Impact of Geology on the Stability of Minna-Lambata Road, North-central Nigeria

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Abstract

The rocks and soils underlying Lambata-Minna road and the neighbourhood in central Nigeria were mapped and subjected to various analyses in order to determine their impact on the stability of the road they underlay. Vertical electrical soundings were done along the road to determine the soil profile of the road. The geoelectric studies revealed that the soil profiles of the road are composed of laterite, sand and clayey soils. Road traffic statistics revealed that the traffic density road is within the permissible limit. A total of 5 rock samples were collected and each subjected to thin section, XRD and XRF analyses. Groundwater table of wells along the road was observed to determine the variation in seasonal groundwater variation. 35 water samples were collected from wells along the road and subjected to hydrochemical. A total of 47 soil samples were collected and subjected geotechnical analyses. The field mapping, thin section and XRD revealed the road is underlain by migmatites, gneisses, granites, marble, granodiorite and schist. The groundwater occurring within migmatite terrain has higher ionic concentration and physical properties. The soils are gravely soils. Low permeability ranges from 4.73 x 10^{-4}cm/s to 9.78 x 10^{-3}cm/s were obtained. Optimum moisture content ranges from 18 to 27%. The soaked CBR of soils ranges from 0.9 to 70% while the unsoaked CBR ranges from 5 to 70%. The soils underlying the granites are generally more competent than those underlying the migmatite. The consistent failure of the Lambata-Minna road portion underlain by migmatite gneiss and granite is because the soils occurring within those terrains have poor geotechnical properties to serve as either sub-grade, sub-base or base material in their natural state.

Keywords: Geology, Stability, Minna-Lambata road, North-central Nigeria

Introduction

A lot of money and time have been spent by the Nigerian government on the maintenance of Lambata- Minna road. Yet, the road is still unstable. The road condition is worse where it underlay crystalline rocks that are partly weathered to clay minerals. Adequate attention on the understanding of the geology that underlies this road is therefore necessary. This is because the road pavement requires sound and durable support from its subsurface material (underlay geologic material) (Okogbue, 1988). In choosing the route for the highway, one of the important factors considered is the geotechnical properties of the sub-base and subgrade material. When design technique, construction procedure and materials used for road are adequate, and the road still experiences failure, the geological, mineralogical, geotechnical, soil, climate and drainage conditions become critical.

This road has continued to experience failure after construction, and therefore subjected to frequent maintenance. This research was carried out to determine the possible geologic factors responsible for the road failure.

Gidigasu (1972) has attributed the majority of road pavement failures in the tropics to mineralogical and geotechnical factors. Ajayi (1982) noted that the road failure he studied occurred where the pavement was founded on saprolite rather than the strong lateritic horizons. Adeyemi (1992) noted that the degree of stability of the road he studied increased with the amount of kaolinite present in the subgrade soil and with increase in the California Bearing Ratio (CBR) and unconfined compressive strength (UCS) of the sub-grade soils. Adeyemi and Oyeyemi (2000) have noted that the soils below the stable section of the Lagos-Ibadan expressway have higher maximum dry density, unsoaked California Bearing Ratio (CBR), uncured unconfined compressive strength than those below the unstable section. They also noted that the soils below the stable portions have a lower proportion of fines and clay sized fraction and a lower optimum moisture content and linear shrinkage than the soils below the unstable section. Jegede and Oguniyi (2004) attributed the incidence of highway pavement failures for Nigerian highways to improperly compacted edges of the pavements to non- provision of drainage facility along the roads, and low California Bearing values among others.

Some other workers like those of Weinet (1960) Farquhar (1980), Gidigasu (1974), Mesida (1987), Ajayi (1987), Ayangade (1992) and Adeyemi (1992) have shown that the majority of highway failures can be attributed to geological, geotechnical and hygrogeological factors.

Clare and Beaven (1962), Okogbue and Uma (1988) have observed that the patterns of pavement performance in West Africa are considerably controlled by geology, topography, soil and drainage conditions. Gidigasu (1983) and Okagbue and Uma (1988) have noted that depth to water table appears to be the most dominant of the climatic, topographic and drainage factors that affect pavement performance. According to them, when the water table is at the depth of less than 1m, the chances of failure seem to be highly independent of the climate and other environmental conditions.

Study Area

The study area is located along the Lambata-Minna Road. It lies along longitude (06°31'32.4" E) to (06°22'53.8" E) and latitude (09°35'44.4" N) to (09°05'38.3" N). The rock types mapped included fine to medium grainedbiotite granite, granite gneiss, migmatite, marble and schist. The granite has been affected by the Pan African Orogeny with late tectonic emplacement of granites and granodiorites. The end of the orogeny was marked by faulting and fracturing (Abaa, 1983;

Ganduet *al.*, 1986; Olayinka, 1992). The granites are thus fractured, jointed and deeply weathered in some places.

