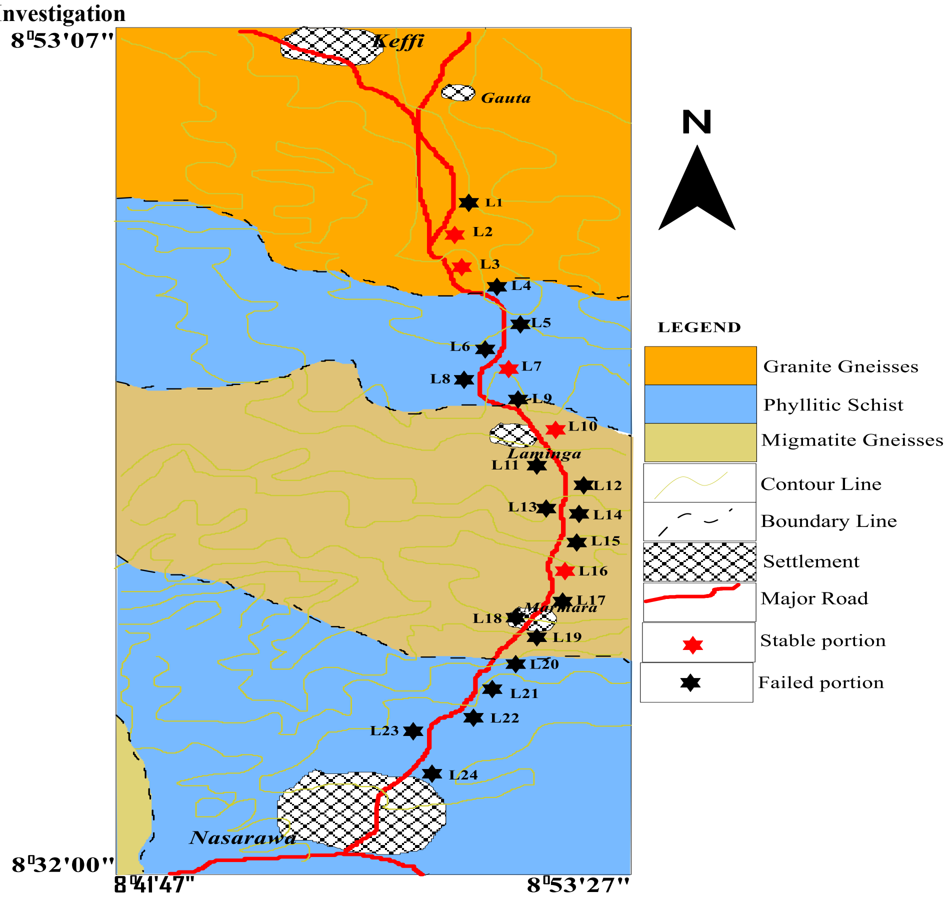


Figure 7: Soil sample collection points (Source: Author's field report)

Table 4: Soil sample collection point

Loc.	Lat.(N)	Long.(E)	Loc.	Lat.(N)	Long.(E)
L1	8° 48' 46" N	7° 52' 8" E	L13	8° 42' 8.8" N	7° 48' 52.6" E
L2	8° 48' 8" N	7° 51' 38" E	L14	8° 41' 53.2" N	7° 48' 50.1" E
L3	8° 47' 37.0" N	7° 51' 23.9" E	L15	8° 41' 29.9" N	7° 48' 46.9" E
L4	8° 46' 33.7" N	7° 50' 46.9" E	L16	8° 40' 22" N	7° 48' 32.5" E
L5	8° 45' 42.4" N	7° 50' 20" E	L17	8° 39' 39.8" N	7° 48' 12.8" E
L6	8° 44' 48.8" N	7° 50' 9.5" E	L18	8° 39' 10" N	7° 47' 56" E
L7	8° 44' 31" N	7° 50' 58" E	L19	8° 38' 16.5" N	7° 47' 23.9" E
L8	8° 44' 5.3" N	7° 50' 4.5" E	L20	8° 37' 29.8" N	7° 46' 56.8" E
L9	8° 43' 44.4" N	7° 49' 58.8" E	L21	8° 37' 10.3" N	7° 46' 28.4" E
L10	8° 43' 9.9" N	7° 49' 34.2" E	L22	8° 35' 42.2" N	7° 45' 17" E
L11	8° 42' 51.7" N	7° 49' 16.2" E	L23	8° 35' 28" N	7° 45' 10" E
L12	8° 42' 31.5" N	7° 49' 1.6" E	L24	8° 34' 49.6" N	7° 44' 27.3" E

