Engineering Properties of Lateritic Soils from Anambra Central Zone, Nigeria

Aginam C. H, Nwakaire Chidozie, Nwajuaku A.I

Abstract-* *This study was carried out to investigate the geotechnical properties of lateritic soils from Anambra Central senatorial zone of Nigeria. Four samples were collected from four different locations in the zone, namely, Neni, Nimo, Obeledu and Enugwu Ukwu and were designated as LAT-1, LAT-2, LAT-3 and LAT-4, respectively. The tests carried out on the soil samples include the Atterberg limit tests, particle size distribution analysis, specific gravity, compaction test using the British Standard Light (BSL) Compactive effort, and California Bearing Ratio (CBR) test as specified by the West African Standard (WAS). The tests revealed that all the samples are poorly graded. The liquid limits ranged from 28.85% to 35.7% while the plasticity indices ranged from 9.18% to 14.55%. The Maximum dry densities (MDD) and Optimum moisture contents (OMC) ranged from 1.77g/Cm^3 to 1.98g/Cm^3 and 9.5% to 14.6% respectively. The CBR values obtained were 28%, 27%, 25% and 22% respectively. Apart from the Neni sample which was classified as A-2-4 with the AASHTO classification, the other soils were classified as A-2-6 soils. All the samples were classified as SC (Clayey sands) according to USCS classification system. It was concluded that the four lateritic soil samples were suitable for sub-grade and sub-base type 2, but should not be used in road construction as a base material. Stabilization of the soil was equally recommended.

KEYWORDS-California bearing ratio, compaction, Geotechnical properties, lateritic soil.

I. INTRODUCTION

Lateritic soils are highly weathered and altered residual soils formed by the in-situ weathering and decomposition of parent rocks under tropical and subtropical climatic conditions. This weathering process primarily involves the continuous chemical alteration of minerals, the release of iron and aluminum oxides, and the removal of bases and silica in the rocks. The geotechnical properties of lateritic soils are influenced by climate, drainage, geology, the nature of the parent rock and the degree of weathering or linearization of the parent rock. These factors also differentiate laterite from other soils that are developed in the temperate or cold regions. Some lateritic soils are thought to have been transported from their place of origin by wind or other action, but most of those with which is used for road construction is likely to have been formed in-situ. Lateritic soils contribute to the general economy of the tropical and subtropical regions where they are in abundance because, they are widely utilized in civil engineering works as construction materials for roads, houses, landfill for foundations, embankment dams, etc. As a road construction material, they form the sub-grade of most tropical road, and can also be used as sub-base and base courses for roads that carry light traffic.

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They can also be used in other works in agronomic, mining research (iron, aluminum and manganese) deposits etc. Lateritic soils are economically convenient in road construction, in the sense that they are cheaper than other materials that can achieve comparable strength with them and they are more available than those materials. In Anambra State, laterite is a major road construction material that is used for the sub-grade and, occasionally, the sub-base and base courses of the roads. Adequate information on its geotechnical properties is important because the durability and strength of the road depends on this information. Such geotechnical parameters include the strength, the maximum dry density (MDD), the amount of fines (clay, silt, sand and gravel) as well as its compaction performance.

II. REVIEW OF PAST WORKS

Laterite is described as a product of in-situ weathering in igneous, sedimentary, and metamorphic rocks commonly found under unsaturated conditions (Rhardjo, et al 2004). Lateritic soil is one of the most important and common materials used in earth work engineering construction in the tropics and subtropics where it is in abundance.

The name laterite was coined by an English surgeon Francis Buchanan in 1807 in India from a Latin word "later" meaning brick in the 19th century. He coined the term laterite when he wrote "What I have called indurated clay is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification and is placed over the granite that forms the basis of Malayala. It is full of cavities and pores, and contains a very large quantity of iron in the form of yellow and red ochres. In the mass, while excluded from the air, it is so soft, that any iron instrument readily cuts it, and is dug up in square masses with a pick-axe, and immediately cut into the shape wanted with a trowel, or large knife. It very soon becomes as hard as brick, and resists the air and water much better than any brick I have ever seen. The most proper English name would be laterite, from lateritis, the appellation that may be given to it in science". Since then lots of researches and write ups have been carried out on laterite and a lot of terms referring to many soil types have been produced. There is a tendency to apply the term to any red soil and rock in the tropics (Abebaw, 2005). Laterite soils are formed in situ from the intense weathering of parent material, whether primary or sedimentary, in the tropical and sub-tropical climate environment. This weathering process primarily involves the progressive chemical alteration of primary minerals, the release of iron and aluminum sesquioxides, increasing loss of silica and the increasing dominance of new clay materials (such as smectites, allophones, halloysite, and as weathering progresses, kaolinite)formed from dissolved materials (Northmore et al, 1992). Tuncer, et al, (1977), described the genesis of laterite as the weathering process which involves leaching of

