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Geotechnical Profiling and Experimental Characterization of Lateritic Soils in Abuja Area Councils: A Geographic Analysis

Emmanuel E. NDUBUBA[1], Franklyn O. NNEBE[2], Emmanuel ONCHE[3]

[1]*Department of Civil Engineering, University of Abuja, Abuja, Nigeria*
[2]*Department of Civil Engineering, Nile University, Abuja, Nigeria*
[3]*Department of Mechanical Engineering, University of Abuja, Abuja, Nigeria*

[1]*emmanuel.ndububa@uniabuja.edu.ng*, [2]*nnebe.franklyn@nileuniversity.edu.ng*, [3]*emmanuel.onche@uniabuja.edu.ng*

Abstract
Lateritic soils are highly weathered soils formed in the tropical regions through environmental conditions that favor the formation of iron, aluminum, manganese and titanium oxides. These conditions differ by region leading to the importance of assessing the lateritic soils found in Abuja and their applications. An investigation was carried out on the geochemical and engineering properties of lateritic soil within the six Area Councils of Abuja comprising of Abaji, AMAC, Bwari, Gwagwalada, Kuje and Kwali for its engineering characterization. A total of 24 samples were taken from laterite deposits in each area council and had a total of 168 tests carried out on them for this research. The samples were subjected to X-Ray Fluorescence tests, Grain size distribution, Atterberg limit, Compaction and California Bearing Ratio test in BS and USCS standards. The test results on soil samples based on estimates indicated 75% high Sesquioxide while the remaining 25% were low sesquioxides found at abaji and Kwali; 100% poorly graded and Clayey sand in nature; 66.7% at low plasticity and >5 CBR value while the remaining 33.3% were at intermediate plasticity and <5 CBR value found at AMAC and Kuje; and 100% MDD > 0.04 and OMC < 18. Based on applications, comparisons with local standards were also made, Abuja lateritic soils were found to be favourable which fall within acceptable limits for less demanding general constructions and unacceptable for more demanding constructions such as highway where emphasis is made on very low plasticity index and high CBR value.

Keywords: *Lateritic soils, characterization, sesquioxide, Engineering, and geography.*

1.0 Introduction

In the advancement of modern civilization, civil engineering constructions has evolved to employ more adaptive uses of site materials with efficiency and economy in mind. Common understanding of the regional groundwater conditions and site materials such as laterite, sand, and gravel have a great role to play as they are regarded as one of the main criteria to be considered when planning for a construction. It is significantly impactful for the economy and efficiency in road construction, where the site materials used for subgrade, subbase and base materials can be considered on a large, infinite and time boundless scale at the planning stage. In building construction though on a limited scale, river sand or well graded sand is predominantly used in all high value construction encompassing concrete mixing and site filling which leads to higher budget cost [1]. The most common classification of site materials under soil types are gravel, sand, silt, and clay, which is typically based on particle size. The standards for this classification come from various organizations like American standard for testing and materials (ASTM), British Codes (BS), European Codes (EUROCODES) and unified soil classification system (USCS). Similarly, the key difference between laterite and lateritic soils lies in their particle size: lateritic soils are fine-grained materials, whereas laterite contains larger particles and has a gravel component. For laterite and lateritic soils classification, the Silica-Sesquioxide (S-S) ratio is used [2] [3]. The S-S Ratio Classification groups soil into three types of lateritic soils namely High sesquioxides, low sesquioxides and non-lateritic soils [4]. Deducting the most likely engineering properties of site conditions and materials which enable the engineers and other construction team involved to plan ahead and select the best appropriate materials/design methods for constructions before testing is carried out on site is also necessary and vital. Through this research knowledge regarding the engineering applications and possible locations of High sesquioxides and low sesquioxides is developed based on minimum average data estimates so as to ascertain the engineering properties of lateritic soils in six Area Councils in Abuja, Nigeria.

2.0 Methodology

2.1 Materials

A geographical assessment pattern was developed based on the derivatives where four laterite soil samples were collected from large existing laterite deposits with their corresponding geological coordinates

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well detailed within each of the six area councils of Abuja. The accuracy of this study is based on the 4th derivative so as to get representation of the soil sample in each of the are councils.

