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RESEARCH ARTICLE

The Lateritic Potential of Soils Developed over Enugu Shale for Civil Engineering Construction in Enugu and Environs

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ABSTRACT

The increasing cost associated with high-quality construction material occasioned by the inflation and unstable economic policies of the government of Nigeria has led to the need for the use of available local soils and soils developed over Enugu Shale in civil engineering work in Enugu and environs. The need for adequate evaluation of the suitability of the soils developed over Enugu Shale for its use in engineering construction cannot be overemphasized to prevent the failure of engineering structures. The Physico-chemical properties of soils developed over Enugu Shale were evaluated to understand its potential as a laterite. A total of twenty soil samples were collected and tested for X-Ray Fluorescence (XRF) and Atterberg's limits. The XRF test revealed that the soil samples are mostly dominated by elemental oxides of SiO2, Al2O3 and Fe2O3 ranging from (50.4-84.98%), (6.26-28.23%) and (0.98-12.25%) respectively while the Atterberg's limits revealed a liquid limit range of (22-66%) and plasticity index range of (0-39%). The obtained results show that elemental oxides can significantly affect the swelling characteristics of lateritic soils in Enugu and environs. The results equally show the non-viability of the studied soil as laterites.

***Keywords**: Lateritic Potential of Soils; Civil Engineering Construction; Plasticity Index; Enugu*

Introduction

Among all the important groups of the tropical and subtropical soils of the world, the laterite soils occupy a very important place, in regards to their extensive occurrence, use and peculiar properties. The economical point of view of laterite soils is important to the world because of their good tilth and excellent drain ability. From a geotechnical point of view of lateritic soils, there are confined to engineering properties of soils, especially those of importance in low-cost road construction. Road construction is an important infrastructure for the development of any country. Good roads provide access to the movement of goods and humans. Many stakeholders in the transportation industries have attributed road accidents majorly due to road failures (Wazoh et al. 2016). In tropical regions of the world, lateritic soils are used as fill materials for road construction (Lar et al. 2011). Lateritic soils contain chemical compositions like Iron oxides and Alumina sesquioxides with little silica contents. Emmanuel et al. (2021), Amadi et al. (2015) and Abubakar (2006) reported the need to understand the engineering properties of lateritic soils such as swelling/shrinkage phenomena to determine the damages the lateritic soils may pose to road construction. Wrong application of geologic materials such as lateritic soils by Construction companies can result in road failure and eventually loss of lives and properties (Oke et al. 2009, Nwankwoala, et al. 2014). Most tropically weathered red residual soils are regarded as lateritic soils. Most lateritic soils contain an appreciable quantity of clay fraction. Under some favourable conditions, tropical weathering processes may be so intense and may continue so long that even the clay minerals, which are primarily hydrous aluminium silicates, are destroyed. If the weathering is continued, the silica may be leached entirely and the remaining geological materials will consist of aluminium

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oxides such as gibbsite, or hydrous iron oxide such as limonite or goethite derived from Iron. This process is regarded as lateralization. The extent to which a residual soil has been lateralized may be measured by the ratio of silica, SiO_2, remaining in the soil to the amount of Fe_2O_3 and Al_2O_3 that has accumulated over time. This is known as silica sesquioxide ratio ($^{SiO2}/_{Fe2O3 + Al2O3}$). This ratio is used in the classification of residual soils. Any ratio less than 1.33 can be considered indicative of true laterites, between 1.33 and 2.0 is regarded as lateritic soil and those greater than 2.0 as non-lateritic tropically weathered soils (Rossiter, 2004). In Enugu and its environs, it is common to observe cracks, potholes, depressions and ruts on roads constructed over a short period of time. It has been reported that soils developed over Enugu Shale in Enugu and environs are of low to medium swelling soils (Nnamani and Igwe, 2020). Hence there is a need to determine the quality of laterite developed over Enugu Shale. It is important to note that other factors may necessitate the poor road condition in the study area which may include but are not limited to geomorphology conditions, geotechnical factors, poor design and poor supervision. The mineralogical composition of lateritic soil has a significant effect on a geotechnical parameters such as Atterberg's limits, specific gravity, shear strength and swelling potential. Topographically, the area is dominated by highland in the western part and lowland in the eastern part. These variations in topography will definitely impact the lateritic conditions of soils developed over Enugu Shale.