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silica, formation of colloidal sesquioxides, and precipitation of the oxides with increasing crystallinity and dehydration as the soil is weathered. The three major processes of weathering are the physical, chemical and biological processes. The physical weathering is pre-dominant in the dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and temperature (Abebaw, 2005). As the disintegration of underlying rocks occurs, the Primary elements are broken down by the processes of physical and chemical weathering to simple ionic form. The silica and bases in the weathered material such as sodium, potassium, calcium magnesium etc. are washed out by the percolated rain water (vadose water) and oxides and hydroxides of sesquioxides are accumulated thereby enriching the soil and giving the soil its typical red colour. This process is called laterization and it depends on the nature and extent of chemical weathering. Laterization is a gradual process which must be active for centuries. In tropical countries, the "vadose waters" are also at a higher temperature, than in the colder climates and they contain more carbonic acid, alkaline carbonates, organic matters, etc. These elements explain why rocks that are leached by the "vadose waters" in the tropics are more rapidly altered and also why laterite is much more commonly seen in tropical countries than in the colder ones. After weathering, dehydration occurs. Dehydration (either partial or complete) alters the composition and distribution of the sesquioxide rich materials in a manner which is generally not reversible over wetting (Abebaw, 2005). It leads to the formation of strongly cemented soils with a unique granular soils structure. The topography and drainage of an area also influences the rate of weathering because to some extent, it determines the amount of water available for laterization to occur and the rate at which it moves through the weathering zone. It controls the rate at which the weathered material is eroded. Deep weathering cannot occur on steep slopes. This is because the surface run-off on steep slopes is greater than the rate of infiltration thereby increasing the rate of erosion. Hence, lateritic gravels tend to be found on slopes (sometimes locally termed *ridge gravels*), to a lesser extent on uplands and not in low poorly drained areas. (Jiregna, 2008). The structure of Lateritic soil varies with the type of parent rock from which it was formed, the location (i.e. where it was formed), and also on the weathering process that lead to its formation. Studies in some lateritic soils shows that they have a porous granular structure consisting of iron impregnated clayey material in minute spherical aggregation (Hamilton, 1964). The aggregation derives its strength from the thin film found within the micro-joints of the elementary clay particles, which in addition coats the particles (Gidigasu, 1988). Thus the thin film found within the micro joints of the elementary clay particles and as coatings over particles provides the strength of the aggregation. Viewing carefully prepared thin sections of laterite under the optical microscope has shown that these soils contain rough materials with sizes tending from silt to fine sand spread throughout the soil with very finely-divided iron oxides, and a porous structure of peds or clay clusters which are usually not cemented by coatings of iron oxide but rather, they are weakly bonded. The surface of laterite soil initially exists as a gelatinous coating. After losing moisture, it becomes denser but retains its non-crystalline structure after which it crystalizes slowly into different forms, which gives them strongly cemented surfaces covered by iron oxides (Sergeyev et al., 1978). The structural development depends on the deposition of iron oxides at different stages of the weathering process (Malomo, 1989). Field and laboratory studies have shown that residual soils consist of different zones of weathering with differing morphological, physical, and geotechnical characteristics; and vary for different locations due to the heterogeneous nature and highly variable degree of weathering (Adekoya, 1987 and Rahardjo, 2004).

The study of parent rock factor on the engineering properties of lateritic soils developed over different rock types can be determined by keeping other factors constant. These parent materials are of importance in the early stages of weathering since they supply the starting material (Bayewu et al, 2012). Research has shown that laterite soils possess very favourable geotechnical properties, and this is evident in the widespread use of the materials in the construction industry (Ikiensinma 2005). The geotechnical properties of laterite are very much affected by compaction. Before using this soil for any construction purpose, the soil has to undergo some stabilization process so as to avoid failure or collapse or failure of the construction work. Unlike other soil types, the properties of laterite vary from region to region.