2.2 Preparation of Lateritic Soil Samples

In each borrow pit, samples were collected at several sections, (0.5m, 1.0m, and 1.5m), mixed together (about 5kg in all), and packed in polyethene bags for laboratory analysis. The samples were taken to chemistry lab where geochemical test for the investigation and verification of samples to be lateritic soil was done Silica-Sesquioxide (S-S) ratio. After which they were taken to an engineering lab for geotechnical tests conducted in accordance with British Standard (BS 1377).

2.3 Geochemical Characterization of samples

Geochemical tests were carried out for the chemical oxide compositions and Mineral content of sample soils. X-ray Fluorescence Spectrometry (XRF) test was adopted and utilized for determining oxide composition of soil samples to identify scientifically if the samples were truly laterite soil based on Silica-Sesquioxide (S-S) ratio.

The XRF test was carried out in X-Ray Spectrometer model EDX-700HS where samples were dried and grinded till it passes through 80µm sieve size. Discs of samples were placed in the model EDX-700HS and exposed to x-rays, the energy measured was then used to determine the chemical oxide compositions and Mineral content of sample soils.

2.4 Geotechnical Characterization of samples

The Geotechnical tests upon which the samples were subjected to include Grain size distribution analysis, Atterberg limit tests, Compaction test and California Bearing ratio (CBR) test for engineering properties of lateritic soils.

2.4.1 Grain size distribution analysis

The Grain size distribution for the coarse and fine particles of the soil samples were determined through sieve grain size test and sedimentation using hydrometer.

The sieve grain size test was conducted using a mechanical sieve shaker where weighed crushed soil samples were place in the 4mm sieve size and shaken. The weight of the sieve sizes from 4mm to 0.075mm with and without soil was calculated and used for the grain size distribution of the course particles. The remaining soil sample left on the pan from the sieve grain size was subjected to sedimentation test. In the sedimentation test, the hydrometer at a given time t, measured the specific gravity of the suspension near the vicinity of its bulb (depth L) upon which the percentage by weight finer was calculated. Stoke's Law was then utilized to derive the diameter of the particles grain size distribution of the fine particles.

2.4.2 Atterberg limits

Atterberg limits also known as consistency limits between solid and liquid states of soil was determined through Casagrande's test and hand roll tests.

The Casagrande test involved placing a soil paste made of very fine soil sample and water in the Casagrande apparatus, levelling, grooving and adding blows till the groove closes. Then part of the paste was taken and rolled into a thread of 3mm thick or till it breaks, weighed and then dried in an oven. The weight of soil sample with and without water at different stages were assessed to determine the plastic and liquid limits.

2.4.3 Proctor compaction test (standard)

The Proctor Compaction Test was utilized to determine the compressibility of the soil samples. The Proctor Compaction Test involved weighing and placing sieved soil sample in a mould, adding water steadily while compacting 25 times for 3 cumulative layers. The weight of the soil, mould with and without water were measured to attain the optimum moisture content and maximum dry density.

2.4.4 California bearing ratio (CBR) test

The California Bearing Proportion Test (CBR Test) was carried out assess subgrade strength of soil samples for further engineering applications. In this test, the soil sample was placed and compacted in a mould beneath the penetration piston and stack load of 10lb was placed on top. The stack load penetration at 0.5, 1.0, 2.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, and 12.5mm were noted. The CBR estimate was then determined through charts of penetrations against penetration loads.

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3.0 Results and Discussion

3.1 Materials

The twenty-four (24) soil samples were collected from lateritic soil deposits located at each of the six area councils of Abuja namely Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW). All soil samples used in this study were fine-grained and verified to be lateritic soils and not laterites or non-laterites through oxide compositions. They were also reddish-brown in color and had their physical and chemical compositions confirmed scientifically with XRF geochemical test and grain size distribution tests. The results of the analysis of other geotechnical parameters of the soil samples are presented and subsequently discussed.

