NAU Journal of Civil Engineering (NAUJCVE) May/June 2026

Nnamdi Azikiwe University Journal of Civil Engineering (NAUJCVE)

Volume-5, Issue-3, pp-85-92
www.naujcve.com
Research Paper Open Access

Geo-Spatial Evaluation of Soil Nitrogen Holding Capacity On A Farmland In Bosso, Niger State, Nigeria

Jirgba, K.[1], Tyogo, M.[2] and Abaver Z.[3*]

[1'2'3]*Department of Civil Engineering, Joseph Sarwuan Tarka University, Makurdi, Nigeria*

**Corresponding author: jirgbakavnen@yahoo.com*

***ABSTRACT** : This research investigates the effectiveness of Groundnut Shell Ash (GSA) as a sustainable stabilizing material for improving the nontechnical properties of lateritic soil used in road construction. Lateritic soils, although abundant and widely used across Nigeria, often exhibit high plasticity, low strength, and moisture susceptibility, which undermine pavement performance. The study seeks to address these deficiencies through GSA stabilization as a cost-effective and environmentally friendly alternative to conventional binders such as cement and lime. Laboratory-based tests, conducted in accordance with BS 1377 (1975), were performed on lateritic soil samples obtained from Ikpayongu, Gwer East Local Government Area, Benue State in Nigeria. The investigation assessed parameters including Atterberg limits, compaction characteristics, and California Bearing Ratio (CBR) at varying GSA contents of 0%, 2%, 4%, 6%, and 8% by dry weight of lateritic soil. The results revealed a general improvement in the engineering properties of the soil with increasing GSA content up to an optimum of 6%. At this level, the Maximum Dry Density (MDD) increased from 1.88 Mg/m3 to 2.15 Mg/m3, while the Optimum Moisture Content (OMC) decreased from 10.5% to 7.8%. The Plasticity Index (PI) reduced from 25% to 20%, and the unsoaked and soaked CBR values rose to 30.17% and 26.40%, respectively representing a strength enhancement of about 25-29% over the untreated soil. These findings demonstrate that GSA significantly improves the strength, compaction efficiency, and moisture resistance of lateritic soils, making it a viable, eco-friendly stabilizer for subgrade applications. The study recommends the adoption of 6% GSA content for low- to medium-traffic road subgrades in tropical regions and emphasizes its potential for sustainable infrastructure development through agricultural waste valorisation.*

***KEYWORDS**: Lateritic soil, Groundnut shell ash, Soil stabilization, Subgrade improvement, California Bearing Ratio, Sustainable construction.*

Date of Submission: 14-07-2026 Date of acceptance: 28-07-2026

I. INTRODUCTION

Articulate soils are widely distributed in tropical and subtropical regions and constitute the primary construction material for road subgrades across Nigeria due to their abundance and relatively low cost (Ubi et al., 2022). Despite their widespread use, these soils frequently exhibit unfavourable geotechnical properties, including high plasticity, low shear strength, and high susceptibility to moisture variations. These deficiencies often result in pavement distress such as rutting, cracking, and reduced service life (Adeniyi et al., 2025).

Soil stabilisation is a technique employed to improve the engineering properties of problematic soils for highway construction. Although conventional stabilisers such as cement and lime are effective, their application is increasingly constrained by high cost and significant environmental concerns, particularly the carbon emissions associated with cement production. Consequently, there has been growing interest in the use of sustainable, locally available materials derived from agricultural waste (Adetayo et al., 2021).

Among such alternatives, groundnut shell ash (GSA) has emerged as a promising pozzolanic stabiliser. It is produced from the controlled combustion of groundnut shells as an abundant agricultural by-product. In Nigeria GSA contains reactive silica and alumina that facilitate the formation of cementitious compounds in the presence of moisture, thereby enhancing soil strength and durability. Recent studies conducted in Nigeria have demonstrated that the incorporation of GSA into lateritic soils reduces the plasticity index and improves compaction characteristics and California Bearing Ratio (CBR) values (Ubi et al., 2022; Adeniyi et al., 2025).