The physical properties of residual soils, commonly known as the index properties, vary from region to region due to the heterogeneous nature and highly variable degree of weathering controlled by regional climatic and topographic conditions, and the nature of bedrock, (Nnadi, 1988). It also varies with the depth of the soil and can be determined by simple laboratory tests. Studies on the effect of weathering on the physical properties of laterite soil by (Tuncer et al., 1977 and Rahardjo et al., 2004) have revealed the following;

- Pore-size distribution varies with the degree of weathering.
- Higher pore volume and larger range of pore-size distribution indicates advancement in the weathering stage.
- Soil classification and Atterberg limits do not show any correlation to weathering.
- High specific gravity is a good indication of advanced degree of weathering.
- Soil aggregation increases with increasing weathering.

The Table 1 shows some of the physical properties of laterite soil in some part of Eastern Nigeria as revealed by Nnadi 1988.

Table 1- Physical Properties of Laterite Soils in parts of Eastern Nigeria

PROPERTY	ONITSHA	IMO AIRPORT	OKIGWE
HRB Classification	A-2-4	A-2-4	A-2-4
Unified System	SC-SM	SC-SM	SC
Sand %	63	75	65
Silt %	20	13	15
Clay %	17	12	20
Liquid Limit %	33.7	44.2	32.8

Plastic Limit %	16.4	23.2	17.6
Specific Gravity	2.65	2.64	2.74
Moisture Content %	8	7	6

Source: Nnadi 1988 (Eastern Nigerian Laterite Soils)

Laterite soil chemistry and mineralogy is shown by studies to greatly influence the geotechnical properties, and in certain circumstances, significantly affects the economic potential in the construction industry (Ogunsanwo, 1995). Studies by (Tuncer and Lohnes, 1977) also revealed that the degree of weathering is very well connected with the mineralogy of laterite, as the kaolinite content is high in the early stages of weathering and decreases with increase in weathering; whereas the amount of sesquioxides increases.

The soil profile of laterite is defined as that in which laterite horizon exists or is capable of developing under favourable conditions (ikiensinma, 1998). The alteration of rock by the processes of chemical weathering takes place progressively through a series of events and stages which result in a profile of weathering. Lateritic gravels stand out as low humps in the terrain. They consist of gravel sized concretionary nodules in a matrix of silt and clay. They may take up an area of several hectares and a thickness of between 1 to 5m (Jiregna, 2008).

III. SAMPLING AND TESTING METHODS

Four lateritic soil samples designated as Lat-1, Lat-2, Lat-3, and Lat-4, respectively were obtained from borrow pits in Neni, Nimo, Enugwu Ukwu, and Obeledu, respectively, all located at Anambra Central Zone of Anambra State, Nigeria (see Map of the study area as indicated in the Appendix I). These soils belong to the group of ferriginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi, 1998). The reddish-brown coloured lateritic soils used in this study are low-plasticity clays according to the Unified Soil Classification System, USCS (ASTM D 2487). The choice of these sites and soil is justified by the fact that it is a borrow pit from where various construction companies get their material for road construction in Anambra state.The natural moisture content was determined by the oven drying method. Specific gravity of soils, particle size distribution, plasticity characteristics were determined in accordance with procedures outlined in BS 1377 (1990). Hydrometer method was used to obtain values of the clay-size (% < 0.002mm) fraction of the soil particles. The British Standard Light Compaction (BSL) method was used. The BSL compaction procedure is described in clause 3.3 of Part 4, BS 1377 (1990). The California Bearing Ratios (CBR) tests for the samples were carried out after 24 hours of soaking.

IV. RESULTS AND DISCUSSION

A. Properties of the lateritic soils

Table 2 - Index Properties of the Soil Samples.

Property	LAT-1	LAT-2	LAT-3	LAT-4
Liquid limit (%)	28.85	31.5	35.6	34.2
Plastic limit (%)	19.67	18.05	21.15	21.22
Plasticity index	9.18	13.45	14.45	12.98
Group Index	0	0	0	0
D10	0.28	0.25	0.22	0.3
D30	0.4	0.45	0.36	0.44
D60	0.54	0.64	0.59	0.58
Coefficient of Uniformity (Cu)	2.0	2.56	2.68	1.93
Coefficient of Curvature (Cc)	1.1	1.27	1.00	1.11
Maximum dry density (g/Cm^3)	1.96	1.77	1.98	1.91
Optimum Moisture Content (%)	10.2	14.6	9.5	10.8
In situ moisture content (%)	10.76	8.07	14.03	13.84
C.B.R. value (%) (24hrs soaked)	28	27	25	22
Specific Gravity	2.66	2.65	2.66	2.67
Unified soil classification system(USCS)	SC	SC	SC	SC
American Association of State Highway and Transportation Officials (AASTHO)	A-2-4	A-2-6	A-2-6	A-2-6