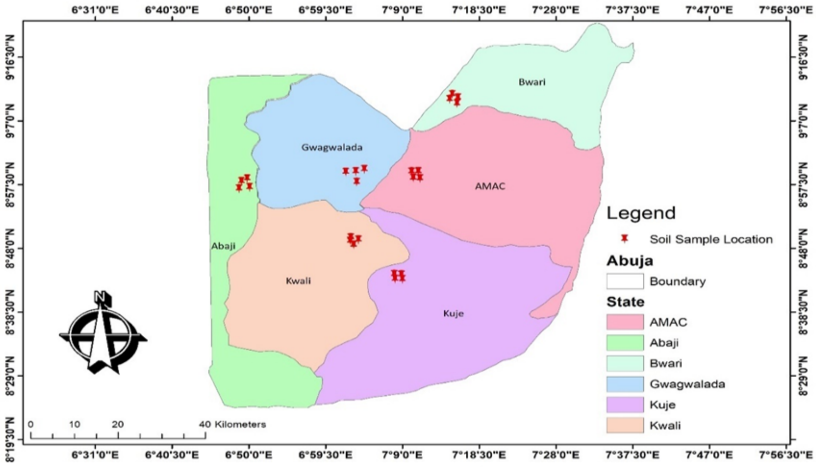

Figure 1: Abuja map showing specific sample locations (ArcGIS software)

The samples were collected from massive lateritic soil deposits beyond 500 square meters in land size [5]. The specific areas include Garki in AMAC, Katipe in Bwari; Gui at Gwagwalada; Dobi-chikuku in Kuje; and Yangoji in Kwali area council, as can be seen in the map of Fig 1.

3.2 X-ray Fluorescence (XRF) Test

To classify Lateritic soils based on S-S ratio system, Geo-chemical test (XRF) was carried out [6]. The X-ray Fluorescence (XRF) test conducted on the samples scientifically classified the soils into three categories namely, high Sesquioxide, low Sesquioxide and non-lateritic soil as shown in Fig 2.

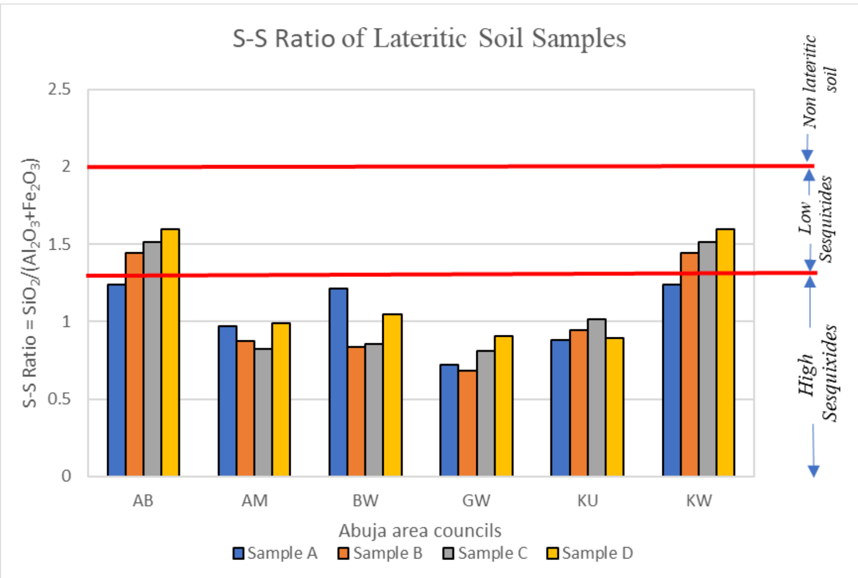

Figure 2 Graph showing S-S Ratio of Lateritic Soil Samples

Due to the findings that 75% of the primary elements required for classification of lateritic soil using s-s ratio falls under a ratio of 1.33. The 24 soil samples collected from the six area councils of Abuja namely Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) were assessed to be lateritic soils and were found to have S-S ratios ranging from 1.2 to 1.6, 0.8 to 1.0, 0.8 to 1.2, 0.6 to 0.9, 0.8 to 1.0 and 1.2

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to 1.6 respectively. It was scientifically proven that more than 75% of the samples were of high sesquioxide category of lateritic soil, hence Abuja lateritic soils can be termed as roughly high sesquioxide based on results of this research as can be seen in Fig 2.