Despite these advances, the effectiveness of GSA stabilisation is known to vary with soil mineralogy, environmental conditions, and mix proportions. Furthermore, limited research has evaluated the performance of GSA on lateritic soils sourced specifically from Benue State, particularly those along the Makurdi–Aliade road corridor. This paucity of site-specific data restricts the development of locally optimised design guidelines for sustainable road construction in the region (Osinubi&Nwaiwu, 2006; Mezie et al., 2023).

The present study therefore investigates the effectiveness of groundnut shell ash as a stabilising agent for lateritic soil obtained from Ikpayongu along the Makurdi–Aliade road in Benue State, Nigeria. The research evaluates the influence of GSA at varying contents (0%, 2%, 4%, 6%, and 8% by dry weight of soil) on Atterberg limits, compaction characteristics, and California Bearing Ratio, with the aim of determining the optimum stabiliser content for subgrade improvement in tropical environments.

Lateritic soils, formed under intense tropical weathering, are the dominant subgrade material for road construction across Nigeria because of their wide availability and low cost. However, these soils are characterised by high plasticity, low shear strength, and pronounced moisture sensitivity, leading to premature pavement failures such as rutting, cracking, and excessive settlement (Ubi et al., 2022; Adeniyi et al., 2025).

Conventional chemical stabilisation using cement or lime has been widely adopted to improve the engineering properties of lateritic soils. While these binders effectively reduce plasticity and increase strength, their application is increasingly limited by high procurement costs, non-availability in remote areas, and significant environmental footprints associated with cement production (Adetayo et al., 2021). These drawbacks have stimulated research into sustainable alternatives derived from agricultural and industrial wastes.

Recent Nigerian studies have consistently reported favourable results when GSA is used alone or in combination with small quantities of lime or cement (Amu et al., 2011; Adetayo et al., 2021; Faluyi et al., 2024).

Ubi et al. (2022) investigated GSA stabilisation of lateritic soils in the South-South region and observed a reduction in plasticity index from 28 % to 19 % and an increase in unsoaked CBR from 18 % to 32 % at 6 % GSA content. Similarly, Adeniyi et al. (2025), working on soils from Oyo State, recorded maximum dry density increases of up to 12 % and soaked CBR values exceeding 25 % at 6–8 % GSA replacement, confirming the optimum stabiliser range for subgrade applications. Adetayo et al. (2021) and Faluyi et al. (2024) further demonstrated that partial replacement of lime with GSA not only maintains strength gains but also reduces the overall cost of stabilisation by 30–40 % while lowering the carbon footprint.

Despite these encouraging findings, several limitations remain evident in the existing body of literature. Most studies have been conducted on soils from South-Western and South-South Nigeria; very few have examined lateritic soils from the North-Central region, particularly those in Benue State, where climatic and mineralogical conditions differ. Moreover, the majority of investigations relied on standard laboratory tests without chemical characterisation of the GSA or long-term durability assessments under tropical wetting–drying cycles. These gaps limit the development of locally optimised design guidelines for sustainable road construction in Benue State and similar tropical environments.

The present study therefore addresses this research gap by systematically evaluating the influence of groundnut shell ash (0–8 % by dry weight) on the index, compaction, and strength properties of lateritic soil obta ined from Ikpayongu along the Makurdi–Aliade road in Benue State, Nigeria.

II. MATERIALS AND METHODS

2.1 Study Area and Soil Sampling

Lateritic soil samples were obtained from borrow pits at Ikpayongu along the Makurdi–Aliade road in Benue State, Nigeria (latitude 7° 15′ N, longitude 8° 35′ E). The area lies within the tropical savanna climatic zone characterised by distinct wet and dry seasons that significantly influence subgrade soil behaviour. Samples were collected at depths of 1.0–1.5 m below the ground surface to minimise organic matter and surface contaminants. The collected material was sealed in polythene bags, transported to the geotechnical laboratory, air-dried, pulverised, and sieved through a 4.75 mm sieve prior to testing.

