# The Imperativeness of Laterite in Building and Road Construction Sectors for Sustainable Infrastructure in Nigeria: A Review of Laterite for Socio-Economic Development

**Lucas Albert Jerome Hamidu** [1], **Aliyuda Yohanna Adamu** [1], **Yakubu Isheni** [1]

[1] Nigerian Building and Road Research Institute
10 NBRRI Way / I.T. Igbani Street, off Awolowo Way, Jabi, Abuja, Nigeria

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Corresponding Author:
lucadohamidu@yahoo.com



**Abstract.** The challenges of housing accommodation and road construction due to insecurity and searching for socio-economic activities had over populated urban cities in Nigeria. In this study, a review on the importance of laterite as a significant engineering component used in building, road and dam constructions were reviewed. Laterite is formed due to weathering from the parent rock material, rich in iron and aluminium oxides. Quality laterites are obtained based on the geographical location and topography with rainfall above 90 cm. Better laterite is found in Nigeria's central and southern regions, with 100-300 cm of rain. Therefore, Plateau State in the Northcentral region is endowed with natural resources such as laterite, which could be utilized in housing and road construction for low-income earners to own a house and ease access between the rural-urban communities to cushion the effect of the high cost of building materials.

**Keywords:** building; imperativeness; laterite; road; review; socio-economic.

## INTRODUCTION

The availability of natural resources in any country contributes immensely to its wealth and socio-economic development. The potentials to which these resources are utilized to aid socio-economic development in developing countries like Nigeria are still at a juvenile stage. The over-dependence on crude oil has been the major challenge to natural resource utilization. Author [20] defined natural resources as those things available to man as "gifts of nature", which are either renewable or non-renewable. Mining and exploration are considered the key drivers of economic growth and development for any nation, leading to its social and economic well-being, among the key drivers of the socio-economic activities in the housing and infrastructural development. Nigeria, with over 200 Million population with an expected growth rate of 2.63 %, faces challenges of housing accommodation and poor road networks to serve as a linkage between the rural communities [16].

In separate publications, several authors had reported that subgrade soils known as lateritic soils are among the significant natural resources used to build and construct dams and roads [35]. Whereas authors [21] defined laterite as highly weathered tropical soil, rich in the secondary oxide of iron, aluminium and manganese, categorized into laterite, lateritic and non-lateritic soils. Depending on the geographical location, it is usually red, reddish brown and dark brown. Author [10] categorizes lateritic soil as generally having a low bearing capacity and low strength due to the high content of clay which stability cannot be ascertained under load in the presence of moisture that might result in cracking.

Conversely, [42] investigated marine clay by geochemistry characterization on the parameters such as; pH, loss of ignition, sulphate, chloride, nitrate and carbonate ions. Investigations into the sources of heavy metals in the environment revealed that the significant soil and air pollution sources are road construction materials and vehicular emissions, such as Zn, Pb, Mn, Cr, Cd, Cu and Ni [30]. Furthermore, [29] investigated the characteristics and presence of a heavy metal concentration in soils in some selected dump sites in Port Harcourt. When traces of heavy metals are found in the soil, it is dangerous to living organism due to their adverse effects.

Nigeria, a developing country, is considered a low-income generation. As a result, providing accommodation to the more than 200 million population is imperative to using local content in building materials [4]. The search for improved living conditions has resulted in the mining, and other mineral explorations in Northcentral Nigeria, comprising Benue, Abuja, Kogi, Kwara, Nasarawa, Niger and Plateau states endowed with abundant natural resources that have not been adequately harnessed for economic value.

The Nigerian Building and Road Research Institute, over the years, has been researching the use of laterite stabilized with cement to produce compressed stabilized earth blocks to carter for the teaming population as a result of rural-urban migration, to find affordable and economic housing accommodation and road construction, via the use of lateritic subgrade soils in moulding blocks. Previous studies on the subgrade soil quality parameters in the building and road construction sector did not consider the investigation of the chemical, mineralogical properties and presence of heavy metals, which could threaten human life. This *research aims* to review several works on laterite and lateritic subgrade soil quality as principal raw material for mass housing and road construction in Nigeria, complimenting the Nigerian content in technology innovation.

## RESULTS AND DISCUSSION

There is a desired call for urgent attention and a lasting solution to the rate of building and road failures in Nigeria. The role of engineering properties in providing lasting solutions cannot be overlooked, especially when it comes to material properties and component formulations as the basis for construction. Soils' chemical and mineralogical properties and morphologies must be well understood to avoid superstructure and foundation failures.