The large number of high sesquioxides upon data interpretation is attributed to the local weathering nature of the region, inferring that the weathering conditions of Abuja area councils' tilts toward the formation of high sesquioxides [7] [8].

3.3 Geotechnical Characterization of samples

The samples were also subjected to Geotechnical tests such as Grain size distribution analysis, Atterberg limit tests, Compaction test and California Bearing Ratio (CBR) test for engineering properties of lateritic soils [9] [10].

3.3.1 Grain size distribution analysis

Particle size distribution analysis was carried out for this classification using sieve grain analysis (coarse grains comprising of sand only) and hydrometer analysis (fine grains comprising of silt and clay) according to Table 2.1. In summary, the distribution of the properties of samples A through D were analyzed by mechanical sieving analysis for a particle size range above 200µm sieve following with hydrometer that was performed on samples with range below 200µm [11].

To represent each area council, the average estimates from the four different samples from each area council was used and the gradation curve of these average estimates is shown in Fig 3. The primary results of the Grain size distribution analysis for samples A, B, C and D of the 24 soil samples collected from the six area councils of Abuja; Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) shows that the percent of fines ranged from 3.8 to 13.8, 2.5 to 5.5, 3.9 to 14.4, 6.8 to 13.3, 2.2 to 5.4 and 1.6 to 2.4; And the amount of coarse fraction are 86.2 to 96.5, 94.4 to 97.5, 85.6 to 96.5, 86.7 to 93.2, 94.5 to 97.8 and 94.5 to 97.8 respectively. The fines category was further sized into silt and clay, with silt having 3.8 to 13.8, 2.5 to 5.5, 3.9 to 14.4, 6.8 to 13.3, 2.2 to 5.4 and 1.6 to 2.4; and clay ranging from 0.005 to 0.011, 0.03 to 0.09, 0.06 to 0.027, 0.014 to 0.026, 0.001 to 0.007 and 0.006 to 0.011.

This was done in accordance with UCS standard which states that any particle with diameter greater than 4.75mm is gravel, between 4.75-0.075mm is sand, from 0.075 – 0.002mm is silt and less than 0.002mm is considered as clay. The tick read vertical line on the graph show the boundary of each compartment. This result shows that all the samples are poorly graded and of "Clayey sand" nature, with negligible amount of silt and clay which is a positive benefit for construction purposes.

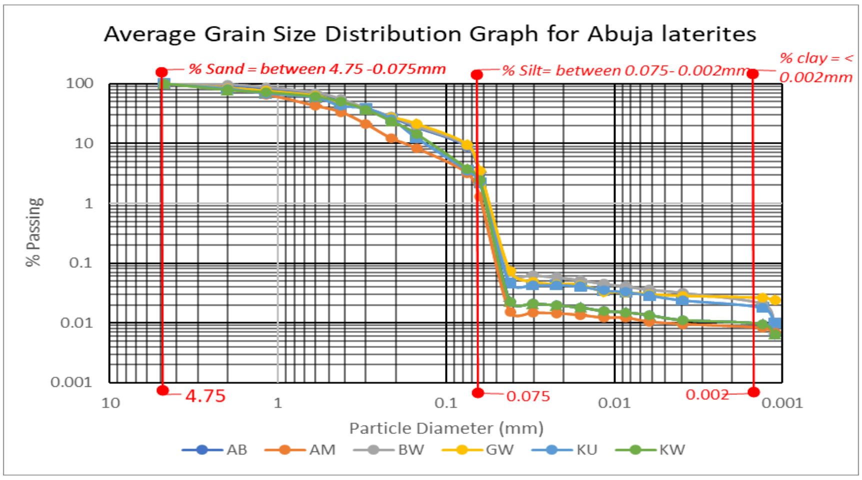

Figure 3 Average Grain Size Distribution Graph for Abuja lateritic soil

Fig 3 presents an illustration of the gradation curve based on the average estimates of each area council. This indicated that no gradation curve was concave in nature and all lateritic soil samples can be graded as poorly graded soils under unified soil classification system. Other parameters such as percentage of gravel, sand, silt and clay: D10, D30 and D60 values; coefficient of uniformity and curvature; and unified soil classification system remarks for each sample from each area council were also determined.