Table 5: Summary of soil classification

LOC	Cu	Cc	LL	PL	PI	AASHTO	USCS	Description	Remark
1	3	1	23	0	23	A-6	SM	Low – Medium compressibility clays	Poor
2	25	0	23	0	23	A-2-6	SW	Silty or Clayey gravel sand	Good
3	41.7	0	23	3	20	A-2-6	SW	Silty or Clayey gravel sand	Good
4	13	0	26	24	2	A-4	CL/ML	Low compressibility silts/clays	Poor
5	25	4	26	17	9	A-2-4	SM	Silty or Clayey gravel sand	Good
6	16.4	1	26	20	6	A-2-4[0]	SW	Sands, gravels with elastic silts	Good
7	20	1	36.5	0	36.5	A-2-6	SW	Sands, gravels with clay	Good
8	5.7	1	32	0	32	A-6[11]	CL	Low – Medium compressibility clays	Poor
9	2.5	1	36	8	28	A-6[13]	CL	Low – Medium compressibility clays	Poor
10	13.8	0	25.5	0	25.5	A-2-6[2]	SW	Sands, gravels with clays	Good
11	3.1	1	30	0	30	A-2-6[0]	SM	Sands, gravels with clays	Good
13	2.1	1	24.5	0	24.5	A-6	SM	Low – Medium compressibility clays	Poor
14	3.6	1	29.5	0	29.5	A-2-6[0]	SM	Sans, gravels with clay	Good
15	2.1	1	25	0	25	A-2-6	SM	Silty or Clayey gravel sand	Good
16	2.4	1	28	0	28	A-2-6[1]	SM	Sands, gravels with clay	Good
18	18	0	27.5	25.6	2	A-2-4	SW	Silty or Clayey gravel sand	Good
19	8.3	0	17.5	0	17.5	A-2-6[0]	SW	Sands, gravels with clay	Good
20	5	1	29	0	29	A-6[6]	SM	Low – Medium compressibility clays	Poor
21	3.5	1	22.5	0	22.5	A-2-6[0]	SM	Sands, gravels with clay	Good
22	2.1	1	28	2	26	A-2-6	SM	Silty or Clayey gravel sand	Good

Soil samples was collected, analyzed and classified using the American Association of Highway and Transportation Officials [AASHTO] classification and Unified Soil Classification System [USCS]. Table 5 above shows a summary of the results and most of the samples lie between low – medium compressibility clays, which are poor for construction - silty or clayey gravel sands, which are relatively good for construction.

From the analysis done using AASHTO classification, the soil samples were classified between A-2-6 to A-6 soils. Soil samples from locations 1, 4, 8, 9, 13, and 20 show low – medium compressibility clays while samples from locations 2, 3, 5, 6, 7, 10, 11, 14, 15, 16, 18, 19, 21, and 22 show silty or clayey gravel sands. Samples from location 12, 17, 23, and 24results were not obtained.

Table 6: Summary table of California Bearing Ratio Values of samples

Loc.	Soaked CBR value [%]	Un-soaked CBR value [%]	Bearing Capacity	Soil strength
1	1.21	1.35	Weak	Low
2	0.97	1.27	Very Weak	Low
3	2.0	2.12	Weak	Low
4	2.78	3.87	Fair	Low
5	1.93	2.18	Fair	Low
7	13.28	13.4	Good	High
8	4.8	7.14	Fair	Low
9	7.91	11.98	Good	High
10	0.93	3.36	Very Weak	Low
11	1.33	1.89	Weak	Low
12	0.46	0.93	Very Weak	Low
13	1.87	2.05	Weak	Low
14	9.78	12.92	Good	High
15	21.13	52.4	Very Strong	High
16	7	7.06	Good	High
17	7.94	23.96	Good	High
18	8.09	12.01	Good	High
19	4.61	9.09	Fair	Low
20	6.04	9.12	Good	High
21	16.66	23.78	Strong	High
22	1.33	1.45	Weak	Low
23	1.69	2.36	Weak	Low
24	7.61	14.67	Good	High