Based on Buchanan's time date back to 1807 in India, "the word laterite has been used to describe a wide variety of tropical soils without reaching an agreement on the exact origin, composition and properties of laterites" [44]. It is a soft material that becomes hard without void when exposed to air. Laterite is a highly weathered material rich in secondary oxides of iron, aluminium, or reduced silicates, but it may contain large quartz and kaolinite. Author [6] described laterite as any rocks coloured red to dark maroon which is either hardened or in the decomposition stage due to environmental variation.

Laterite formation requires specific criteria that would concentrate the iron- and aluminium-rich weathering products adequately to allow concretionary development before advancement to a cemented horizon within the weathering profile, which usually occurs in phases in the production of concretionary laterite from humid tropical weathering to produce the minerals of laterite, the concentration of these minerals in a discrete zone and concretionary development within the horizon [27]. The process by which this formation occurs is due to leachate from silica resulting in the colloidal sesquioxides, crystallization of the oxides and dehydration as the rock weathered. While lateritic soils may contain clay minerals with poor silicate content, this is leached out due to water passing through the soil [17]. Thus, the mineralogical composition of feldspar expressed in the ternary system is converted to kaolinite and finally to gibbsite, as presented in Equation 1 [11], while the cationic is precipitated.

$$\underset{\text{Feldspar}}{XAlSi_3O_8} \xrightarrow{hydrolysed} \underset{\text{kaolinite}}{Al_2O_3 2Si_2.2H_2O} \rightarrow \underset{\text{Gibbsite}}{Al_2O_3.3H_2O} + X \updownarrow \text{precipitate} \quad (1)$$

where X – potassium ion (K+) or sodium ion (Na+) or calcium ions ($Ca_2$+)

The ferromagnesian minerals are converted from goethite to hematite when crystalized. The resulting crystallization leads to the formation of iron or aluminium oxides continually cemented crust together. More details about the engineering properties of laterite and lateritic soil are reported [44].

Lateralisation occurs as a result of tropical climatic geographical locations having district dry and wet periods that lead to facial decomposition of the parent rocks, with "removal in a solution of combined silica, lime, magnesia, potash" and with residual accumulation assisted by capillary changes of a hydrated mixture of oxides of iron, alumina and manganese [17]. The physicochemical breakdown of primary minerals characterizes the decomposition and the release of constituent elements, including $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO, MgO, $K_2O$, $Na_2O$ and others appearing in simple ionic forms.

The existence of the laterite depends on the geographical location, topography, drainage system and vegetation as varied from one area to the other. Thus, rainfall becomes a factor in the laterite formation and the quality of laterite expected. Authors [9, 43] in separate publications reported that high kaolin content occurs in regions with 65–90 cm annual rainfall. In comparison, kaolin does not exist in an area with above 90 cm of rain. By implication, regions with high rainfall will have more laterite than regions with low rainfall due to leached fine soils considered rich in silicate materials.

The Nigerian climate varies from one region to another, as likewise the rainfall, which also affects the laterite formation and its quality. Laterite is extensively used in building, road construction and dams as basic engineering materials at an affordable cost depending on the source. Figure 1 presents a map of Nigeria and the annual rainfall pattern across different regions with their respective ranges [7].

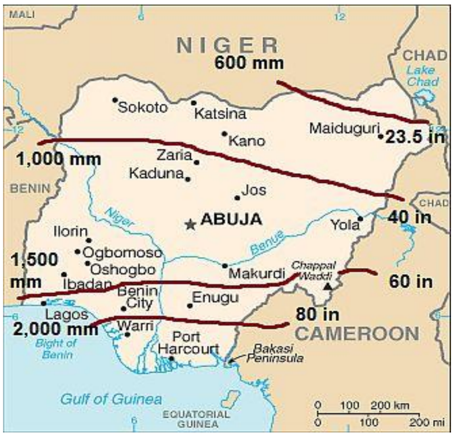


Figure 1

Based on Figure 1, Northern region from Sokoto, Katisna, Kano to Maiduguri, the rainy season lasts from June to September with annual precipitation of 600 mm; more kaolinite materials are expected than laterite. While in the central states of Abuja, Jos, Kaduna, Niger and so on, rainfall is from April to October with annual precipitation in the range of 1000–1500 mm. In this region, high-quality laterite is expected with low or no kaolinite material to provide adequate cementitious properties to serve as building and construction materials. Furthermore, rainfall is from March to November in the southern region, with annual precipitation in 2000–3000 mm, characterized by fine sands.