3.3.2 Atterberg limits analysis

The Atterberg Restrain or Limit test was performed on the soil tests in aim to decide the consistency of the fine-grained due to assortment of water substance. The two limits related with versatility of soil are Liquid Limit and Plastic Limit. These two were utilized to calculate the Plasticity List (PI) which measures the

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affectability of the soil to changes in its dampness substance [12] [12] [13]. The comes about of Atterberg consistency limits tests carried out on lateritic soil tests A, B, C and D of the 24 soil tests collected from the six area councils of Abuja; Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) include; Plasticity indices ranging from 7.2 to 19.6, 10.9 to 24.2, 8.3 to 15.3, 6.6 to 14.7, 9.8 to 20.5 and 7.0 to 23.0; Plastic limit ranging from 17.1 to 23.3, 17.2 to 27.5, 18.1 to 23.4, 18.0 to 25.2, 18.3 to 26.6 and 8 to 24.0; and Liquid limit ranging from 26.3 to 42.5, 34.0 to 44.2, 26.1 to 33.3, 26.1 to 33.3, 35.8 to 47.1 and 22.0 to 42.0 respectively. This data is presented in a chart in Fig 4.

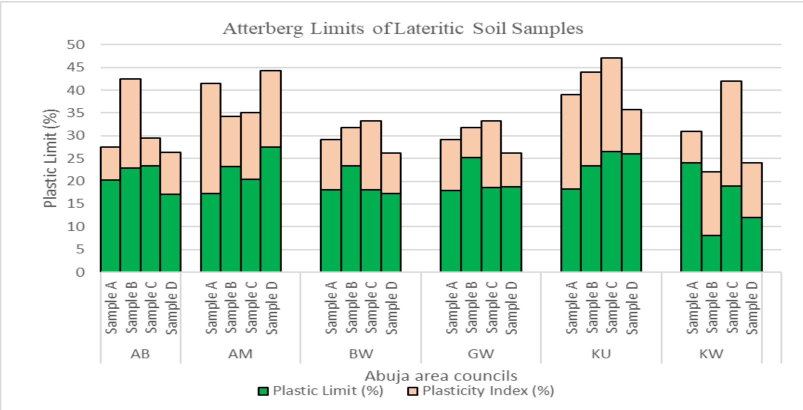

Figure 4 Graph showing Atterberg limit for all 24 samples of lateritic soil

Fig 4 illustrates where laterite soils with liquid limit less than 35% signifies low plasticity, between 35-50% signifies intermediate plasticity, between 50-70% high plasticity and between 70-90% signifies very high plasticity and greater than 90% signifies extremely high plasticity. Hence, it is scientifically proven from the values of Atterberg test results of the lateritic soil samples that out of the six are councils; Abaji (AB), Bwari (BW), Gwagwalada (GW), and Kwali (KW) are low plasticity lateritic soils which are very good in construction as they fall within acceptable limits of swell and shrinkage with negligible effects in building; while AMAC (AM) and Kuje (KU) are intermediate plasticity lateritic soils and may have potential to swell or recoil and are subsequently anticipated to stand the hazard of falling flat when utilized as development materials.

For applications in construction, the 24 soil samples collected from each of the six area councils of Abuja namely Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) were assessed in comparison to Nigerian Standards (NS). The Nigerian standards used were NS-1 "General specification for roads and bridges, Vol II, Abuja, Nigeria: Federal Ministry of Works and Housing, 1997" and NS-2 "Highway manual part 1 design Volume 3: pavement and material design, Federal Ministry of Works, Federal Republic of Nigeria 2013" [14] [15]. These comparisons were made with NS-1 and NS-2 by means of the lesser of their arithmetic average and modal average parameters based on area councils. This data is presented in table 1 and 2.