Geologic Setting

The tectonism in Southern Nigeria likely started in the Early Cretaceous, with the separation of Africa from the South American continent and the opening of the Atlantic oceanic. This resulted in the development of the Benue Trough through the failed arm of the triple junction which stretched in a NE-SW direction (Fig. 1) and rested unconformably upon the Pre-Cambrian basement complex (Table 1). It extends from the Gulf of Guinea to the Chad Basin and is thought to have been formed by the Y-shaped triple junction ridge system. After the evolution of the Benue Trough, sediments started depositing into the trough with the Asu River Group being the oldest sediment followed by the Ezeaku Group, and Awgu Group respectively (Nwajide, 1990). Santonian age marked the stage when the basin experienced another phase of tectonic event that involved deformation, folding, faulting and uplift of the Pre-Santonian sediments leading to the formation of the Anambra Basin which evolved as a depression to the west of the uplift (Benkhelil, 1987). Anambra Basin is a Cretaceous depo-centre that received Campanian to Tertiary sediments (Nwajide, 1990, and Adeigbe and Salufu, 2009). The stratigraphic setting of Southern Nigeria comprises sediments of three major sedimentary cycles. The first two cycles belong to the Pre-Santonian sediments while the third cycle belongs to Post-Santonian sediments which are found in the Anambra Basin and Afikpo Syncline (Nwajide, 1990). In Anambra Basin, the strongly folded Albian-Coniacian succession (Pre-Santonian sediments) is overlain by a nearly flat-lying Campanian-Eocene succession (Table 1). The oldest sediment in the Anambra Basin is Nkporo Shale and Enugu Shale. The two sedimentary units are lateral equivalent to each other (Nwajide, 1990).

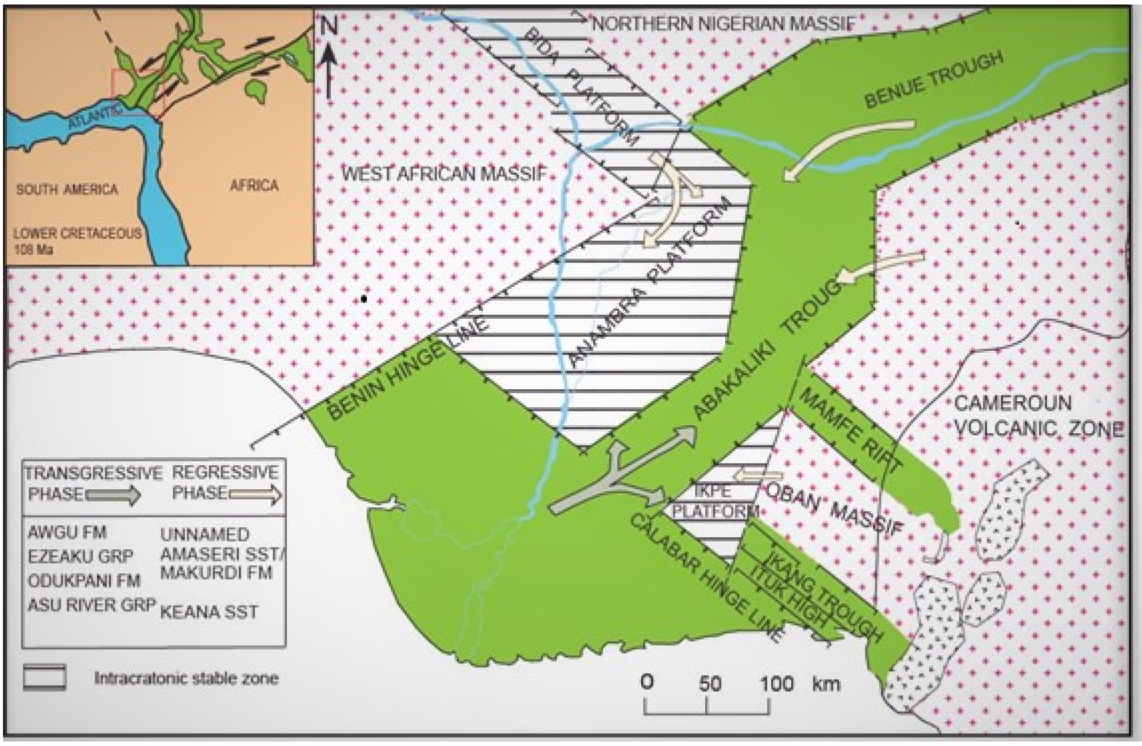

Figure 1: Tectonic map of southeastern Nigeria (After Murat, 1972)

Table1: Correlation Chart for Early Cretaceous Tertiary strata in the Southeastern Nigeria (After Nwajide, 1990).