The area has an average annual rainfall of about 1,000 mm. Rainy season usually starts during the month of April, and reaches the peak by August and ends in October. Low average temperature of 24°C is recorded between the months of July and September while high temperature is usually recorded during the months of February to April, at an average of 35^0C. The harmattan wind is experienced between December and January.

Methodology

Geological field mapping and soil profile study were performed. Fresh rock samples were collected with the aid of geological hammers and carefully labeled for chemical and mineralogical analysis. Trial pits were dug from where soil samples were collected for geotechnical studies. Vertical electrical sounding (VES) was conducted in order to obtain information on the character of the subsurface formations along the road. Groundwater fluctuation that may affect moisture content of subgrade was monitored. Static water levels were measured from hand-dug wells located very close to the road during the peak of the dry (April) and rainy (September) seasons. The depths of the wells (D), dry (A) and wet seasons (B) water depths were measured from which the groundwater fluctuation and percentage of variation

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Standard, ASTM D1883 and AASHTO T193 in order to identify the engineering properties of the soils.

Water samples (35) were analyzed for anions and cations as well as their physical parameters in order to relate the ionic concentration to weathering and the stability of the road. Colorimetric, Titrimetry and Flame Photometry (Sherwood Flame Photometry) methods were employed using HACH DR/890 Colorimeter, Sherwood Analog Colorimeter Model 252 as described by Idris-Nda (2010).

Results and Discussion

The rock types mapped included fine to medium grained biotite granite, granite gneiss, migmatite, marble and schist. The granite has been affected by the Pan African Orogeny with late tectonic emplacement of granites and granodiorites (Figure 1a).