Table 1: Comparisons with NS-1

PARA-METER	NS-1	AVERAGE ESTIMATES OF ABUJA AREA COUNCILS					
		AB	AM	BW	GW	KU	KW
GENERAL FILL AND EMBANKMENT							
LL	< 40	P	P	P	P	F	P
PI	< 20	F	F	P	P	P	P
Quality		Good	Good	Good	Good	Good	Good
SUB-BASE COURSE							
LL	< 35	P	F	P	P	F	P
PI	< 16	F	F	P	P	P	P
Quality		Good	Poor	Good	Good	Good	Good
BASE COURSE							
LL	< 30	P	F	P	F	F	P
PI	< 13	F	F	P	P	F	F
Quality		Good	Poor	Good	Good	Poor	Good
LEGEND	F = FAIL		G = GOOD				

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Table 2: Comparisons with NS-2

PARAMETER	NS-2	AVERAGE ESTIMATES OF ABUJA AREA COUNCILS					
		AB	AM	BW	GW	KU	KW
SUB-BASE COURSE							
LL	< 25	F	F	F	F	F	F
PI	< 6	F	F	F	F	F	F
Quality		Poor	Poor	Poor	Poor	Poor	Poor
BASE COURSE							
LL	< 25	F	F	F	F	F	F
PI	< NP	-	-	-	-	-	-
Quality		Poor	Poor	Poor	Poor	Poor	Poor
LEGEND		F = FAIL			G = GOOD		

According to Table 1, lateritic soils in Abuja can be seen to have generally good plasticity conditions that are favourable in construction, but from Table 2 Abuja lateritic soils have generally good plasticity conditions can be seen as unsuitable for highway constructions.

3.3.3 Compaction test analysis

Compaction test was carried out on all the test samples and the Optimum Moisture (OMC) that is required to attain the maximum density was determined. Shear quality of laterite decreases with expanding molding water substance, hence compacting laterite soil on the dry side of optimum, leads to the achievement of a greater shear [16] [17]. The Compaction test results on lateritic soil samples A, B, C and D of the 24 soil samples collected from the six area councils of Abuja; Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) include; Maximum Dry Density (MDD) ranging from 1.6 to 1.8, 1.9 to 2.1, 1.7 to 1.8, 1.7 to 1.8, 1.6 to 1.8 and 1.6 to 1.8; and Optimum Moisture Content (OMC) ranging from 17.2 to 23.5, 10.1 to 17.8, 17.3 to 17.9, 16.5 to 17.9, 18.0 to 23.0 and 16.2 to 18.0 respectively are shown in Table 4.9. This data is also presented in a chart in Fig 5 and 6.

