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ENGINEERING GEOLOGICAL ASSESSMENT OF SOME LATERITIC SOILS IN IBADAN, SOUTH-WESTERN NIGERIA USING BIVARIATE AND REGRESSION ANALYSES

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ABSTRACT: *Bivariate correlation and regression techniques were employed to evaluate the relationship between pairs of geotechnical variables for residual lateritic soils derived from three genetic crystalline rocks in Ibadan metropolis, south-western Nigeria. The significance of mean group differences (parent-rock and level of compactive effort) at 5% level of significance was determined using paired t-test analysis. This is with a view to ascertaining the influence of the pedogenic factor of parent rock, percentage fines, and energy of compaction on engineering index properties of the lateritic soils. The clay-size contents had positive correlations with both Optimum Moisture Content (OMC) and plasticity index, and a negative correlation with the Maximum Dry Density (MDD). The MDD and OMC had significant negative and positive correlations respectively with the amount of fines. The amount of fines and Unconfined Compressive Strength (UCS) had significant negative and positive correlations respectively with the California Bearing Ratio (CBR). The study shows significant parent-rock group differences in most engineering properties. The bandedgneiss-derived soils were found to be better engineering soils than the migmatite-gneiss- and quartzite/quartz- schist-derived soils. The modified AASHTO level of compactive effort which produced better compacted soils than the West African level is recommended for the soils.*

Key words: *Regression analysis, engineering properties, lateritic soils, pedogenic factors.*

INTRODUCTION

The suitability of some lateritic soils for engineering purposes had been tied to naturally stable gradings coupled with a suitable proportion of clayey materials acting as binder (Ackroyd, 1960). The percentage of silt- and clay-size contents of a soil is a strong determinant of its sensitivity to moisture. Careful soil investigation is therefore indispensable prior to utilization of soils for any engineering purpose. Where necessary, appropriate modification of the properties of the soil is made so that its engineering performance is improved. The influence of the pedogenic factor of parent rock, percentage of silt- and clay-size contents, and energy of compaction on engineering index properties of lateritic soils can not be overemphasized in lateritic soil engineering.

This paper reports on the studies carried out on lateritic soils derived from quartzite/quartz-schist, banded gneiss, and migmatite gneiss in parts of Ibadan, south-western Nigeria (Fig. 1). The quantitative influence of amount of fines (%), clay-size contents (%), level of compactive effort and pedogenic factor of parent rock were investigated. Engineering geological variables determined were subjected to statistical treatments such as paired (correlated) *t*-test- a parametric test used to compare the means of two sets of observations from pairs of lateritic soils derived from different genetic rock typeswhich are significantly different from one another.

THE STUDY AREA

The study area lies within latitudes $7^{o}25^{l}$ N and $7^{o}27^{l}$ N and longitudes $3^{o}53^{l}$ E and $3^{o}56^{l}$ E (Fig. 1). The climate is of the West African monsoonal type, characterized by distinct wet and dry seasons typical of West African regions. Average temperatures reach a peak of about 32^{o} C around February and a threshold of about 21^{o} C around August.