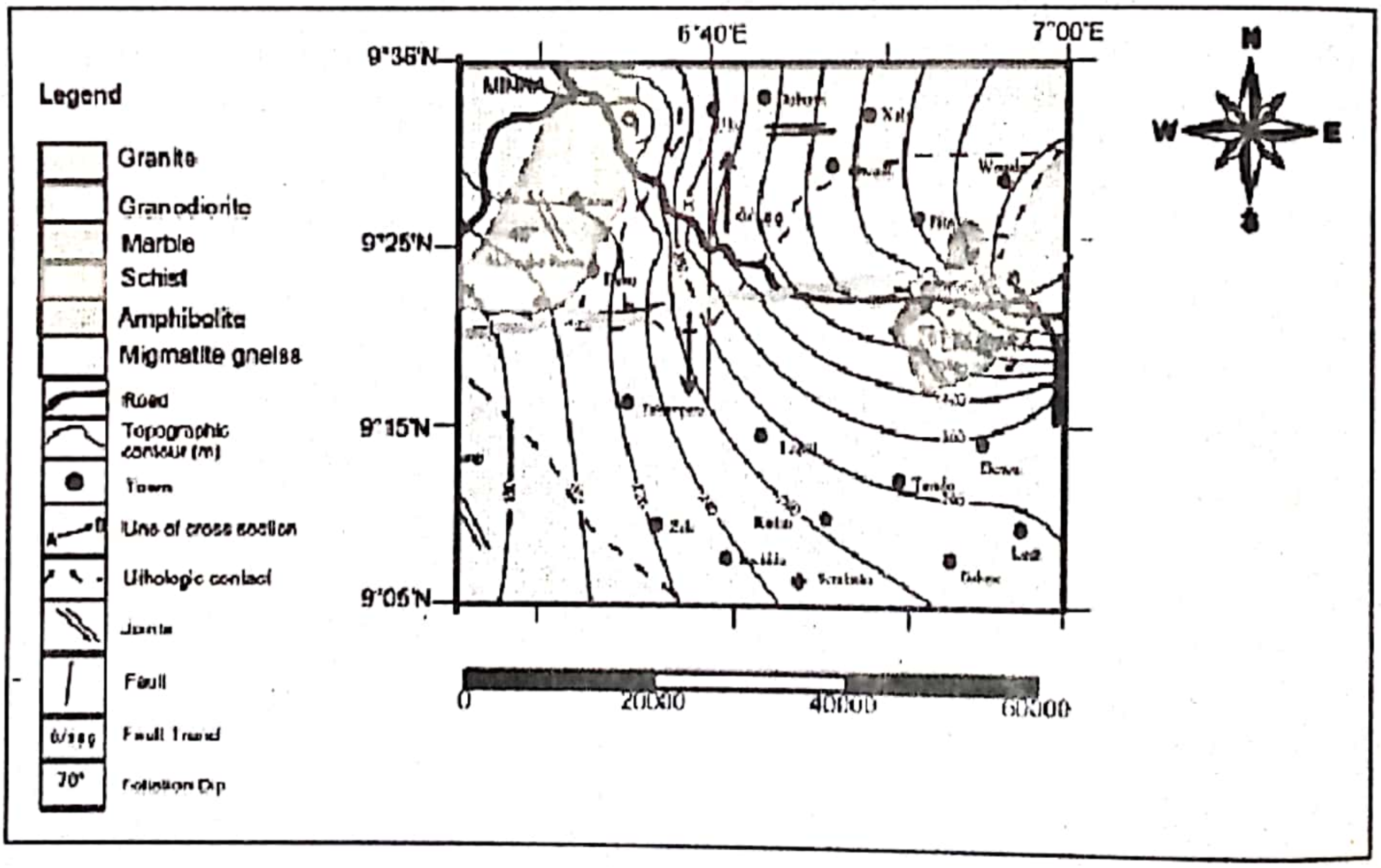

Figure 1a: Geological map of the study area. The inter-seasonal water table variation varies according to the rock type is presented in figure 1b.

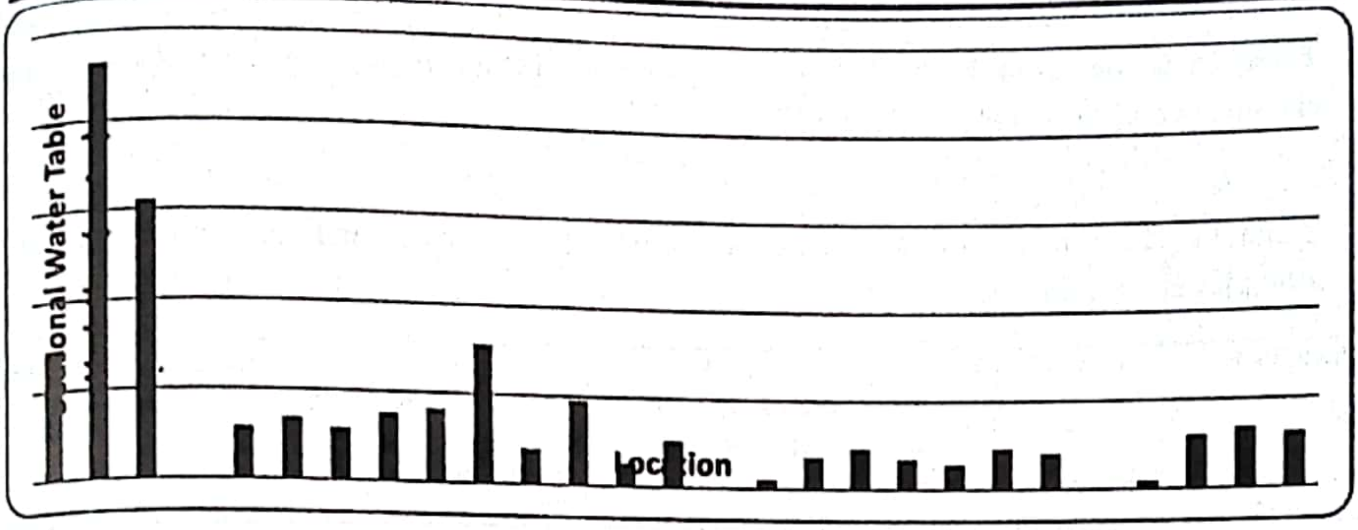

Figure 1b: Inter-Seasonal water table variation among the observed water wells according to the rock types along Lambata-Minna Road (from the left, 1st batch = migmatites; 2nd = Gniess; 3rd = Granite; 4th = Schist).

Figure 1b shows that the, migmatites have the highest inter-seasonal variation than the granite indicating that permeability also vary with the different rock types along the road. The fracturing of the granites could be responsible for the lower inter-seasonal water variation observed within the granites. Four geo-electric layers have been identified within the granitic rocks (Figures 2b) namely laterite, sand, weathered and fresh basement, while five geo-electric layers namely laterite, sand, clay, weathered and fresh basement occur within the migmatite (figure 2a and 2c). The high soil/weathered zone spatial depth variation can be attributed to the extensive fracturing and weathering of the underlying rocks.