MA	TIME		STRATIGRAPHY	
	OLIGOCENE		OGWASHI ASABA FORMATION	
30	EOCENE		AMEKI FORMATION	
54.9	PALEOCENE		IMO FORMATION NSUKKA FORMATION	
65	MAASTRICHTIAN		AJALI SANDSTONE MAMU FORMATION	
74	CAMPANIAN		NKPORO GROUP (OWELLI SANDSTONE / NKPORO SHALE / ENUGU SHALE)	
83.0	SANTONIAN		FOLDING	
86.6	CONIACIAN		AGBANI SANDSTONE	AWGU SHALE GROUP
88.5	TURONIAN	U	NKALAGU FORMATION / AWGU SHALE	
		M	AGU OJO/AMASERI/AGALA SANDSTONES	EZE - AKU SHALE GROUP
		L	NARA SHALES	
90.4	CENOMANIAN	U	EZILLO	
		M		ODUKPANI FM
		L	IBRI AND AGILA SANDSTONES	ASU RIVER GROUP
97	ALBIAN	U	NGBO	
		M	EKEGBELIGWE	
100	PRE ALBIAN - ALBIAN		UN - NAMED UNITS	
CRETACEOUS	PRECAMBRAIN		BASEMENT COMPLEX	

Location of the Study Area

The study area covers Enugu metropolis and its environs and is bounded by Latitude N6°20 and N6°50; and Longitude E7°25 and E7°45 (Fig. 2) with an area extent of about 2053km^2. It lies within the eastern part of Anambra basin (Fig.3) and is dominantly underlain by Enugu Shale and partly underlain by Mamu Formation in the western part of the study area. The study area is well accessible. It can be accessed through Enugu Onitsha expressway, Enugu-Abakiliki expressway and Enugu–Portharcourt expressway. The road networks in the area depict that of an urban centre as it can be accessed through many tarred roads.