Table 2 above displays the index properties of the soil samples collected from the four areas. They actually have identical values for the parameters tested. From the result, it was opined that the lateritic soils within Anambra Central senatorial zone were formed from the same weathering process. The uniformity in the climatic condition and how identical the topography of the area is also supports the identical properties observed from the laterites. One expects to have the same structural and geotechnical performance from the laterites for any given project.

B. Particle Size Distribution

Figure 1 is the logarithmic plot of the particle size distribution of the soil samples. From the graph of figure 1, the coefficient of uniformity (Cu) of the LAT-1, LAT-2, LAT-3, and LAT-4 soil samples are 2.0, 2.56, 2.68, 1.93 and their coefficient of curvature (Cc) are 1.1, 1.27, 1.00, 1.11 respectively, as shown in table 2. According to USCS, the soils were classified as SC (Clayey Sand) soils which show that the samples contain both clay and sand particles. Apart from LAT-1 which has been classified as A-2-4, the rest of the soil samples were classified as A-2-6 soils, according to ASHTO classification.

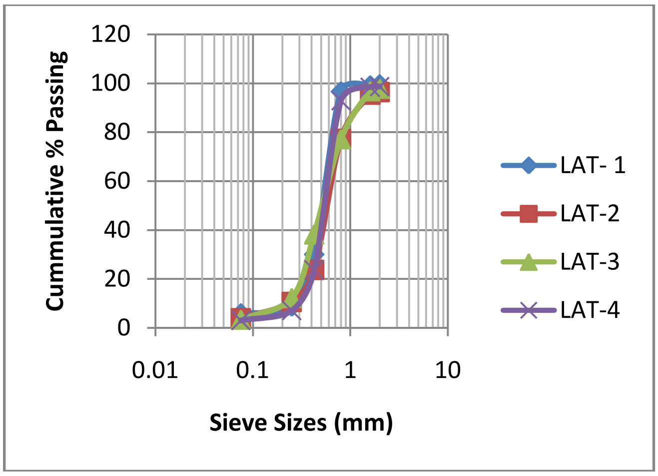

Figure 1- Particle Size Distribution of the Soil Samples

C. Specific Gravity

The specific gravity of the soil is defined as the ratio of the weight of the soil to the rate of equal volume of water. For LAT-1, LAT-2, LAT-3, and LAT-4, the average specific gravity of the samples computed were 2.66, 2.65, 2.66, and 2.67 respectively. These values are close to themselves and are similar to the values obtained with most lateritic soils. The range of specific gravity from 2.65 to 2.67 suggests the presence of clay or silt which actually can be of advantage at the sub-grade and sub-base levels of road construction.

D. Atterberg Limits

The Atterberg limits test on the samples shows that the LAT-1 has an average plasticity index of 9.18 therefore it is of low plasticity. The LAT-2, LAT-3, and LAT-4 samples have average plasticity index of 13.45, 14.45 and 12.98 respectively, therefore the soils are of medium plasticity. The Federal Ministry of Works Standard specification states that the liquid limit of sub-grade materials should not exceed 80% and the plasticity index of sub-grade materials should not exceed 55%. This shows that the soils satisfy the requirements for sub-grade materials.