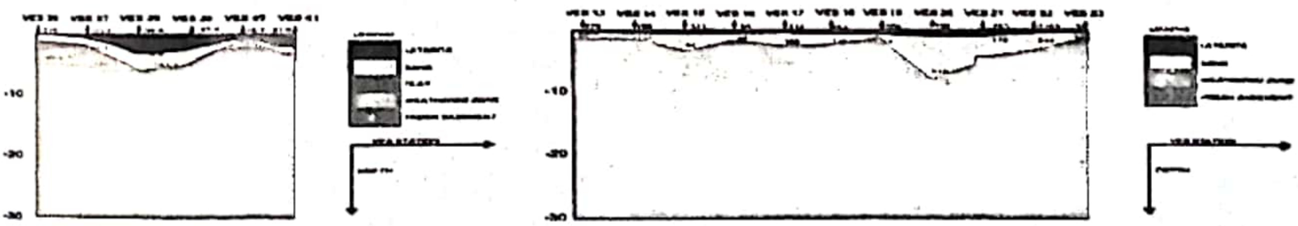

Figure 2a &b: Geo-electric section of VES L36 - L41 and L13 - L23 along Lambata-Minna Road.

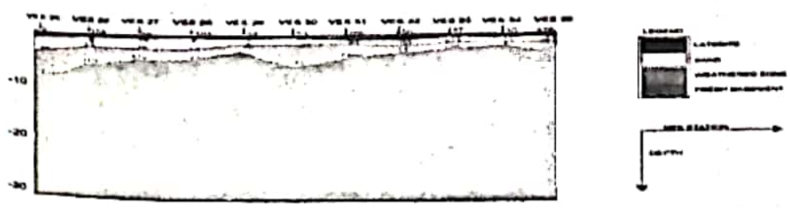

Figure 2c: Geo-electric sections of VES a. L36 - L41 b. L13 - L23 and c. L25 to L35 along Lambata-Minna Road.

Table 1a is the result of the X-Ray Difraction and photomicrograph of the rocks while the chemical composition is presented on Table 1b

Table 1a: X-ray diffraction and photomicrograph results of rocks and soil samples collected along Lambata-Minna Road.

SAMPLE	LOCATION		X-RAY DIFFRACTION MINERALS	PHOTOMICROGRAPHY ANALYSES		INFERRED ROCK NAME
	Longitude	Latitude		Minerals (%)	Texture	
A	07° 00' 08.5"	09° 21' 28.7"	Quartz, Albite, Cristobalite (quartz), Siderophilite	Biotite (45), Plagioclase feldspar (30), Muscovite (10), Quartz (10), Opaque mineral (5)	Granular	Gneiss
E	07° 42' 42.5"	09° 25' 56 8"	Graphite, Annite (Biotite), Nacaphite, Berlinite(phosphate)	Biotite (40), plagioclase feldspar (20), Hornblende (15), Quartz (10), Accessory minerals (15), Opaque minerals (10)	Granular	Gneiss
F	06° 38' 08"	09° 25' 56 8"	Quartz, Muscovite, Albite, Wulfrenite	Quartz (35), Biotite (25), Hornblende (25), Opaque minerals (10), Accessory minerals (5)	Equigranular and poikilitic	Granite
H (soil)			Quartz, Baumite			
D	06°34'55.0"	09° 31' 28.3"	Zn-Al silicate, Nacaphite, Ferriwinchite	Biotite (30), muscovite (20), Codierite (20), Quartz (20), Sericite (10)		Schist
G	06°34'55.0"	09° 31' 28.3"	Zn-Al silicate, Nacaphite, Ferriwinchite	Biotite (50), Muscovite (20), Quartz (15), Cordierite (10), Epidote (10)	Lipidoblastic	Schist

Table 1b: Major oxides of rock along Lambata-Minna road.

Sample no.	Major Oxides (pp)										
	SiO_2	AlO_3	K_2O	Na_2O	CaO	MgO	TiO	MnO	Fe_2O_3	LIO	Total
F	70.2	2.78	6.73	3.61	2.49	1.2	0.94	0.16	8.17	0.53	96.8
A	61.7	13	3.61	0.78	6.03	0.91	1.41	0.10	10.52	0.53	98.68
D	51.2	15	1.13	0.34	8.23	1.14	1.03	0.27	19.08	1.01	98.62
E	49.6	9.61	2.32	0.68	12.4	1.48	2.5	0.23	19.08	1.01	98.91
G	53.8	14.01	5.15	1.03	3	0.88	1.99	0.18	17.97	0.97	98.71

Table 1a shows that the studied rocks consist of quartz, biotite, muscovite, plagioclase grahite, and opaque minerals. The abundant oxides in the basement rocks along the road are in the order SiO_2>AlO_3>TiO2>Fe_2O_3>CaO>K_2O>MgO>Na_2O (Table 1b).