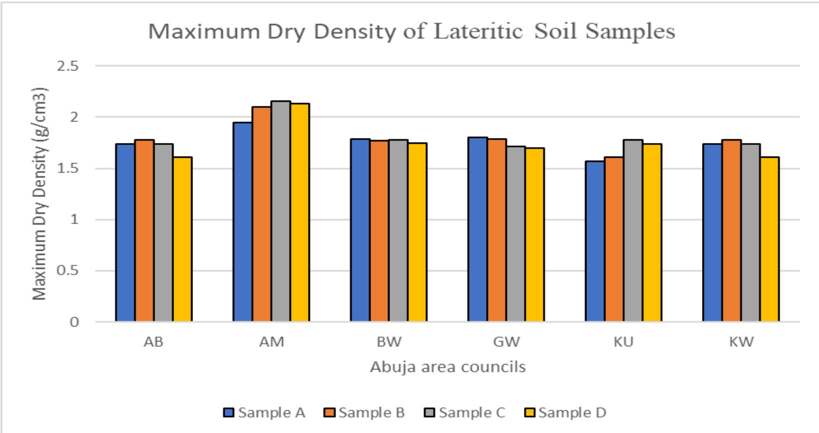

Figure 5 Graph showing MDD for all 24 samples of lateritic soil

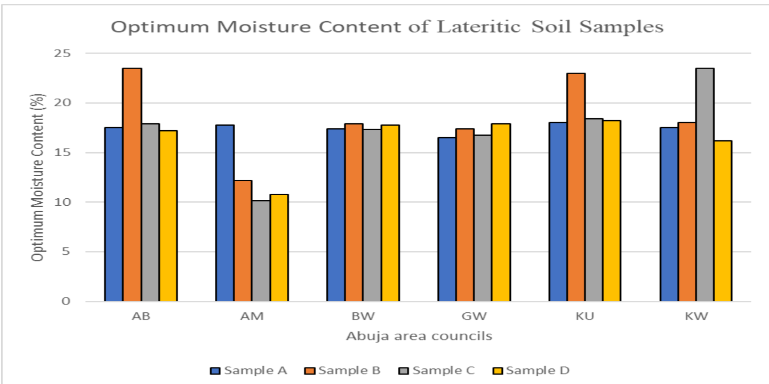

Figure 6 Graph showing OMC for all 24 samples of lateritic soil

The remarks and assessment in the compaction test were based on lateritic soils having MDD > 0.04 and OMC < 18,

3.3.4 California Bearing Ratio Test Analysis

California Bearing Ration (CBR) un-soaked was conducted in order to determine the strength of the lateritic soil. The results obtained from the CBR are given in Fig 4.8. The CBR values were calculated for penetration of 2.5mm and 5mm from the graph after correction at the point of curve. The higher value was adopted for the CRB of the said sample. The CBR values of the lateritic soil samples A, B, C and D of the 24 soil samples collected from the six area councils of Abuja; Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) ranges from 3.2 to 7.3, 0.3 to 1.1, 5.4 to 6.8, 5.0 to 5.9, 0.7 to 1.9 and 3.3 to 7.3 respectively.

The assessment was carried out under the conditions of CBR values less than 5 as poor materials, 5 – 15 as fair construction materials and greater than 20 as good construction materials [18]. The resulting assessment showed that AMAC and Kuje having CBR less than 5 generally have lateritic soil with poor CBR values while Abaji, Bwari, Gwagwalada and Kwali have favourable and fair CBR value range are a better fit for construction within the geographical region of Abuja.

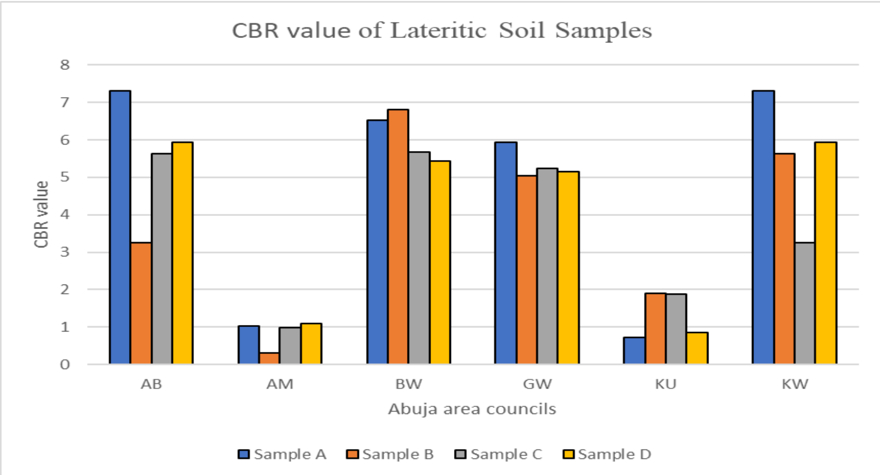

Figure 7: Graph showing CBR for all 24 samples of lateritic soil

The data shown in Fig 7 for samples A, B, C and D of the 24 soil samples collected from the six area councils of Abuja; Abaji (AB), Bwari (BW), Gwagwalada (GW), and Kwali (KW) have CBR values greater than 5 which are very good in construction as they fall within acceptable limits; while AMAC (AM) and Kuje (KU) having low CBR values less than 3 are very poor and susceptible to differential settlement.

The data shown in Fig 7 can also be collaborated with the sieve analysis and Atterberg limits; For Abaji (AB), Bwari (BW), Gwagwalada (GW), and Kwali (KW), the lateritic soil sample passing through the sieve 200 (0.075μm) in the sieve analysis less than 50% which suggested that the soil is Coarse-grained soil and should have a high CBR value (validates the >5 CBR value); while as for AMAC (AM) and Kuje (KU), despite having the lateritic soil sample passing through the sieve 200 (0.075μm) in the sieve analysis at less than 50% which suggested that the soil is Coarse-grained soil, it has a low CBR value which signified the presence of OH soil (Organic soil of high plasticity). From Fig 4 AMAC (AM) and Kuje (KU) are also the only areas capable with potential to swell or shrink due plasticity (with liquid limit ≥35) [19] [20].