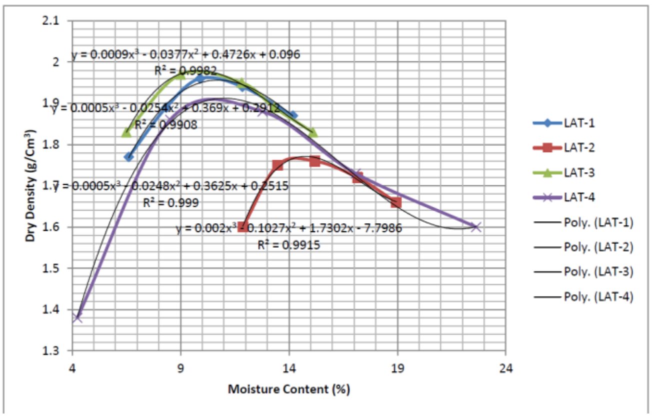

Figure 2- The Compaction Curves for the Soil Samples

The maximum dry densities of the soil samples at their optimum moisture contents were determined using the British Standard Light compaction method. Figure 2 shows the compaction curves for the soil samples tested. From the curves, it was observed that the maximum dry densities of the samples LAT-1, 2, 3, and 4 are **1.96g/Cm^3, 1.77g/Cm^3, 1.98 g/Cm^3**, and **1.91 g/Cm^3** respectively. Their optimum moisture contents are **10.2%, 14.6%, 9.5%,** and **10.8%** respectively. From the result shown, LAT-3 has the best compaction quality being that it achieved the highest maximum dry unit weight at the same compaction effort. Besides, LAT-1, 3, and 4 have very similar compaction characteristics. Looking at the values of their MDD's and OMC's, one can observe a very close relationship. LAT-2 has an evidently lesser MDD. From the curves, it was observed, as well, that the optimum moisture contents decreased with increase in dry densities. This agrees with Proctor (1933),Venkatramaiah (2006), Rowe (2000) and other concluded research works. This fact is illustrated in Figure 3 which is the curve of optimum moisture contents against maximum dry densities of the soils. Using the Microsoft excel software, the linear model obtained for the curve is **Y= -23.93X+56.84** with an **R^2** value of **0.987** which shows that the linear model for the curve is statistically significant. The negative slope further illustrates that as the MDD increases, the OMC actually decreases.

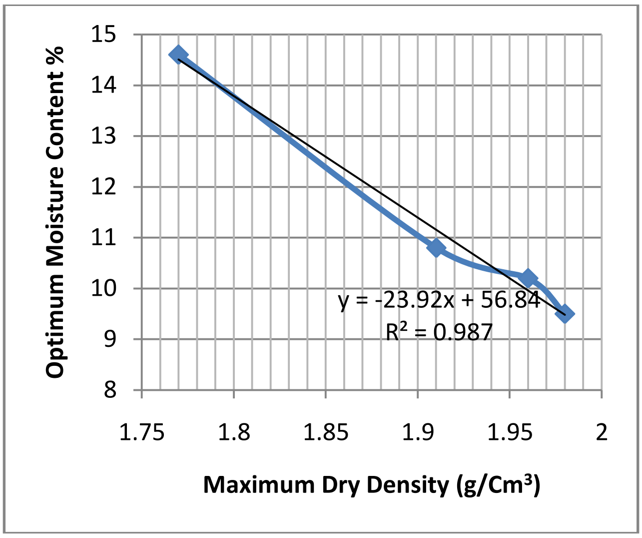

Figure 3- Relationship of Optimum Moisture Content with Maximum Dry Density

D. California Bearing Ratio (CBR)

The California bearing ratio (CBR) test results for the samples after 24 hours soaking are 28%, 27%, 25%, and 22% for LAT-1, 2, 3, and 4 respectively. Since the four samples have CBR less than 80%, they are not suitable for use as road base materials. The Federal Ministry of Works standard specification states that the "sub-base type 2" material shall have a minimum CBR of 20% and the "sub-base type 1" material shall have a minimum CBR of 30% after at least 24hours soaking. The test results shows that all samples have CBR values greater than 20% therefore they are suitable to be used as "sub-base type 2" material in road construction and consequently, they are also suitable as Subgrade materials.

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

From the result of this research work, the following conclusions can be drawn;

1. According to the USCS (Unified Soil Classification System), the lateritic soils in Anambra central zone of Anambra state, Nigeria are classified in group SC (Clayey sand). Based on the

USCS classification, these soils can be used as sub-grade and sub-base materials but are not suitable for base course of roads. They are also classified as silty or clayey gravel and sand according to AASHTO (American Association of State Highway and Transportation Officials) classification.

2. The materials satisfy the requirements for "sub-base type 2" and sub-grade as stated by the Federal Ministry of Works standard specification for roads and bridges (FMW 1997).
3. It can also be concluded that these soils can be stabilized by compaction and they will yield maximum strength if they are compacted on the dry side of their optimum moisture content.