## Qualities of Laterite Soil

Laterite, a significant engineering component used in building roads and dam construction, should possess certain qualities that can withstand the test of time in conformity with international standards, providing lasting solutions to infrastructural deficits in developing countries like Nigeria. Furthermore, the location and source of laterite play a critical role in the formulation that can optimize the process that can avert failure in usage. Based on this fact, not all soils are suitable for use as engineering materials in their natural form. Therefore, properties that make soils unsuitable are problematic soils, which could either be expansive soil or collapsible soil that can lead to low bearing capacity. Clayey materials characterize such soils. Therefore its usage could result in cracks in buildings, roads or underground infrastructure damage [8].

According to [41], laterite has a wide variety of red, brown-yellow, acceptable grain-sized residual with granular structure and composition of silica ($SiO_2$) to the oxide of ($Fe_2O_3$ + $Al_2O_3$) is between 1.33 and 2.0, while above 2.0 is not laterite. Based on the degree of Lateralization, a critical consideration is given to swell, shrinkage properties, cracking patterns, type and amount of organic matter, and its effect in moulding is paramount, as reported by [12, 45, 46]. Author [6] in the study on laterite from the scientific point of view revealed that variations in the qualities of laterite could be influenced by the pH of the clay sedimentation and further suggested that compacted laterite strength should be above 2000 $kg/cm^2$. Similarly, another work by [22] revealed that laterite used for the commercial purpose indicated a high pH value due to a large amount of $Ca_2+$ and $Mg_2+$ ions, which affects the formation process due to significant features of lateritic clay showing unique high colour, poor fertility, high clayey content and lower cation exchange capacity [3]. Their findings were supported by [5] emphasizing that the higher the clay and mineral content in the lateritic soil, the lower the soil strength, which cannot be used in building. Therefore, it is undesirable to have clay soil as an engineering material property due to its low share strength from wetting. Clay is generally a hydrophilic material subject to expansion when wet and stabilizes when dried. Table 1 presents the typical chemical composition of laterite and lateritic material from related literature and their possible original parent material [13, 18, 27].

Table 1 – Chemical Composition of Laterite and Lateritic Soils

| Component | Percentage by weight (%) | | | Main form of occurance |
|---|---|---|---|---|
| $SiO_2$ | 5-70 [a] | 63.93 [b] | 9.48–30.71 [c] | Quartz, Feldspar, Clay minerals |
| $Al_2O_3$ | 5–35 [a] | 17.06 [b] | 12.50–18.00 [c] | Feldspar, Clay minerals, gibbsite |
| $Fe_2O_3$ | 5–70 [a] | 5.88 [b] | 48.20–55.63 [c] | Goethite, hematite |
| $TiO_2$ | 0–5 [a] | N. d. | N. d. | Anatase, rutile |
| MnO | 0–5 [a] | N. d. | N. d. | |
| MgO | N. d. | 2.3 [b] | 2.51–2.60 [c] | |
| $P_2O_5$ | 0–1 [a] | N. d. | N. d. | |
| $H_2O$ (M.C) | 5–30 [a] | 0.097 [b] | 1.21–1.77 [c] | Clay minerals, goethite, gibbsite |
| CaO | N. d. | 3.91 [b] | 0.36–0.41 [c] | |
| $K_2O$ | N. d. | 3.13 [b] | N. d. | |
| $Na_2O$ | N. d. | 3.1 [b] | N. d. | |
| LOI | 5–30 [a] | 0.64 [b] | 4.08–8.35 [c] | Clay minerals, goethite, gibbsite, OM |
| OM | 0.2–2 [a] | N. d. | | Organic matter (OM) |

Notes: [a] – according to [26]; [b] – [13]; c – [18]; M. C – moisture content; OM – organic matter; LOI – loss on ignition, N. d. – not detected

Based on the review of literature presented in Table 1, the chemical and mineralogical compositions of laterite and lateritic soils varied from region to region.