For applications in construction, the 24 soil samples collected from each of the six area councils of Abuja namely Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW) were assessed in comparison to Nigerian Standards (NS). The Nigerian standards used were NS-1 "General specification for roads and bridges, Vol II, Abuja, Nigeria: Federal Ministry of Works and Housing, 1997" and NS-2 "Highway manual part 1 design Volume 3: pavement and material design, Federal Ministry of Works, Federal Republic of Nigeria 2013". These comparisons were made with NS-1 and NS-2 by means of the lesser of their arithmetic average and modal average parameters based on area councils. This data is presented in Table 3.

Table 3: Comparisons with NS-1 and NS-2

PARAMETER	NS-1	AVERAGE ESTIMATES OF ABUJA AREA COUNCILS					
		AB	AM	BW	GW	KU	KW
GENERAL FILL, EMBANKMENT, SUB-BASE AND BASE COURSE							
CBR	> 3	P	F	P	P	F	P
Quality		Good	Poor	Good	Good	Poor	Good

PARAMETER	NS-2						
SUB-BASE AND BASE COURSE							
CBR minimum	> 20	F	F	F	F	F	F
Quality		Poor	Poor	Poor	Poor	Poor	Poor
BASE COURSE							
CBR minimum	> 80	F	F	F	F	F	F
Quality		Poor	Poor	Poor	Poor	Poor	Poor
LEGEND		F = FAIL		G = GOOD			

Based on the assessments in Table 3, the CBR values of lateritic soil can be said to be generally small and will need stabilization for higher traffic loads. The CBR values at AMAC and Kuje were seen to be the lowest when compared with other area councils. Hence, it can be concluded that lateritic soils are more favorable to use in general fill, embankment, sub-base and base course with light traffic or loading according to NS-1 comparison. While lateritic soils without modifications cannot be used in highway construction with heavy traffic or loading according to NS-2 comparison.

4.0 Conclusion

From the investigation of the geochemical and engineering properties of lateritic soil samples taken from each of the six area councils of Abuja namely Abaji (AB), AMAC (AM), Bwari (BW), Gwagwalada (GW), Kuje (KU) and Kwali (KW), the following conclusion were made

i. Based on S-S ratio, low sesquioxides can be predominantly found in Abaji (AB) and Kwali (KW); and high sesquioxides can be predominantly found in AMAC (AM), Bwari (BW), Gwagwalada (GW) and Kuje (KU).
ii. Based on USCS, lateritic soil in Abuja generally tends to be "Clayey sand" or "Silty Sand" in a ratio of 4:1 respectively.
iii. Lateritic soil in Abaji (AB), Bwari (BW), Gwagwalada (GW), and Kwali (KW) are low plasticity lateritic soils while AMAC (AM) and Kuje (KU) are intermediate plasticity lateritic soils
iv. The Lateritic soils in Abuja have MDD and OMC ranging from 1.5 to 1.9 and 16.0 to 18.0 respectively falling within satisfactory limits to be used as construction materials.
v. Abaji (AB), Bwari (BW), Gwagwalada (GW), and Kwali (KW) have CBR values greater than 5 which are very good in construction as they fall within acceptable limits; while AMAC (AM) and Kuje (KU) having low CBR values less than 3, are very poor and susceptible to differential settlement.
vi. The performance of Abuja lateritic soils in NS-1 comparison were satisfactory, except for AM and KU lateritic soils having high values of liquid and plastic limits considered as poor foundation materials.
vii. The performance of Abuja lateritic soils in NS-2 comparison were very dis-satisfactory and are found to be very poor highway construction materials.
viii. The lateritic soil found in Abuja are concluded to be suitable for general constructions, filling, housing and low traffic roads.
ix. The lateritic soil found in Abuja are concluded to be not suitable for highway constructions or roadPPs with high traffic loads unless modified to meet the desired requirements.

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