Samples collected was analyzed and table 4 above shows the summary of the result. The CBR value of each sample was calculated at both 2.5mm and 5.0mm penetration for both the top and bottom of each sample [soaked and un-soaked] and the highest value was selected as the CBR value.

The selection of the highest value of the CBR is a standard practice in geotechnical engineering, to ensure consistency and reliability in design. It also represents the soil's best condition, reduces the risk of overloading the soil and it corresponds to the peak strength of the soil, which is the maximum resistance to penetration.

From the analysis, fourteen (14) sample locations indicate that their bearing capacity was weak and the soil strength is low which represents about 58.3% of the samples analyzed. In contrast, about 41.7% of the analyzed samples showed good bearing capacity and high soil strength.

The CBR value ranges from 0.46% - 4.61% in areas that indicated weak bearing capacity and 7% - 21.13% in areas of high bearing capacity.

Table 7: Summary table of compaction of samples

LOC	Maximum Dry Density [MDD]g/cm^3	Optimum Moisture Content [OMC]%
1	1.98	13.5
2	2.07	15.5
3	2.036	17
4	1.86	21
5	2.2	19.5
6	2.0	13
7	2.23	12
8	1.88	14
9	1.9	12.5
10	2.005	13.5
11	2.01	15
12	1.95	22
13	1.955	12.5
14	1.96	15
15	2.0	10.5
16	2.02	13
17	1.98	12.0
18	2.005	14.8
19	2.3	9.5
20	2.0	11
21	2.1	11
22	2.05	13.2
23	2.07	15
24	1.98	13

From table 6 above, the MDD ranges between 1.86 - 2.23 while the OMC ranges between 9.5 - 22

Correlation between Soil Type, Soil Thickness, and Engineering Properties

Soil types can significantly influence road pavement performance, durability and maintenance. There are different types of soils and each type of soil has its own unique characteristics under the influence of pressure, and the presence of moisture. Clayey soils are prone settlement, low load bearing capacity, more prone to cracking and rutting, susceptible to moisture changes. Silty soils are prone to settlement and erosion, fair load bearing capacity, settlement and rutting, sensitive to moisture changes. Sandy/Gravelly soils are generally stable, high bearing capacity, resistant to cracking and rutting, good drainage, resistant to moisture changes but can be prone to erosion and settlement if poorly compacted. (Terzaghi, et al (1996), ASTM D 2487)

Soil thickness varies as shallow soils, medium – thick soils and thick soils. Shallow soils are those that are less than 1m thick and they are more susceptible to frost heave, settlement and erosion. Medium – thick soils are those that are between 1m – 3m thick and can experience settlement and instability due to change in moisture content, Thick soils are those that are greater than 3m thick, they are more stable but can still experience settlement and instability.(Nigeria FHWA, (2018), ASTM D 2435)

Some engineering properties of soil include bearing capacity, soil strength, plasticity index, moisture content etc.

These engineering properties have great effects on road pavement as moisture content, compressibility, load-bearing capacity, and plasticity index, can lead to soil settlement and deformation, reduced load bearing capacity, increase cracking and rutting, pavement weakening, drainage issues and increased maintenance cost. Most engineering properties related to pavement distress include potholes, cracking, rutting, settlement, joint damage and edge cracking.

Integration of Geological, Geophysical and Geotechnical data and How They Affect Road Pavement

From the geophysical investigation carried out, the study area can be categorized in to two zone; zone one are areas of relatively low thickness [<1.3m] and zone two are areas of relatively medium to high thickness [>1.4 – 2m]. It further went to show that the topsoil thickness in the failed sections of the road are mostly composed of clay, mud clayey with apparent resistivity of 80 – 849(Ωm) which indicates an aquiferous zone that that of the stable portion are composed of sandy materials. Most of the failed section are underlain by schist and clayey soils formed schist are mostly problematic [swell in nature] in nature than those from the granite formation.