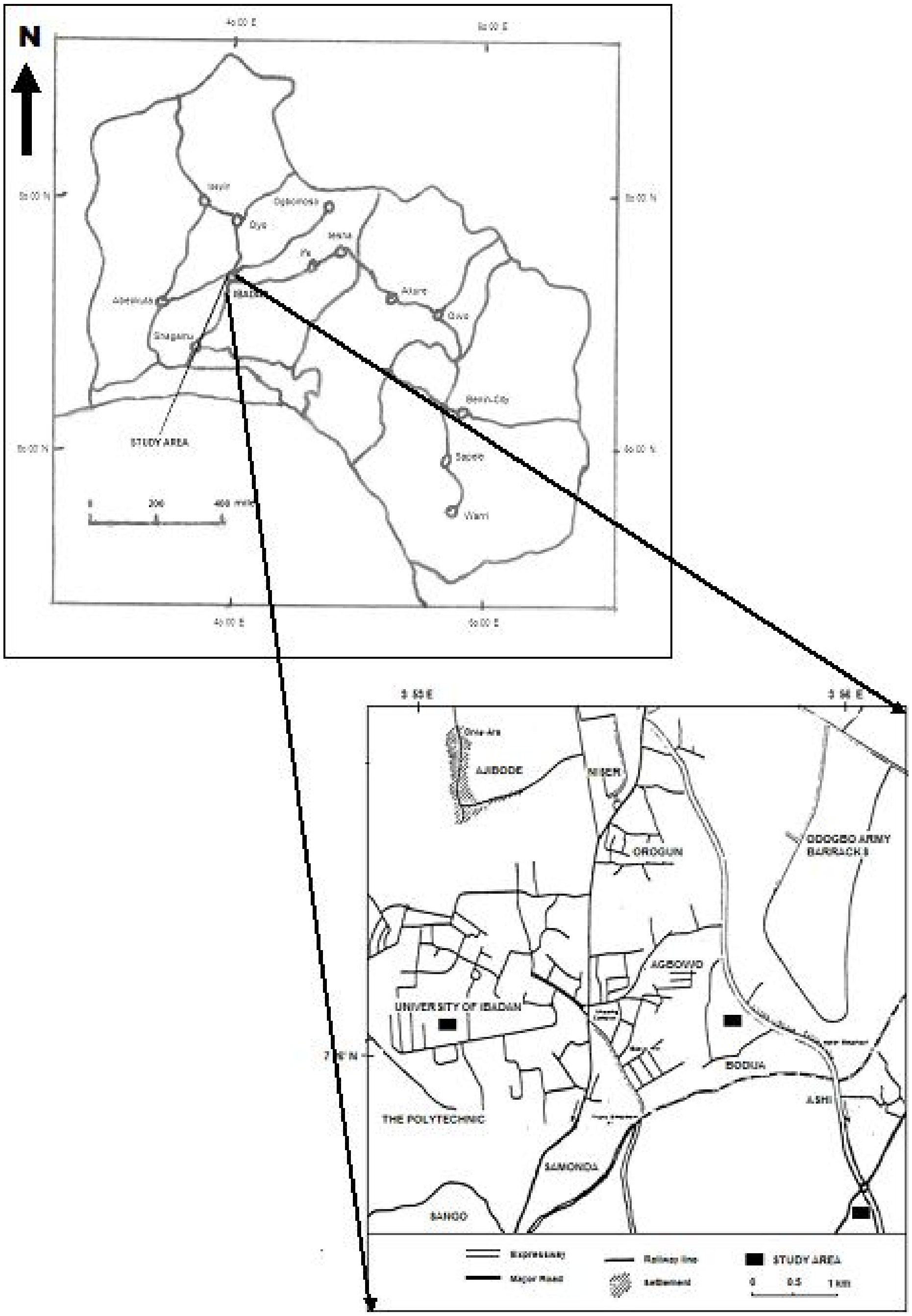


Figure 1: Location Map of the Study Area

Relative humidity ranges from about 70% around January to about 90% in July. The climate is considered the most important primary factor of lateritization. Maignien (1966) suggested that contemporary lateritic soils have developed at mean annual temperatures of around 25° C and lateritic soils are believed to always correspond to climates in which the wet period is warm.

GEOLOGICAL SETTING OF THE STUDY AREA

The area under investigation lies within the Precambrian Basement Complex of Nigeria (Fig. 2a). Researchers have variedly classified the assemblages into four lithological groups, viz; minor intrusives, Older granites, schist belts and migmatite-gneiss-quartzite complex. The study area is underlain by the migmatite-gneiss-quartzite complex (Odeyemi, 1981; Rahaman, 1988; Elueze, 2002; Adekoya et al., 2003).

Three rock types within the migmatite-gneiss-quartzite complex were encountered in the study area (Fig. 2b). The massive Quartzite component in association with quartz-schist) have a pseudo-conglomeratic and schistose nature. The quartz-schist outcrops strike between 160° and 170° with dips ranging between 46°E and 58° E. They stand as topographic highs above the surrounding terrain. The banded gneisses exhibit some quartzo-feldspathic veins. There is a generally north-south strike direction and average dip angles of 36° – 47° E.

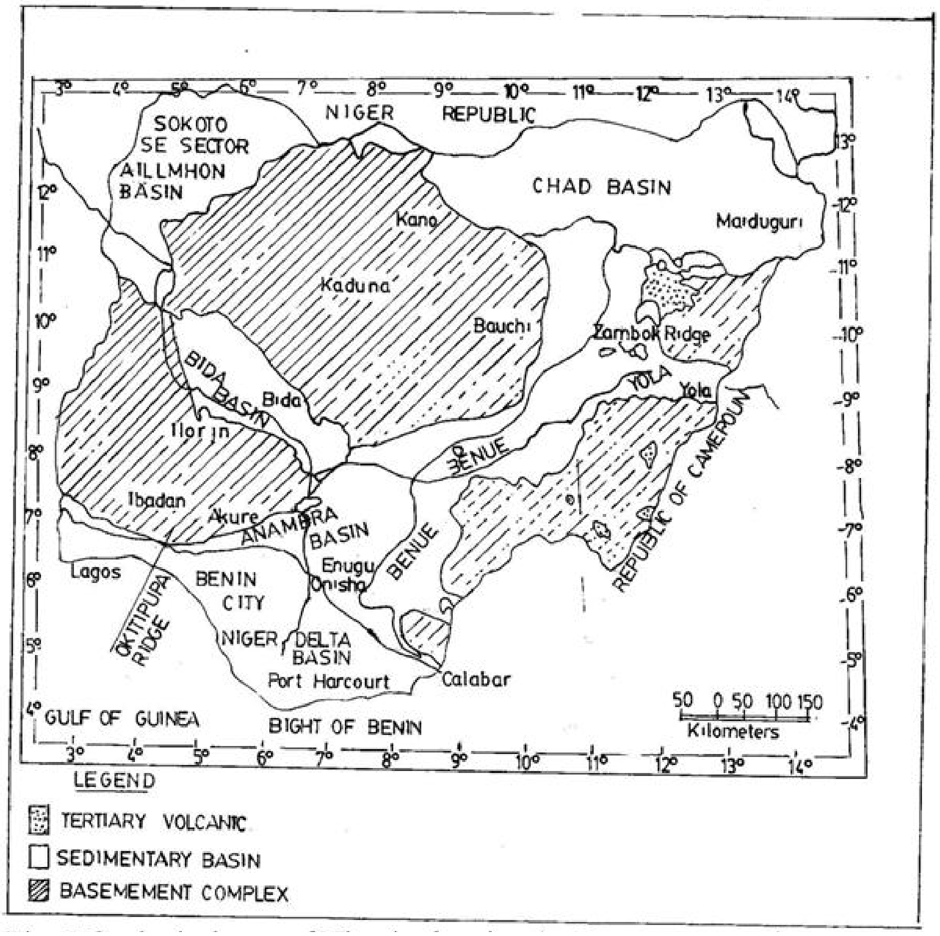


Figure 2a: Geological map of Nigeria showing the Basement Complex (Rahaman, 1988)