The dominant cations from the analyzed water samples are Ca^{2+}, Mg^{2+} and Na^+ with an average of 19.85, 14.82 and 9.19mg/l respectively while the dominant anions are Cl^- and SO_4^{2-} with average of 49.81 and 5.2.8 respectively (figure 2d).

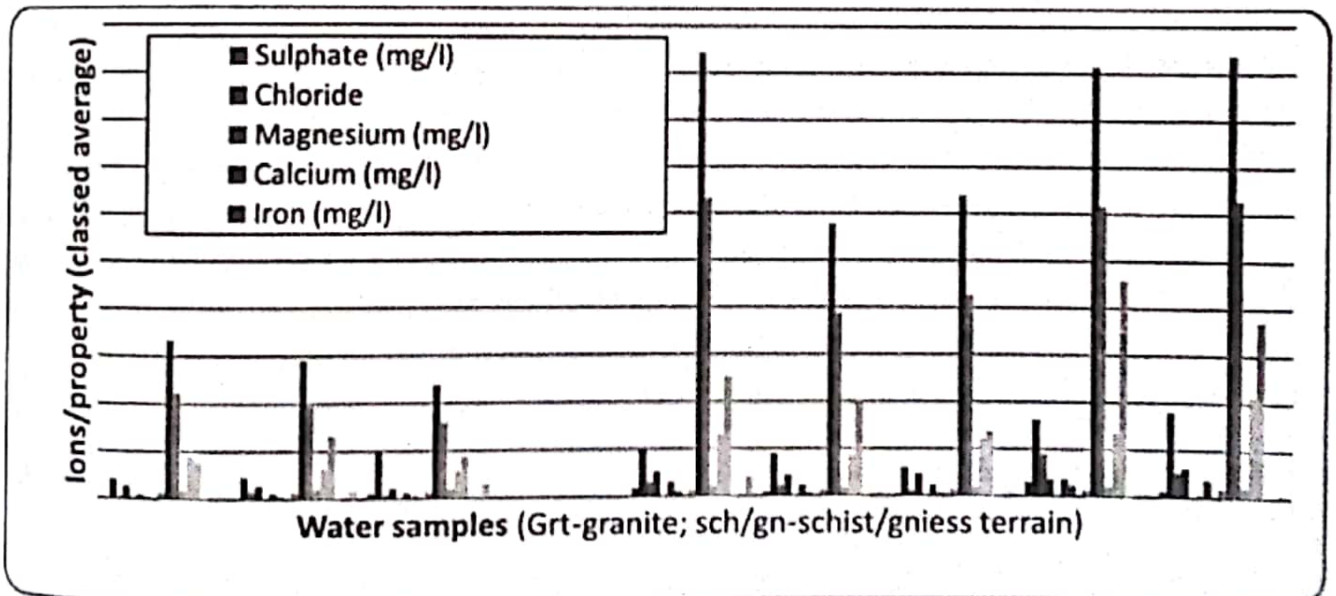

Figure 2d: Comparison of physico-chemical parameters of groundwater samples collected in granite and gneiss/schist terrain along Lambata-Minna Road

The pH of the water samples ranges from 5.4 to 9.64; the electric conductivity ranges from 13 to 1,113μS/cm; the total dissolved solids (TDS) ranges from 8.71 to 754.7mg/l and the hardness ranges from 10 to 502mg/l. It can be seen from Figure 2d that the concentrations of these ions and cations vary with the underlying lithology. Water samples collected from the schist/gneiss (metamorphic) terrain have higher ionic and cation concentration than those collected from the granitic terrain. This is attributed to the higher weatherability of these metamorphic rocks relative to the granitic rocks as well as to their high composition of minerals like biotite, cordierite, hornblende and epidote that are rich in Mg^{2+}, Ca^{2+} and/or Na^{+}. This agrees with works of Gidigasu (1974), Transport and Road Laboratory (1974) and Offodile (2002) that ions occurring in groundwater of basement rocks result from the weathering of the basement rocks. It is generally believed that the nature of the parent rock controls the pH in the soil and water (Kovalevsky, 2004).

These higher concentrations of these cations (Mg^{2+}, Ca^{2+} and/or Na^{+}) clearly explain why the samples have higher electrical conductivity and hardness. The neutral to acidic medium nature of most of the studied groundwater supports the weathering in the study area. Higher EC and TDS values as well as higher concentrations of magnesium, calcium, sodium and potassium are recorded in the waters from the migmatitic than from the granitic environment.