From the geotechnical investigation carried out, it revealed that the bearing capacities of most areas have weak/low bearing capacity/soil strength, which could be because of the soil type, and their plasticity indexes of most areas are high.

The integration of geophysical and geotechnical data reveals that sections underlain by clayey/silty soils with low top soil thickness are highly susceptible to failure. The resistivity values (80 -849 Ωm) corresponds to clayey to sandy formations as documented in previous studies.

Correlation analysis between average overburden resistivity and geotechnical parameters [CBR, OMC, MDD, PI] revealed weak linear relationships but stronger polynomial correlations, particularly for plasticity index ($R^2 = 0.73$) and maximum dry density ($R^2 = 0.31$). These findings are consistent with geotechnical results showing high plasticity indices and low bearing capacities. Therefore, the observed pavement failures are primarily due to poor engineering properties of the underlying soils, including high compressibility, low strength and moisture sensitivity.

CONCLUSION

This study employed an integrated approach combining geological, geophysical, and geotechnical investigations to determine the underlying causes of persistent instability along the Keffi–Nasarawa highway in Nigeria. The findings establish a strong relationship between subsurface geological conditions and pavement failure within the study area.

Geophysical analysis, based on interpreted Vertical Electrical Sounding (VES) data, revealed the presence of up to four subsurface geo-electric layers characterized by curve types such as HA, KHA, HKH, and HK. These variations indicate heterogeneous subsurface conditions, with resistivity structures suggesting that pavement failure is closely associated with near-surface linear geological features, particularly lithological contacts beneath the roadway. These zones act as conduits for water infiltration, thereby weakening the structural integrity of the pavement.

The study further identified clay-rich subgrade materials, including mud clay and alluvium-encased soils, as critical contributors to failure. These materials exhibit high swelling potential due to moisture absorption and subsequent shrinkage during drying, leading to reduced soil strength and increased susceptibility to deformation under load. Additionally, construction practices involving excessive cutting into moisture-sensitive clayey formations—such as laterite, overburden, and weathered layers—further exacerbate instability.

Geotechnical results indicate that most failed sections are underlain by low- to medium-compressibility clays with poor engineering properties. California Bearing Ratio (CBR) values range from 0.46% to 14.8% in weaker zones and from 7% to 21.13% in relatively competent areas. Despite some sections exhibiting moderate strength, failure is often intensified by inadequate drainage systems and localized flooding.

In conclusion, the primary causes of pavement failure along the Keffi–Nasarawa highway include weak silty clay subsoils, unfavorable subsurface geological structures, poor drainage conditions, and water infiltration. It is therefore recommended that proper drainage systems be implemented, subgrade soils be stabilized, and detailed geotechnical and geophysical assessments be conducted prior to road construction to enhance long-term pavement performance.

RECOMMENDATIONS

The survey has facilitated a better understanding of the causes of "road failure" and the characterization of a geo-electric layers segment of the Keffi-Nasarawa highway. To minimize future road pavement failures and address necessary corrections, it is imperative that;

1. The clay deposits and highly weathered geologic materials underneath the road pavement, as well as the clay-filled sections of the road, should be excavated (1 – 4m) and replaced with more reliable materials before applying the asphalt for rehabilitation work.
2. Excavation of the subsurface materials, specifically the topsoil with a thickness of one to four meters (1-4m), may be necessary around the area of unstable pavement where the underlying schists is highly weathered. Additionally, surface water accumulation along these road sections should be addressed by replacing it with competent road-fill materials.
3. Proper drainage system should be constructed alongside the rehabilitation work to ensure a more durable and lasting infrastructure.

Therefore, it is believed that if these recommendations were strictly adhered to within and outside the area of study, the Keffi-Nasarawa highway and other road transportation within Nasarawa state would not only improve considerably but also transform from a much-deteriorated state and nightmare (which is currently the case) to a smooth and pleasant ride.

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