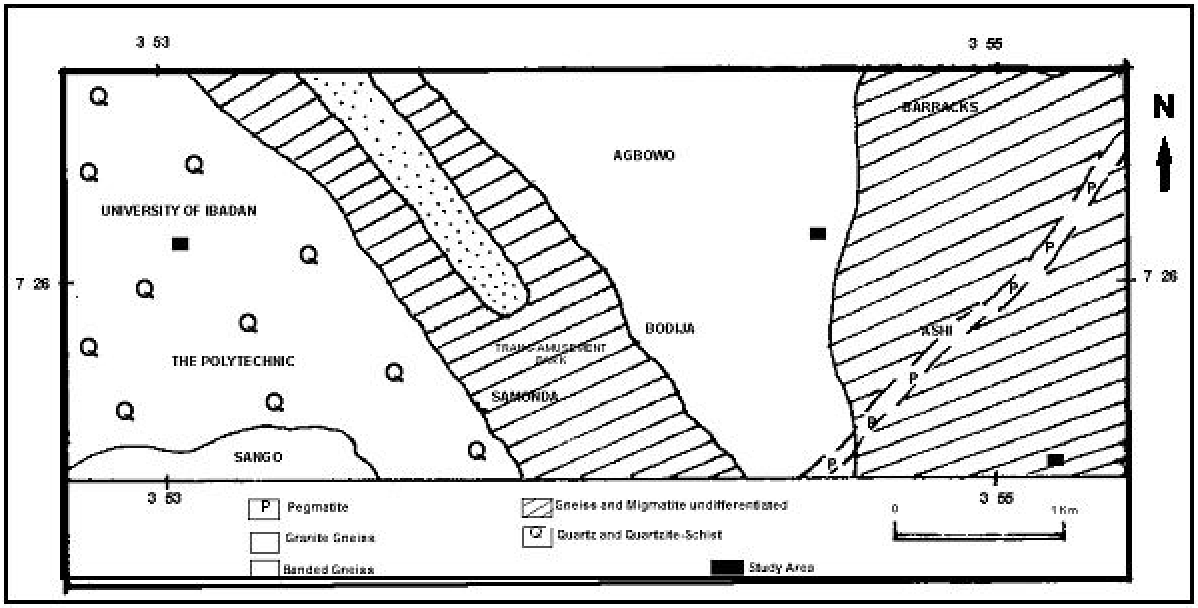


Figure 2b: Geological map of the study area (Modified after Jones and Hockey, 1964)

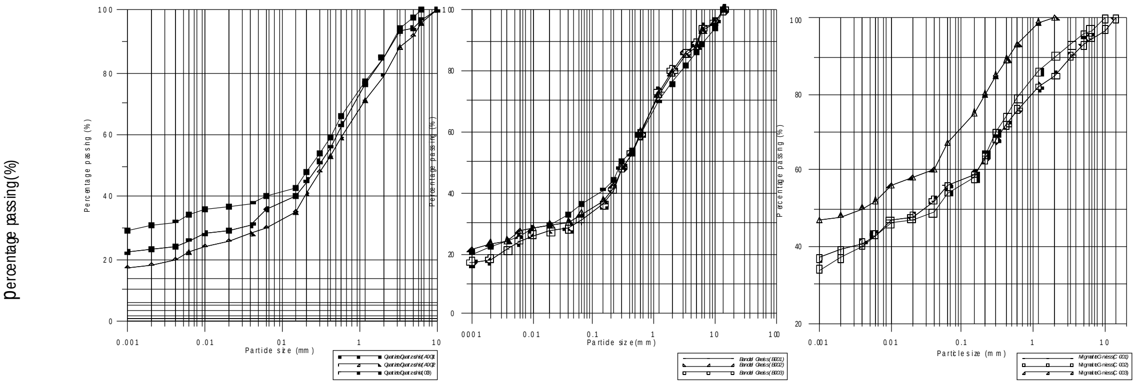
METHODOLOGY

Nine bulk soil samples were collected, three samples from each parent rock type. Various laboratory techniques were applied to test the soil samples for engineering index properties such as grain size distribution, liquid limit, plastic limit, linear shrinkage, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), California Bearing Ratio (CBR), and Unconfined Compressive Strength (UCS). The tests were carried out in accordance with the procedures outlined in the British Standards (BS) 1377 (1990), with necessary modifications. The results were subjected to statistical analysis at 5% level of significance (i.e. a=0.05) with a view to assessing the influence of the pedogenic factor of parent rock, percentage of silt- and clay-size contents, and compactive efforts on engineering properties such as amount of fines, OMC, MDD, UCS and unsoaked CBR. Again, to deduce the degree of correlation between the amount of fines and soaked CBR, and between the UCS and unsoaked CBR. Grapher®, Microsoft Excel® and SPSS® software packages were employed in data analyses and presentation.