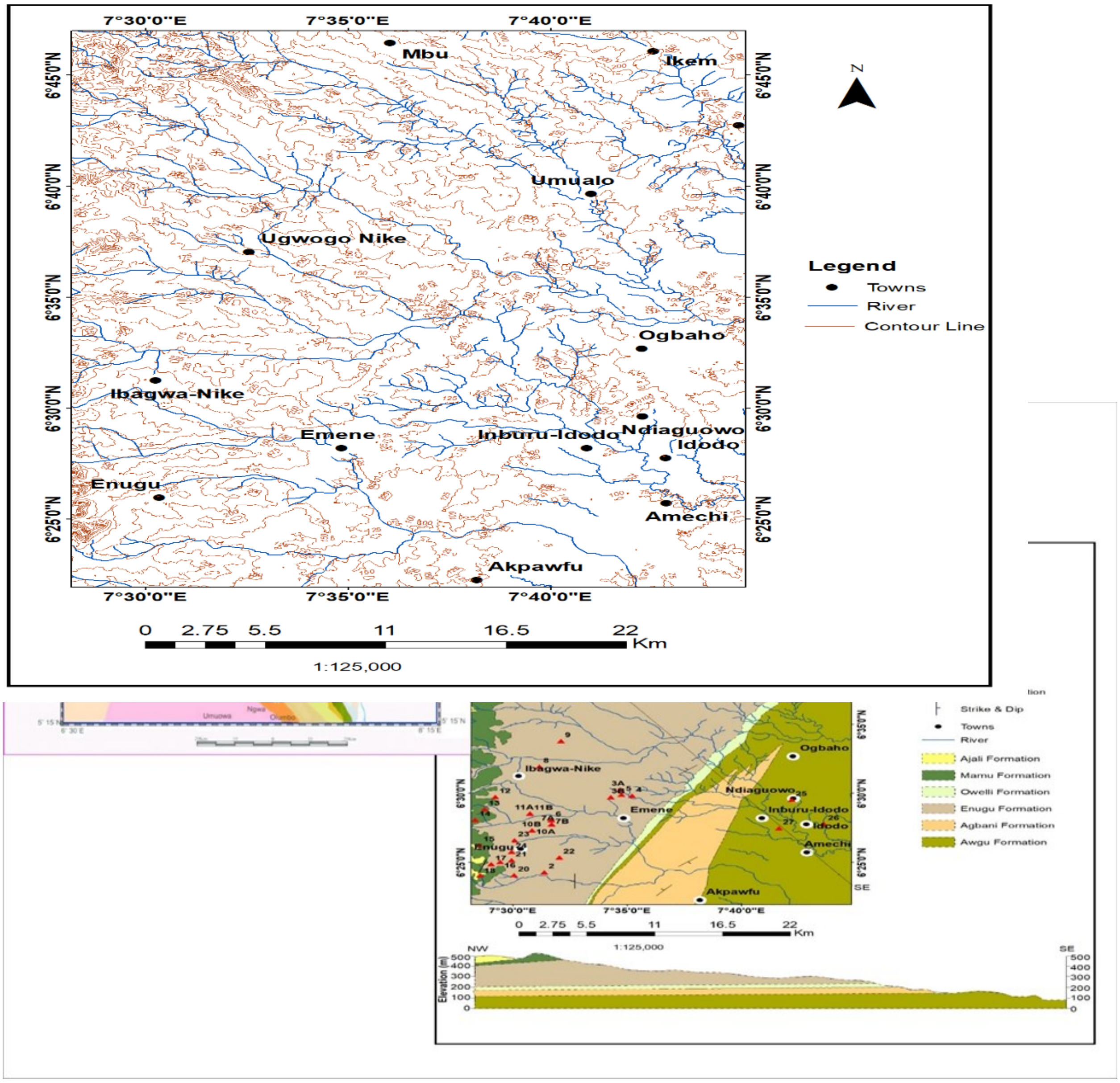

Figure 3: Geologic map of Anambra Basin showing the study area (After Aghamelu, 2011)

Materials and Methods

X-Ray Fluorescence (XRF)

X-Ray Fluorescence (XRF) is a non-destructive analytical technique used to establish the elemental oxides composition of a soil sample. It determines the chemistry of a soil sample by measuring the fluorescent X-ray emitted from the soil sample when it is excited by a primary X-ray source. Every element has a set of characteristic fluorescent X-rays that is unique for the specific element. Twenty samples of soils were collected and analyzed using XRF spectrometer (EDX-700). About 20g of each sample were mashed, submitted to dispersion and sedimentation, physical fractioning process, and the fractions of coarse sand, fine sand, silt and clay were extracted. All samples were reduced to diameters below 53µm and analyzed in dispersive energy XRF spectrometer (EDX-700). The spectra were obtained at 300seconds intervals in a vacuum and semi-quantitative mode.

Atterberg's Limit Test

Atterberg's limit tests were done in accordance with BS 1377 (1990) test.

Results and Discussions

Impact of Elemental Oxides on Some Index Properties of Enugu Soils

The results of X-ray fluorescence (XRF) on the studied samples are shown in Table 2 with SiO_2, Al_2O_3 and Fe_2O_3 dominating the samples. The chemical characteristics of fine-grained soils are mainly the function of its chemistry and mineralogy of the cementing materials as well as the cation exchange capacity of the clay minerals. The XRF results of Table 2 revealed the elemental oxides of each sample in their percentage. All the samples were dominated by SiO_2, and Al_2O_3.

The correlation matrix of Table 3 revealed that the cohesion of the soils correlates negatively with SiO_2 and silica-sesquioxide ratio of the studied soils. The implication is that increase in SiO_2 and silica-sesquioxide ratio will affect the cohesion of the soils of the study area. Also, the matrix showed that cohesion correlates positively with Al_2O_3, Fe_2O_3 and MgO. The mineralogical investigation of Nnamani and Igwe (2020) showed no evidence of swelling clays like montmorillonite. Hence, low to medium swelling soils prevail in the study area as observed. The presence of Al_2O_3, Fe_2O_3 and MgO in the soils may have acted as cementing agents, which also may have contributed to the tensile cracking of the soil of the study area by making the compacted soils relatively brittle. The result is consistent with the finding of Indraratna and Nutalaya (1991) that high Iron oxide and Aluminium oxide content in the residual soil may have influenced the cracking of Shek Pik Dam in Hong Kong. Also, the correlation matrix shows that the amount of SiO_2 is affected by the amount of Al_2O_3 and Fe_2O_3, hence the cohesion of the soils of the study area. The oxides composition from the correlation matrix that increases cohesion is less likely to impact the liquid limit, plasticity index and "activity" of the studied soils.