B. RECOMMENDATIONS

It is recommended, therefore, that;

1. The strength of these materials can be improved to meet the requirements for "sub-base type 1" as required in the above mentioned specification. This can be achieved by applying soil stabilization techniques such as addition of cement, lime, fly ash or improving the grading of the material by addition of certain particle sizes that will improve the mechanical stability of the soil.
2. The recommendation 1 should be subject to further studies to note the percentages of the stabilization techniques that will achieve the desired as well as the optimum of each geotechnical characteristic under consideration.

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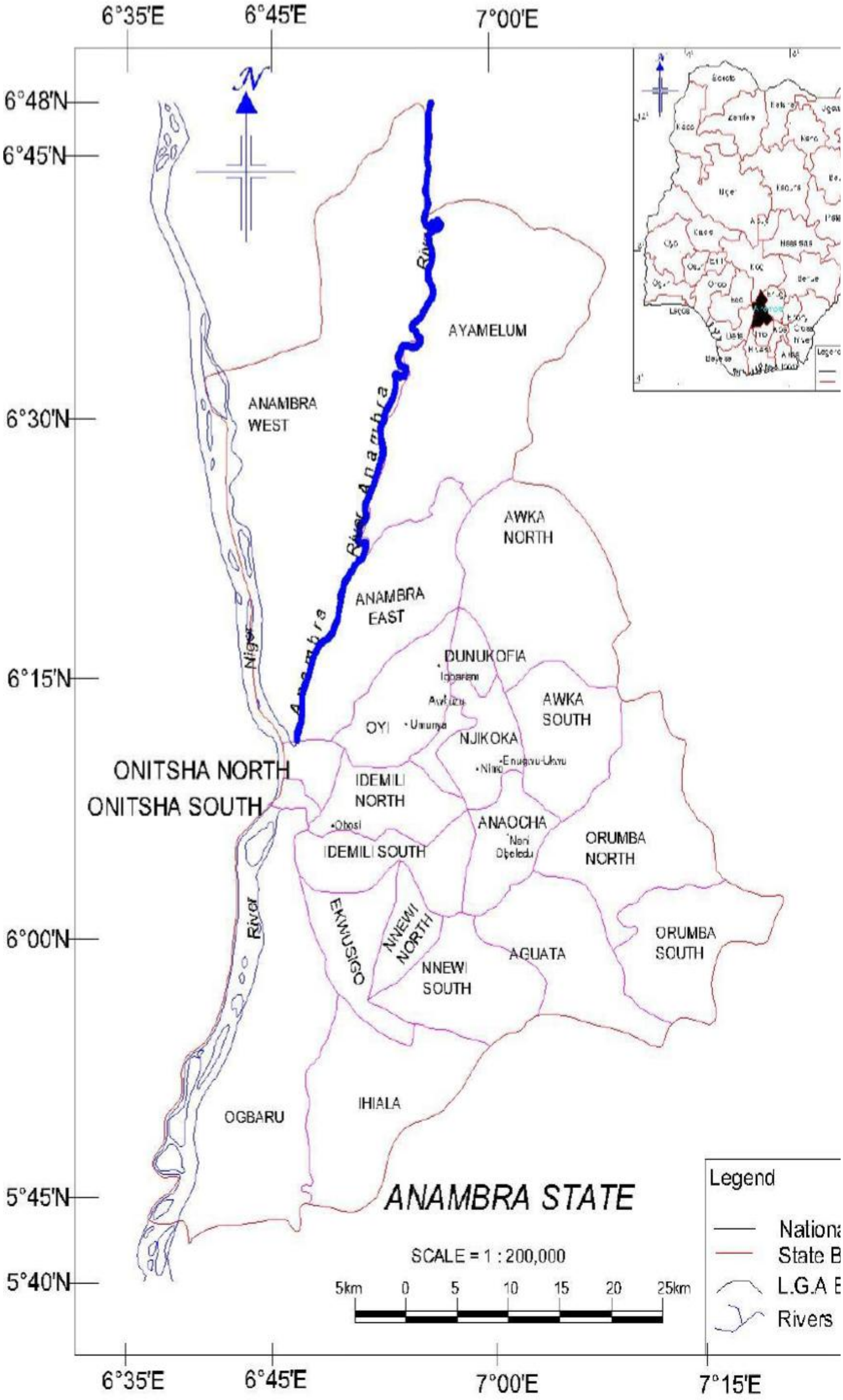
APPENDIX- MAP OF STUDY AREA



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