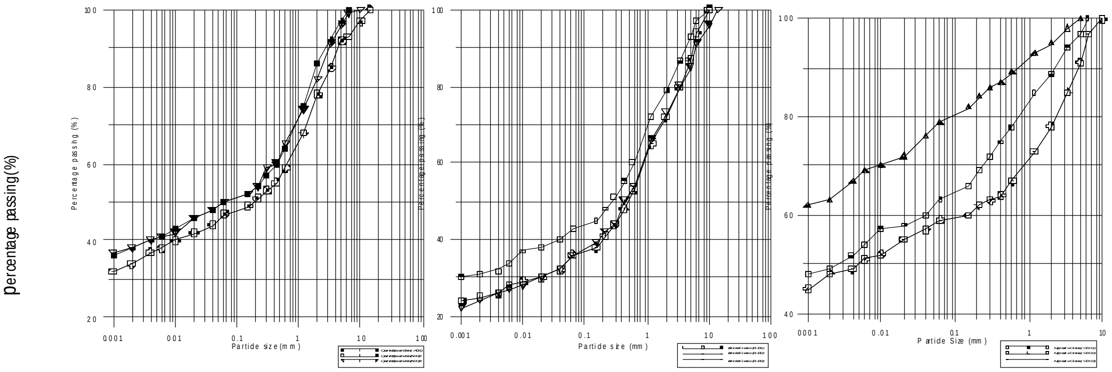
RESULTS AND DISCUSSION

The grain-size distribution characteristics (Fig. 3) show that the soil samples are generally well-graded. Table 1 shows the results of the engineering tests carried out on the soil samples. From the particle-size distribution characteristics, soils derived from banded gneiss (with an average value of 67% gravel and sand-size fractions) are the most sandy, followed by soils from quartzite/quartz-schist (with an average value of 65% gravel and sand-size fractions) while soils from migmatite-gneiss are the least sandy (with an average value of 41% gravel and sand-size fractions). They are generally well-graded, revealing a decreasing degree of both leaching and weathering. This can also be related to the textural characteristics of the parent-rock types. The specific gravity values show that the banded gneiss-derived soils (with an average value of 2.75) has the highest degree of laterization, followed by the quartzite/quartz-schist (with an average value of 2.72), while the soils derived from migmatite-gneiss-derived soils (with an average value of 2.71) is the least lateritized. The banded gneiss-derived soils which have the least linear shrinkage (with an average value of 12.8%) values will be the best for highway construction, followed by the migmatite-gneiss (with an average value of 13%). The quartzite/quartz-schist-derived soils which have the highest linear shrinkage values (with an average value of 14%) would be the worst for highway construction.

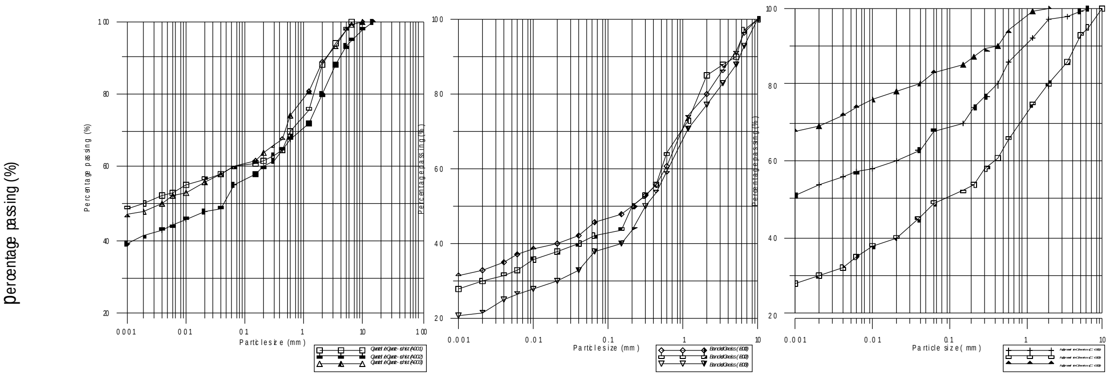
From the Unconfined Compressive Strength and California Bearing Ratio (soaked and unsoaked) values at both modified AASHTO and West African levels of compactive efforts, the banded gneiss-derived soils (with the highest



(a) Uncompacted natural soils



(b) Compacted soils at West African level



(c) Compacted soils at Modified AASHTO level

Figure 3: Grain-size distribution curves

Table 1. Engineering Properties of the Soil Samples

Parent Rock	Sample No.	AASHTO Classification	Gravel + Sand (%)	Silt + Clay (%)	G_s	LL	PL	PI	SL	MDD (Kg/m^3)		OMC (%)		UCS (KN/m^3)		CBR (%)			
										WA	MA	WA	MA	WA	MA	WA		MA	
																Unsoaked	Soaked	Unsoaked	Soaked
Quartzite/ Quartz Schist	A-001	A-6	60	40	2.73	25	11	14	15.2	1770	1940	21	16	279	388	24	15	33	22
	A-002	A-2-7	70	30	2.73	60	34	26	14.1	1780	1`970	17	14	301	420	30	20	40	29
	A-003	A-7-6	64	36	2.7	46	22	24	12.6	1760	1910	21	17	270	354	28	17	36	24
Banded Gneiss	B-001	A-7-6	64	36	2.73	43	25	18	11.2	1780	1950	19	15	296	345	33	22	43	30
	B-002	A-2-7	67	33	2.75	52	23	29	15.6	1800	1980	17	14	341	573	27	18	38	27
	B-003	A-2-7	69	31	2.77	41	24	17	11.7	1780	1960	20	16	225	456	25	14	34	26
Migmatite Gneiss	C-001	A-6	46	54	2.73	37	16	21	13.7	1680	1860	23	18	250	318	22	11	27	18
	C-002	A-7-6	44	56	2.7	55	23	32	11.1	1660	1820	24	19	287	400	20	10	26	16
	C-003	A-7-6	33	67	2.7	51	26	25	14.1	1690	1880	22	17	246	315	18	10	23	14

LL=Liquid Limit, PL=Plastic Limit, PI=Plasticity Index, G_s=Specific Gravity, SL=Shrinkage Limit, MDD=Maximum Dry Density, CBR=California Bearing Ratio OMC=Optimum Moisture Content, UCS=Unconfined Compressive Strength, WA=West African level, MA=Modified AASHTO level

average values) have the highest strength and stability, followed by the quartzite/quartz-schist derived soils while the migmatite-gneiss-derived soils (with the lowest average values) have the least strength and stability. The compaction characteristics indicate that the banded gneiss-derived soils (with the highest average MDD and lowest OMC values) exhibit the highest strength followed by quartzite/quartz-schist-derived soils while the soils derived from migmatite-gneiss (with the least average MDD and highest OMC values) exhibit the least strength.

Paired t-test

Significance of parent-rock group difference

Paired t-test analysis of results of engineering geological variables (such as MDD, OMC, CBR and amount of fines) reveals a strong influence of parent-rock factor. Genetically different soils exhibited varied compaction characteristics and degrees of degradation under compaction at both levels of compactive efforts used (Tables 2 - 4). The study also revealed some significant influence of parent-rock group difference on soaked CBR at OMC of samples compacted at both West African and Modified AASHTO levels(Tables 5).