*Previous Studies on Laterite*. A review revealed more attention to the geotechnical properties of laterite soil by several authors, including; those [15, 14, 24, 26]. Furthermore, [34] evaluated the geotechnical properties of laterite soils in the Asa-Dam area, Ilorin, Southwestern Nigeria, for the soil suitability as a construction material. Authors [38] investigated the geotechnical engineering properties of laterite as a subgrade and base material for road constructions in Nigeria. Also, [21] study the stabilization of Ikpayongo laterite with cement and calcium carbide waste to determine the Atterberg limits test, California bearing ratio (CBR) and unconfined compressive strength for natural and treated soil. Authors [19] studied the effects of different parent materials on the mineral characteristics of soils in the arid region of Turkey.

Similarly, [39] investigated the geotechnical properties of lateritic soil stabilized with yam peel ash for subgrade construction. Author [31] investigated the behaviour of pavement subgrade soil stabilized with shredded polyethene to improve the characteristics of lateritic sub-grade oil. Authors [33] studied the engineering properties of lateritic soils in Ado-Ekiti for rapid urbanization in the city area. Authors [35] carried out engineering properties of lateritic soils around Dall quarry in Sango area of Ilorin by determining the liquid limit, plastic limit, plasticity index, shrinking limit, Atterberg limit and an activity. Regression analyses that may correlate index properties and CBR of some lateritic soil within Oshogbo town of South Western Nigeria were investigated and presented [4].

*Uses and Laterite Stabilization.* Laterite and lateritic soils occupy unique value in the socio-economic development of any country due to their diversified application. Laterite with more clay, known as lateritic soil, which is exemplary, is used as an adsorbent to remove contaminants such as heavy metals in wastewater from industrial discharge and other related waste contaminants. Authors [13] used laterite clay-based geopolymer as a potential adsorbent for removing heavy metals from aqueous solutions. Laterite produces compressed stabilized earth block [37]. Nevertheless, a significant application area is used in housing, road construction and dam. Laterite alone might not provide adequate cohesion as engineering materials. Thus, the desire to stabilize laterite or lateritic soil using admixtures at a low and affordable cost for enabling the environment to the user's comfort.

*Review on Laterite Stabilization*. Laterite and lateritic soils are not wholly used without additives. Therefore, investigation of the chemical and mineralogical composition for the soil stabilization to determine appropriate binding materials is desirous. This will also alter the natural soil to provide cohesiveness that will meet the standard properties such as water permeability and compressibility of the soil, increase in shear strength and other physical properties for usage in buildings, roads and dam constructions. Research on various processes of stabilization revealed that, several engineering materials had been used to stabilize laterite soil as described by different authors includes: soil stabilization methods and materials [25]; use of a liquid chemical as soil stabilizer known as RoadPacker Plus using Malaysian soil were investigated by [23]; selected soil stabilization technique by [1]; geotechnical and environmental evaluation of lime–cement stabilized soil–mine tailing mixtures for highway construction was carried out by [32]; assessment and comparative study on the stabilizing effect of three materials, cement, sodium chloride and brick dust on clay soil found at locations during road construction [28]; laterite from Ikorodu North Local Government Area in Lagos State, Nigeria was stabilized with egg Shell powder, sodium silicate for the purpose of constructing light traffic pavement [33] and [40] in an effort to protect the environment from hazardous pollutants associated with waste generation and its disposal evaluated the strength of Lime-cement stabilized tropical lateritic clay contaminated by heavy metals was carried out among others.

This review was aimed at understanding the formation and basic fundamental properties of laterite and lateritic soil, and the processes of obtaining the best quality engineering material that could be utilized in building affordable housing and office accommodation for proliferating internally displaced persons occasioned by the insecurity in Nigeria with specific interest on Plateau State. The imperativeness of laterite as a significant component of engineering material in building for affordable housing, office accommodation and road construction is justified based on its abundance and sustainability. This will encourage low-income earning to own a house to depopulate the urban city due to insecurity leading to rural-urban migration searching for shelter and socio-economic activities.

## CONCLUSIONS

The following specific conclusion can be drawn from this review on laterite and lateritic subgrade soil.

1. Laterite and lateritic soil form significant components of engineering material in building and road construction.

2. Geographical location and topography determine the formation, quality and classification of laterite and lateritic.

3. Different stabilization processes were based on the geotechnical properties to meet the international standard for use as an engineering material in building and road constructions.

4. We, therefore, recommend preliminary research on the chemical and mineralogical compositions of laterite and lateritic soils in Plateau State, Northcentral Nigeria, for use as engineering materials in building and road construction.

### Conflict of interest

The authors declared no conflict of interest and have not received any grant for the research.

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