The soil profiles examined from the excavated trial pits along the studied highway show variability in soil types both vertically and laterally except for the topsoil, which is generally homogeneous. Visual inspection suggests that the soil is composed of fine to medium grained sand, clayey sand, sandy clays and silty sandy clays while medium to coarse grained materials were also observed in some profiles. Some of the soil horizons contain fragments suspected to originate from gneiss and schist. In some instances, the rocks have weathered into thick saprolite (tropical clayey soil formed from weathering of igneous/metamorphic rocks). The clayey materials swell on absorbing water during the wet season and shrink during the dry season forming cracks that can extend beyond one metre downwards. This seasonal swelling and shrinkage lead to seasonal differential settlement of the road, which can also result to road instability especially where the road base cuts through the mottled horizon. The heterogeneity of the soil profile is a reflection of their parent rocks.

The results of the geotechnical analyses is superimposed on the geology and shown in figure 3.

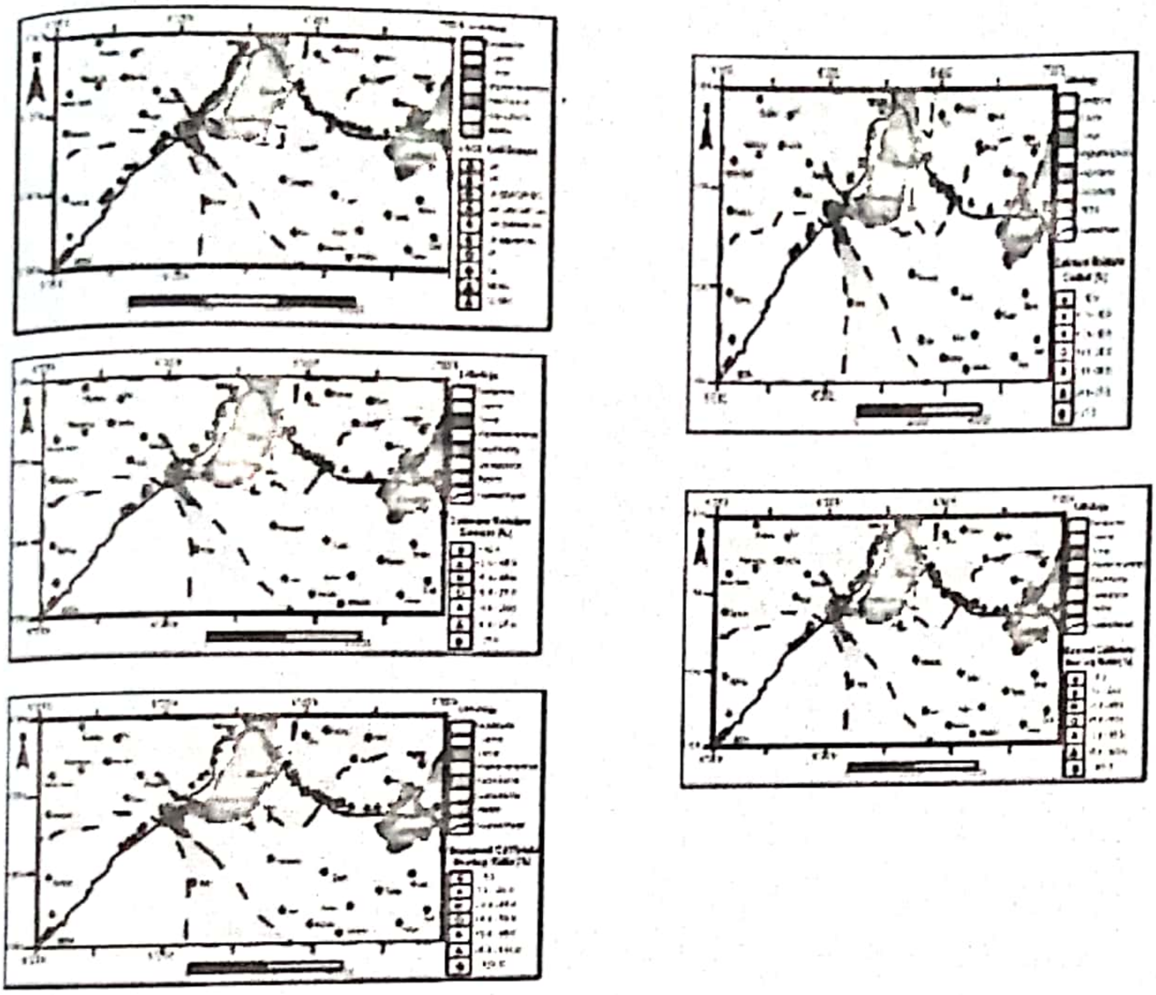

Figure 3: Comparism of geotechnical results and underlying geology.