Significance of energy of compaction group difference

Paired t-test analysis of values of Unconfined Compressive Strength (UCS) of the soils reveals a significant difference between UCS values for West African level and modified AASHTO level of compaction for each of the three genetic soils (Table 6). An analysis of grain-size distribution characteristics also shows some significant difference in percent increase in amount of fines for West African level and Modified level of compaction (Table 7).

Upon compaction, there was a particularly excessive breakdown of soil grains in samples of quartzite/quartz-schist-derived soils (Figures 3b and 3c). The migmatite gneiss-derived soils had proved the most mechanically stable among the studied soils, being the least susceptible to degradation under dynamic load. The observed increase in the amount of fines upon compaction, as the case is with soils developed on Quartzite/quart schist and banded gneiss, can be attributed to the binding effect of sesquioxide on smaller particles - a factor of high degree of leaching and lateritization.

Correlation and regression analysis

Regression analysis of determined parameters gave some useful regression models (Equations 1-8). Pearson correlation coefficient (r) revealed significant correlations between some pairs of engineering geological variables at 5% level of significance (i.e. a = 0.05).

Table 2: Significance of parent-rock group difference in the values of MDD

Parent rock (Group X)	Parent rock (Group Y)	t–in table	West African level		Modified AASHTO level	
			Computed t	Significance of parent rock group difference	Computed t	Significance of parent rock group difference
Quartzite/ Quartz-Schist	Banded Gneiss	2.132	1.65	Not Significant	1.21	Not Significant
Banded Gneiss	Migmatite -Gneiss	2.132	2.62	Fairly Significant	5.62	Strongly Significant
Migmatite -Gneiss	Quartzite/ Quartz-schist	2.132	4.13	Strongly Significant	3.52	Strongly Significant

Table 3: Significance of parent-rock group difference in the values of OMC

Parent rock (Group X)	Parent rock (Group Y)	t–in table	West African level		Modified AASHTO level	
			Computed t	Significance of parent rock group difference	Computed t	Significance of parent rock group difference
Quartzite/ Quartz-Schist	Banded Gneiss	2.132	0.41	Not Significant	0.64	Not Significant
Banded Gneiss	Migmatite -Gneiss	2.132	4.16	Strongly Significant	3.7	Strongly Significant
Migmatite -Gneiss	Quartzite/ Quartz-schist	2.132	2.31	Fairly Significant	2.24	Fairly Significant

Table 4: Significance of parent-rock group difference in the values of amount of fines

Parent rock (Group X)	Parent rock (Group Y)	t–in table	Computed t	Significance of parent rock group difference
Quartzite/ Quartz-Schist	Banded Gneiss	2.132	0.62	Not Significant
Banded Gneiss	Migmatite-Gneiss	2.132	6.01	Strongly Significant
Migmatite-Gneiss	Quartzite/ Quartz-schist	2.132	4.79	Strongly Significant

Table 5: Significance of parent-rock group difference in the values of CBR

Parent rock (Group X)	Parent rock (Group Y)	t–in table	West African level		Modified AASHTO level	
			Computed t	Significance of parent rock group difference	Computed t	Significance of parent rock group difference
Quartzite/ Quartz-Schist	Banded Gneiss	2.132	0.22	Not Significant	0.61	Not Significant
Banded Gneiss	Migmatite-Gneiss	2.132	3.142	Strongly Significant	4.58	Strongly Significant
Migmatite-Gneiss	Quartzite/ Quartz-schist	2.132	3.51	Strongly Significant	4.7	Strongly Significant

Table 6: Significance of level of compactive effort in values of UCS

Parent Rock	Unconfined compressive strength (Group X)	Unconfined compressive strength (Group Y)	t – in table	Computed-t	Significance of energy of compaction group difference
Quartzite/ Quartz schist	West African level	Modified AASHTO	2.132	4.95	Strongly Significant
Banded Gneiss	West African level	Modified AASHTO	2.132	2.33	Fairly Significant
Migmatite Gneiss	West African level	Modified AASHTO	2.132	2.73	Fairly Significant

Table 7: Influence of energy of compaction on amount of fines

Parent Rock	Natural soil	West African level of compaction		Modified AASHTO level of compaction	
	% fines	% fines	% Increase in fines	% fines	% Increase in fines
Quartzite/ Quartz schist	40	50	25	60	50
	30	47	56.67	50	83.33
	36	50	38.89	60	66.67
Banded Gneiss	36	43	19.44	46	27.78
	33	36	9.09	42	27.27
	31	36	16.13	38	22.58
Migmatite-Gneiss	54	63	16.67	68	25.93
	56	59	5.36	49	-
	67	79	17.91	83	23.88

Relationship between amount of fines (%) and compaction characteristics

The correlations established between the amount of fines and compaction characteristics are in agreement with Gidigasu (1972) on some Ghanaian soils. The relationship between the amount of fines (%) and Maximum Dry Density (MDD) at West African and modified AASHTO levels of compaction gave regression equations (1a) and (1b) with significant negative correlations (R^2 being 0.689 and 0.231) respectively.

$y_{MDD} = -3.158x_{fines} + 1906$ ……...(1a)

$y_{MDD} = -1.889x_{fines} + 2024$ ……...(1b)

On the relationship between the amount of fines and Optimum Moisture Content (OMC), regression equations (2a) and (2b) with significant positive correlations (R^2 being 0.467 and 0.150) were obtained respectively.