Table 2: Oxides of the Tested Samples

STA	*SiO_2*	*TiO_2*	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*Na_2O*	*K_2O*	*MnO*	*LoI*	*S-S ratio*	*Soil classification*
2	84.98	0.75	12.53	1.3	1.39	0.51	0.26	0.43	0.02	5.35	6.14	Non lateritic soil
3B	72.19	0.61	17.95	1.39	0.53	0.79	0.24	0.33	0.02	5.98	3.73	Non lateritic soil
4	52	0.75	24.11	12.21	0.4	3	0.47	1.28	0.01	6.28	1.43	Lateritic soil
6	57.85	0.66	19.45	11.75	0.2	2.31	0.13	1.68	0.01	4.96	1.85	Lateritic soil
7B	62.6	0.83	21.57	6.21	0.06	0.51	0.39	0.95	0.01	6.87	2.25	Non lateritic soil
10A	88.1	0.6	7.43	1.02	0.01	0.45	0.76	0.22	0.04	2.19	10.43	Non lateritic soil
10B	86.5	0.53	7.31	1.15	0.01	0.4	0.69	0.19	0.03	3.2	10.22	Non lateritic soil
11A	64.45	0.79	20.45	7.82	0.04	0.93	0.41	0.77	0.02	4.32	2.28	Non lateritic soil
12	79.23	0.71	8.62	2.16	1.01	0.32	2.93	1.37	0.13	3.52	7.35	Non lateritic soil
13	50.4	0.59	26.04	12.25	0.23	2.56	0.51	1.19	0.01	6.31	1.32	Laterite
14	56.85	0.92	28.23	4.56	0.23	0.51	0.32	1.49	0.01	6.88	1.73	Lateritic soil
17	69.41	0.53	17.04	3.44	0.01	1.04	0.82	0.56	0.01	7.14	3.39	Non lateritic soil
19	84.64	0.8	6.26	0.98	0.02	0.63	0.49	0.47	0.03	3.14	11.69	Non lateritic soil
20	54.04	0.96	22.84	11.89	0.04	1.65	0.54	0.98	0.02	7.04	1.56	Lateritic soil
22	76.5	0.63	9.02	3.64	0.38	0.46	0.34	1.42	0.02	7.59	6.04	Non lateritic soil
23	75.84	0.92	7.94	3.92	0.43	0.51	0.38	1.54	0.01	8.51	6.39	Non lateritic soil
24	52.78	0.61	24.16	10.65	0.2	2.53	0.84	1.04	0.02	6.27	1.5	Lateritic soil
25	52.78	0.61	24.16	10.65	0.2	2.53	0.84	1.04	0.02	6.27	1.5	Lateritic soil
26	56.26	0.78	23.42	7.63	0.23	3.54	0.55	1.32	0.01	6.26	1.81	Lateritic soil

27	80.52	1.04	10.78	1.45	0.46	0.4	0.27	0.3	0.02	4.72	6.58	Non lateritic soil

Table 3: Correlation matrix of elemental oxides and some physical parameters

	SiO2	TiO	AL2O3	FE2O3	CAO	MGO	NA2O	K2O	MNO	LL	PI	ACT	SSR
SiO2	1												
TiO	-0.03878	1											
AL2O3	-0.93802	0.046948	1										
FE2O3	-0.91454	-0.01849	0.775763	1									
CAO	0.290856	0.107383	-0.22383	-0.28806	1								
MGO	-0.78825	-0.18572	0.678375	0.818803	-0.1963	1							
NA2O	0.146119	-0.20332	-0.22128	-0.13512	0.285697	-0.10521	1						
K2O	-0.5959	0.166859	0.41108	0.574051	0.055477	0.417607	0.115629	1					
MNO	0.39211	-0.1017	-0.43746	-0.33959	0.408434	-0.3308	0.921923	-0.01393	1				
LL	-0.27671	0.05006	0.279015	0.279007	0.215056	0.418324	-0.47189	0.028147	-0.44864	1			
PI	-0.09859	-0.02526	0.162031	0.046304	0.280365	0.252983	-0.28394	-0.23392	-0.24889	0.847617	1		
ACT	0.036269	-0.23568	0.034915	-0.11014	0.190991	0.053378	-0.16486	-0.27522	-0.06256	0.512086	0.79154	1	
SSR	0.927288	-0.07047	-0.92883	-0.8008	0.101151	-0.65476	0.204804	-0.5353	0.422463	-0.32787	-0.15937	-0.04811	1
COHESION	-0.55402	-0.00927	0.547588	0.452704	0.122974	0.460077	-0.05193	0.376304	-0.26261	0.264693	0.17741	-0.01423	-0.67786

Laterization of the Soil in the Study Area

Lateritic soils may be regarded as all reddish tropically weathered rock materials, irrespective of the details of the degree of their weathering with or without concretions. Rossiter (2004) made a classification of soil by compiling it according to the degree of laterization through the evaluation of their silica-sesquioxide (S-S) molar ratio {SiO_2 / (Fe_2O_3 + Al_2O_3)}. The result of laterization of the study area showed the poor quality of the material for engineering construction in the study area as the area is dominated by non-lateritic soils Table 2. Figure 4 shows the distribution of laterites in study area.