From Figure 3 it can be seen that the studied road is generally underlain by gravelly (GW and GP) and sandy (SW and SP) soils, it can also be seen that the spatial distribution of the soil type is to an extent controlled by the underlying geology. The portions of the road underlain by granite and gneiss, which are coarse grained rocks, are mostly composed of gravelly soils while the portions underlain by marble and schist, which are medium grained rocks, are composed of gravelly and sandy soils. These indicate that these soils are actually residuals that originated from the underlying lithology of the studied road. The soils occurring within the migmatite have higher optimum moisture content (OMC) and lower maximum dry density (MDD) than soils derived from the granites but there is no clear difference in the permeability of the soils derived from the different rock along the road. Soils derived from granite have higher California Bearing Ratio (CBR) than of soil collected from the migmatite environment. The results also show that the CBR, OMC and MDD are controlled by the geology. The possible causes of failure of the studied roads are discussed based on the suitability of analyzed soil samples, underlain by different lithologies, for the stated road sections as specified by the Federal Ministry of Works and Housing (1970). The suitability of the soil samples are summarized in Tables 2a to 2b.

*Table 2a: Suitability of soils underlain by **granite and granodiorite** along Lambata-Minna road (assessed based on Federal Ministry of Works and Housing (FMWH, 1970) specification) for different road sections*

Road section	Property	Soil samples underlain by **Granite**										**Granodiorite**		Suitability percent (scale of 100.00)
		13	15	16	18	19	21	24	27	30	31	33	36	
	Soil type (USCS)	GW-GC	SM-SC	GP-GM	SM-SC	SM-SC	GP	SP-SM	SW-SM	GW	SC-SM	GW	GC	
For Fill & road Sub-grade	% of fines	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Suitable	Suitable	**91.67**
	Liquid limit (%)	Suitable	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	**41.67**
	Plasticity index (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	**0.00**
	Soaked CBR (%)	Suitable	Not suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	**75.00**
	OMC (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Suitable	Suitable	Not suitable	Not suitable	Suitable	Not suitable	Not suitable	**25.00**
	MDD(mg/m^3)	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	**100.00**
For sub-base course	Liquid limit (%)	Suitable	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	**41.67**
	Plasticity index (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	**0.00**
	*Soaked CBR (%)	Suitable	Not suitable	Suitable	Not suitable	Not suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	**58.33**
For base course	% of fines	Suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	Suitable	Not suitable	Not suitable	Suitable	Not suitable	**58.33**
	Liquid limit (%)	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Suitable	Suitable	Suitable	Not suitable	Not suitable	**33.33**
	Plasticity index (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	**0.00**
	Unsoaked CBR (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	**0.00**

USCS=Unified Soil Classification System; MDD=Maximum Dry Density; OMC=Optimum Moisture Content; *=West African Standard; CBR=California Bearing Ratio; % of fines=% less than 75μm

Table 2b: Suitability of soils underlain by *migmatite gneiss and schist* along Lambata-Minna road (assessed based on Federal Ministry of Works and Housing (FMWH, 1970) specification) for different road sections

Road section	Property	Soil samples underlain by Migmatite Gneiss									Schist	Suitability percent (scale of 100.00)
		1b	4b	10b	15b	20b	2	4	7	10	39	
	Soil type (USCS)	GW-GM	SW-SM	GW	SP-SM	SW-SM	GW-GM	GW-GM	GP	GW-GC	SM	
For Fill & road Sub-grade	% of fines	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	100.00
	Liquid limit (%)	Not suitable	Not suitable	Not suitable	Not analyzed	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	10.00
	Plasticity index (%)	Unsuitable	Unsuitable	Unsuitable	Not analyzed	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	Unsuitable	0.00
	Soaked CBR (%)	Not suitable	Not suitable	Not suitable	Suitable	Suitable	Suitable	Not suitable	Suitable	Not suitable	Suitable	50.00
	OMC (%)	Not suitable	Suitable	Suitable	Marginal suitable	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	30.00
	MDD(mg/m^3)	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	Suitable	100.00
For sub-base course	Liquid limit (%)	Not suitable	Not suitable	Not suitable	Not analyzed	Suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	10.00
	Plasticity index (%)	Not suitable	Not suitable	Not suitable	Not analyzed	Not suitable	Suitable	Suitable	Not suitable	Suitable	Not suitable	30.00
	*Soaked CBR (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	0.00
For base course	% of fines	Suitable	Suitable	Not suitable	Suitable	Suitable	Suitable	Suitable	Not suitable	Suitable	Not suitable	70.00
	Liquid limit (%)	Not suitable	Not suitable	Not suitable	Not analyzed	Not suitable	Not suitable	Not suitable	Suitable	Not suitable	Not suitable	10.00
	Plasticity index (%)	Not suitable	Not suitable	Not suitable	Not analyzed	Not suitable	Not suitable	Not suitable	Not suitable	Suitable	Not suitable	10.00
	Unsoaked CBR (%)	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	Not suitable	0.00