$y_{OMC} = 0.121x_{fines} + 14.18$ ………(2a)

$y_{OMC} = 0.047x_{fines} + 13.58$ ………(2b)

Association between amount of fines and soaked CBR gave regression models (3a) and (3b) with significant negative correlations R^2 being 0.485 and 0.461) respectively.

$y_{CBR} = -0.221x_{fines} + 26.6$ ……….(3a)

$y_{CBR} = -0.279x_{fines} + 38.46$ ……….(3b)

Relationship between amount of fines and unsoaked CBR resulted in regression models (4a) and (4b) with significant negative correlations (R^2 being 0.2966 and 0.3895) respectively.

$y_{CBR} = -0.187x_{fines} + 35.632$ ……….(4a)

$y_{CBR} = -0.3018x_{fines} + 50.132$ ……….(4b)

Relationship between amount of clay-size content in the fines and compaction characteristics

This study revealed some correlations between the clay-size content and compaction characteristics. The association between clay-size content and Maximum Dry Density (MDD) at West African and modified AASHTO levels of compaction gave regression equations (5a) and (5b) with significant negative correlations (R^2 being 0.6841 and 0.1295) respectively.

$y_{MDD} = -4.4422x_{clay\text{-}size} + 1926.1$ ……….(5a)

$y_{MDD} = -1.3432x_{clay\text{-}size} + 1975.2$ ………. (5b)

Relationship between the clay-size content and Optimum Moisture Content (OMC) gave regression models (6a) and (6b) with significant positive correlations (R^2 being 0.5146 and 0.077) respectively.

$y_{OMC} = 0.1398x_{clay\text{-}size} + 15.006$ ………(6a)

$y_{OMC} = 0.0323x_{clay\text{-}size} + 14.871$ ………. (6b)

Relationship between clay-size content and consistency limits

This study revealed some correlations between the clay-size content and consistency limits. The association between clay-size content and liquid limit and plastic limit gave regression equations (7a) and (7b) with negative correlations (R^2 being 0.0024 and 0.0916 respectively) while Plasticity index gave regression equation (7c) with significant positive correlation (R^2 being 0.0581).

$y_{liquid\text{-}limit} = -0.0492x_{clay\text{-}size} + 46.972$ ………(7a)

$y_{plastic\text{-}limit} = 0.1836x_{clay\text{-}size} + 27.95$ ………(7b)

$y_{plasticity\ index} = 0.1343x_{clay\text{-}size} + 19.023$ ……….(7c)

Relationship between Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR)

Association between Unconfined Compressive Strength (UCS) and un-soaked CBR at West African and modified AASHTO levels of compaction gave regression equations (8a) and (8b) with significant positive correlations (R^2 being 0.219 and 0.213) respectively. This agrees with the findings of Adeyemi (1992).

$y_{UCS} = 3.365x_{CBR} + 192.3$ ………(8a)

$y_{UCS} = 6.491x_{CBR} + 247.9$ ………(8b)