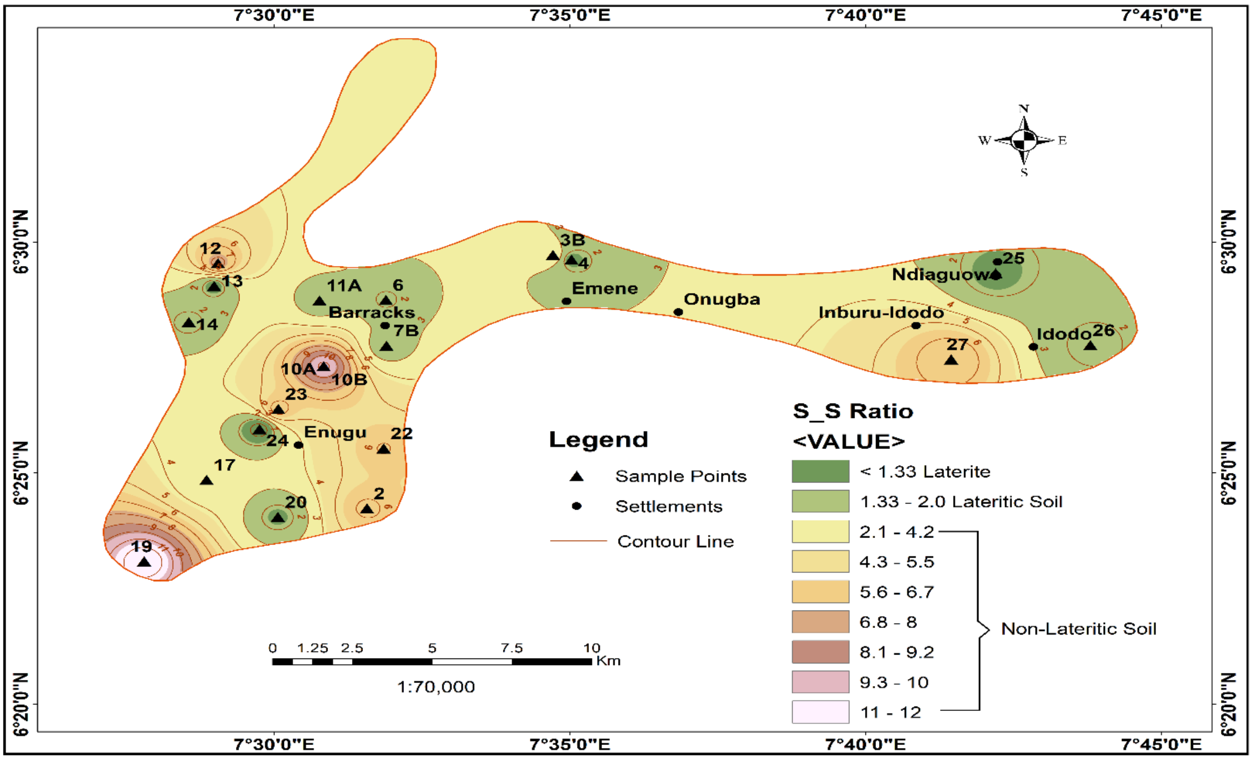

Figure 4: Map showing the distribution of Laterite, Lateritic soil and Non-lateritic soil in the study area

Summary and Conclusion

Samples are dominated by the oxides of Silica, Aluminum and Iron. The relationship between elemental oxides and some parameters such as liquid limit, plastic limit and cohesion showed that elemental oxides significantly affect the swelling characteristics of the lateritic soils in the study area. Studied samples showed that the study area is dominated by non-laterite soil and lateritic soil based on their silica-sesquioxide (S-S) ratio (Rossiter, 2004). This implies that cement, lime, ash etc. need to be added to the material to increase the workability of material for engineering construction in Enugu and its environs.

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