USCS=Unified Soil Classification System; MDD=Maximum Dry Density; OMC=Optimum Moisture Content; *=West African Standard; CBR=California Bearing Ratio; % of fines=% less than 75μm

Table 2a shows that none of the 12 analyzed soil samples occurring within the granite and granodiorite terrain along Lambata-Minna road have plasticity index (PI) suitable for any of the road sections (sub-grade, sub-base or base) while less than half (41.67, 41.67 and 33.33%) of the analyzed samples have liquid limits (LL) adequate to serve as road sub-grade, sub-base or base material. Only 25% of samples have optimum moisture content suitable for sub-grade. 75% of the samples have California bearing ratio (CBR) suitable for sub-grade; 58% have CBR suitable for sub-base while none (0.00%) have CBR suitable for base material. About half (58.33%) of the samples contain the proper amount of fines needed in base materials. It implies that the soils occurring at this portion of the road (granite and granodiorite terrain) cannot satisfactorily serve as sub-grade, sub-base or base course materials in their natural state. This explains the cause of the constant road failure at this portion of the road.

The non-suitability of the soil for any of the road section may be due to the weathering of orthoclase and plagioclase feldspar content of their parent rocks (granite and granodiorite), during the soil formation, to less stable minerals. As it can be seen from Table 2a that the 2 soil sample, occurring in granodiorite terrain, showed non-suitable CBR relative to those occurring in granite terrain, it suggests that residual soils forming from sodic plagioclase-rich rocks (granodiorite) are less competent than those forming from orthoclase/microcline-rich rocks (granite). This is reflected inthe poor geotechnical properties of soils that formed from migmatite gneiss (see Table 2b) that is rich in plagioclase. Only 5 samples (50%) in migmatite gneiss terrain along Lambata-Minna road have CBR suitable for road sub-grade while none (0.00%) have CBR suitable for either road sub-base or base. Only 1 sample (10%) each have LL suitable for road sub-grade, sub-base or base. The PI of the soil is also inadequate for any of the road sections. Again, the soil underlain by migmatite gneiss cannot satisfactorily serve as road sub-grade, sub-base or base in its natural state which also explains the cause of the road portion underlain by migmatite gneiss along the studied road Gidigasu (1972), Federal Ministry of Works and Housing (1970).

The soil occurring within the migmatite gneiss can serve better as sub-grade on the addition of stabilizers like lime, marble dust or limestone ash (Okagbue and Yakubu, 1997; Okagbue and Onyeobi, 1999) in correct proportions to improve the CBR, LL and PI of the soil while the addition of the stated stabilizers to soil underlain by the granites will enable the soil to serve better as sub-grade and sub-base. Stabilizing the soils within the migmatite gneiss terrain with the above stated substances to serve as either sub-base or serve as road base may not be economical. This is because the cost of stabilizing such soil will be more than the cost of replacing the soil.

Conclusions

The groundwater collected from wells within the migmatite terrain along Lambata-Minna road has the highest ionic concentration and groundwater fluctuation. Soils occurring within the granitic environment are more competent than soils occurring within the migmatitic rocks implying that soils derived from granitic rocks are more stable than those derived from migmatitic rocks. Portions of the road underlain by granitic rocks are the most stable than portions underlain by migmatite. The cause of the constant failure of Lambata-Minna road is because most soils occurring within the migmatite gneiss and fractured granite terrain of this road is affected by groundwater and has resulted in the poor geotechnical properties. The soils cannot therefore satisfactorily serve as road sub-grade, sub-base and/or base course in their natural state. The soil can serve as aneffective sub-grade when mixed with correct proportion of stabilizers like lime, wood ash or marble dust. In the long run, it will be economical when compaired with huge maintenance budget being wasted on it. These results and recommendation are of common applicability in areas with similar lithologic compositions.

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