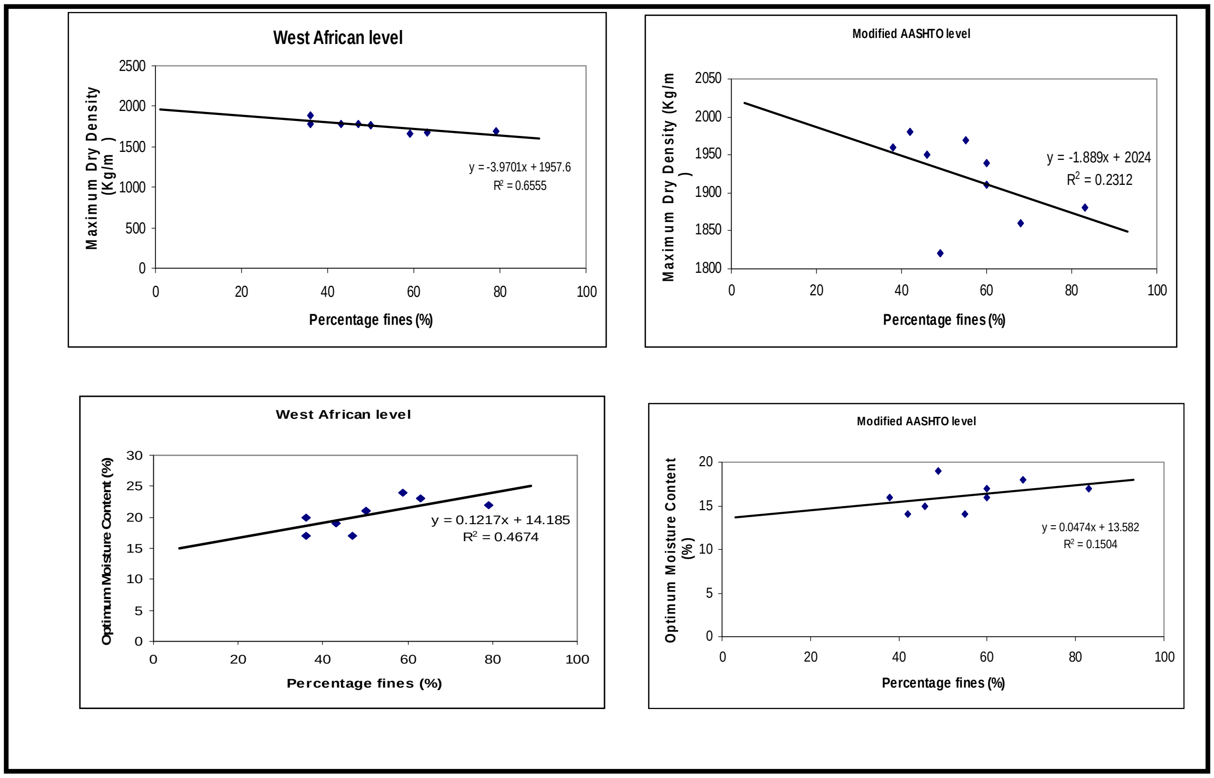


Figure 7: Correlation between amount of fines and Compaction characteristics

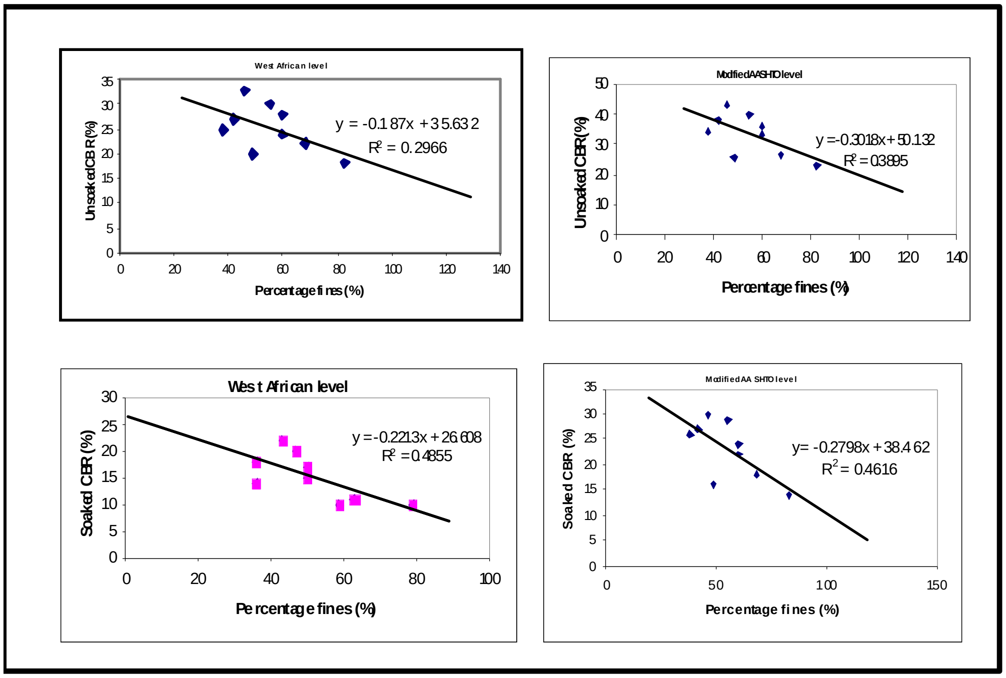


Figure 8: Correlation between amount of fines and bearing capacity

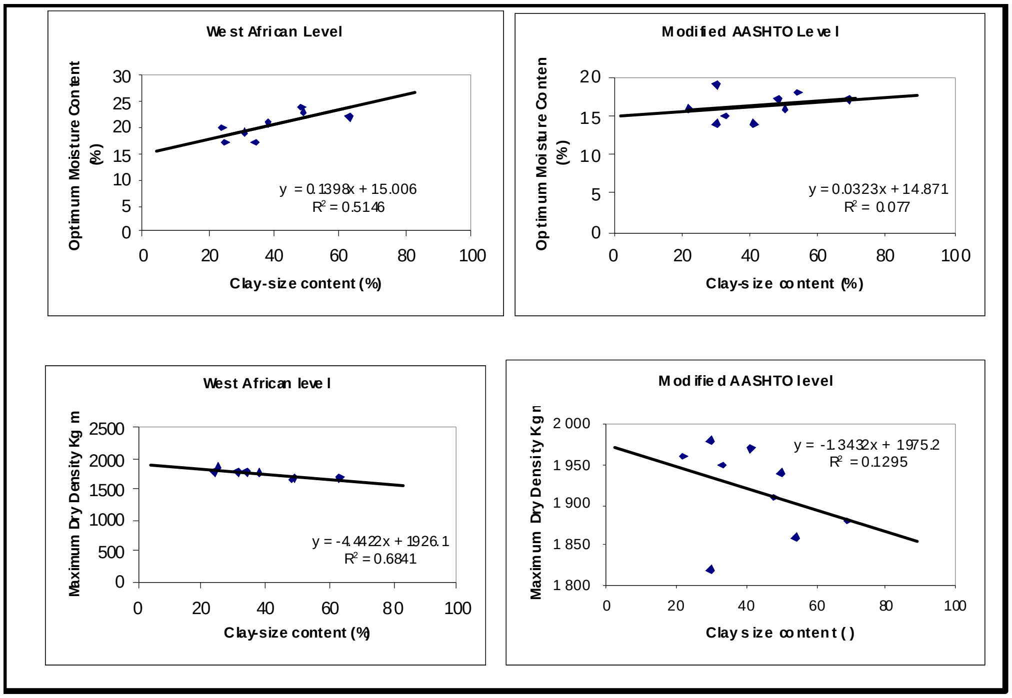


Figure 9: Correlation between Clay-size content in fines and compaction characteristics

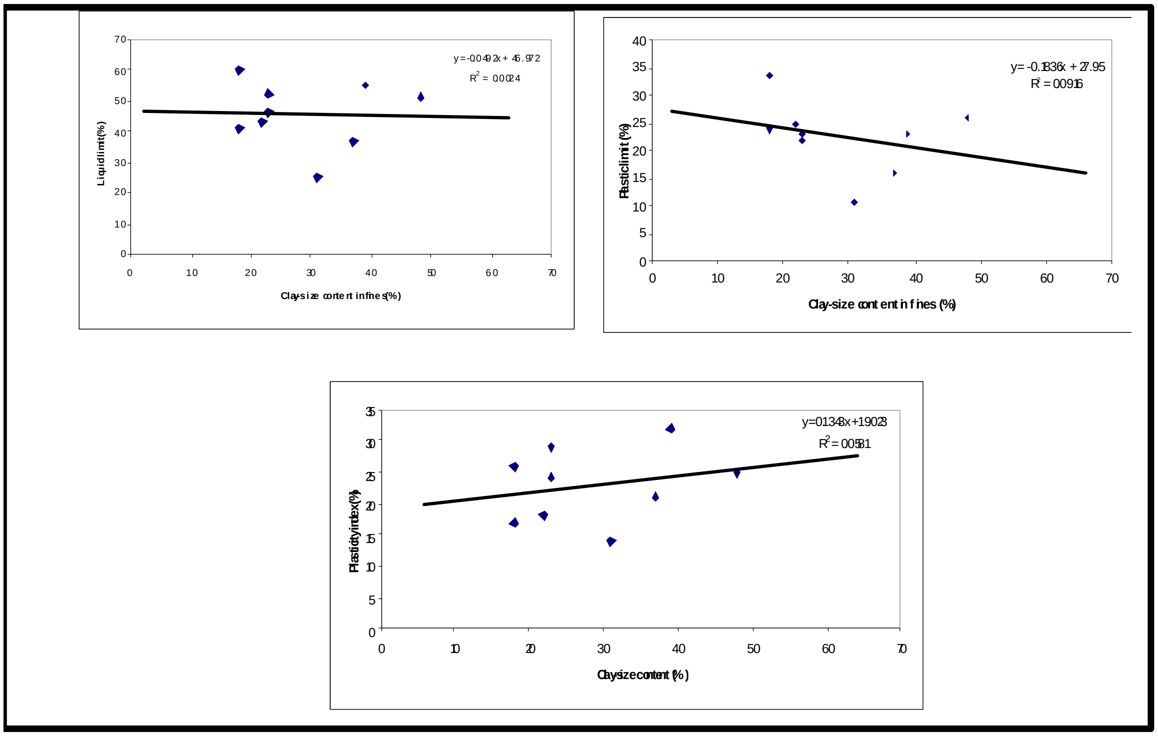


Figure 10: Correlation between Clay-size content in fines and Consistency limits

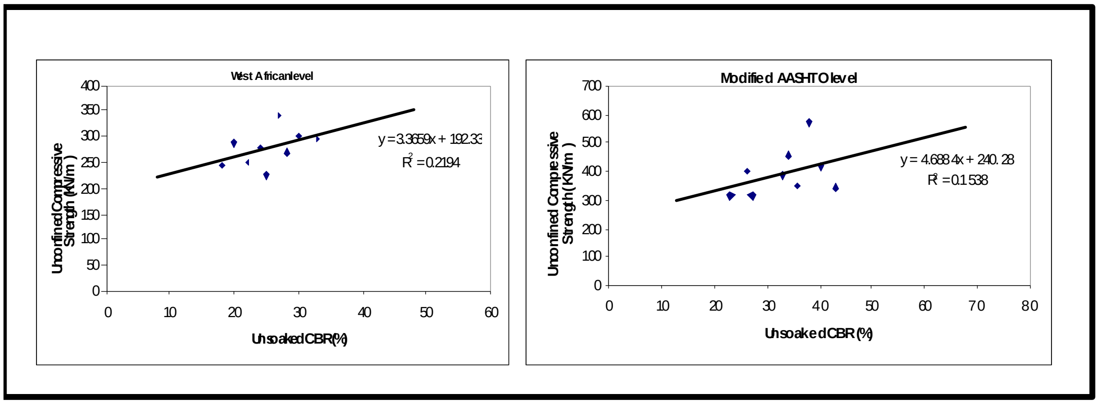


Figure 11: Correlation between UCS and unsoaked CBR

CONCLUSIONS

The grading characteristics suggest that the banded-gneiss- and quartzite/quartz-schist-derived soils may be adjudged poor to fair sub-base and subgrade materials. The banded-gneiss-derived soils which exhibited the least clay-size content, least linear shrinkage and highest Maximum Dry Density can be adjudged the best engineering soil group among the three groups. The modified AASHTO level of compactive effort produced better compacted soils (as evident in the lower values of OMC, and higher values of MDD, CBR and UCS) than the West African level. Based on Madedor's (1983) maximum value of 8% for linear shrinkage, the soils could pose only little compaction problem.

The study revealed that the pedogenic factor of parent rock significantly influenced the engineering index properties of the lateritic soils under investigation. Apart from the parent rock factor, both the level of compactive effort and the amount of fines (especially the clay-size fractions) have been found to play significant roles in the strength characteristics of the soils. The particle-size distribution characteristics of the soils shows that the soils derived from banded gneiss are the most sandy, followed by soils from quartzite/quartz-schist while soils from migmatitie-gneiss are the least sandy, indicating a decreasing degree of leaching and weathering on the one hand and a reflection of the textural characteristics of the parent-rock types on the other hand. The specific gravity values indicate that the banded gneiss-derived soils had the highest degree of lateritization, followed by the quartzite/quartz-schist, while the soils derived from migmatite-gneiss were the least lateritized.

From the Unconfined Compressive Strength and California Bearing Ratio (soaked and unsoaked) values at both modified AASHTO and West African levels of compactivew efforts used, the banded gneiss-derived soils would exhibit the highest strength and stability, followed by the quartzite/quartz-schist-derived soils while the migmatite-gneiss-derived soils would exhibit the least strength and stability. From the compaction characteristics, the banded gneiss-derived soils (with the highest average MDD and lowest OMC values) exhibit the highest strength, followed by quartzite/quartz-schist-derived soils while the migmatite-gneiss-derived soils exhibit the least strength. The banded gneiss-derived soils with the least linear shrinkage values could be adjudged the best highway construction material, followed by the migmatite-gneiss-derived soils. The quartzite/quartz-schist-derived soils with the highest linear shrinkage values could be the worst.

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