2.2 Materials

2.2.1 Lateritic Soil

The natural lateritic soil served as the base material. It is a residual soil formed through intense tropical weathering and is widely used as subgrade fill in Nigerian road projects owing to its abundance. However, its engineering performance is often limited by moderate plasticity and moisture sensitivity.

2.2.2 Groundnut Shell Ash (GSA)

Groundnut shell ash was produced from groundnut shells sourced from local markets in Makurdi. The shells were cleaned, sun-dried, and burnt in a controlled open-air furnace at approximately 600°C to 700°C for 6 hours. The resulting ash was cooled, sieved through a 75 µm sieve, and stored in airtight containers. GSA is a pozzolanic material rich in silica and alumina, capable of forming cementitious compounds when mixed with soil in the presence of moisture.

Plate 1: Processed groundnut shell ash used in the study

2.3 Sample Preparation

Soil samples were stabilized by mixing the natural lateritic soil with varying percentages of groundnut shell ash. The stabilization process involved the addition of GSA at proportions of 0%, 2%, 4%, 6%, and 8% by dry weight of soil. Each mixture was thoroughly blended to achieve uniform distribution of the stabilizing material within the soil matrix prior to laboratory testing.

2.4 Laboratory Tests

Laboratory tests were conducted to determine the index and engineering properties of both the natural soil and the stabilized soil mixtures. All tests were performed in accordance with procedures specified in BS 1377: Methods of Test for Soils for Civil Engineering Purposes.
The following tests were carried out: Particle Size Distribution, Specific Gravity Test, Atterberg Limits, Compaction Test and California Bearing Ratio (CBR)

III. RESULTS AND DISCUSSION

3.1 Geotechnical Properties of the Natural Articulate Soil

The preliminary laboratory investigation was conducted to establish the baseline geotechnical characteristics of the lateritic soil prior to stabilization. These parameters provide a reference for evaluating the improvements achieved through the addition of Groundnut Shell Ash (GSA).

3.1.1 Particle Size Distribution

The untreated lateritic soil was classified as A-2-6 (AASHTO) and SC (USCS), with 96.75 % sand-sized particles and only 3.25 % fines passing the 0.075 mm sieve. The uniformity coefficient (C_u = 5.82) and coefficient of curvature (C_c = 0.88) indicated a poorly graded material. The specific gravity was 2.54, consistent with values reported for Nigerian lateritic soils (Ubi et al., 2022). These baseline properties confirm the soil's fair-to-good subgrade rating when properly compacted, yet its moderate plasticity necessitates stabilisation.

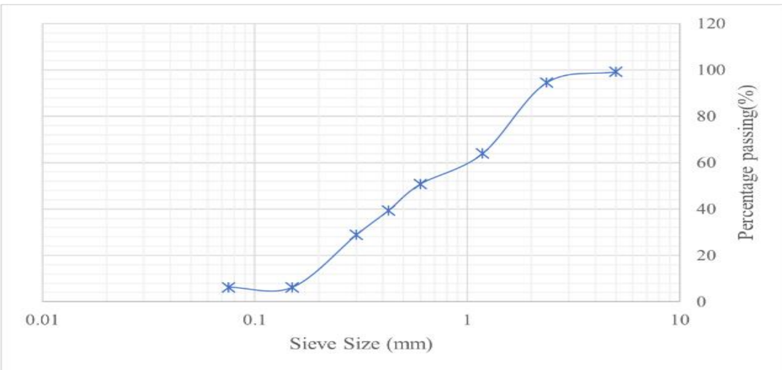

Fig. 1: Gradation curve for natural laterite

Volume-5, Issue-3, pp-85-92
www.naujcve.com
Research Paper Open Access

The relatively coarse-grained nature of the soil promotes mechanical interlocking between particles, which enhances compaction efficiency. However, the presence of clay fractions can still contribute to plasticity and moisture sensitivity, necessitating stabilization for improved engineering performance.

3.1.2 Specific Gravity

The specific gravity of the natural lateritic soil was determined to be 2.54, which falls within the typical range of 2.4–2.7 for lateritic soils in tropical regions.

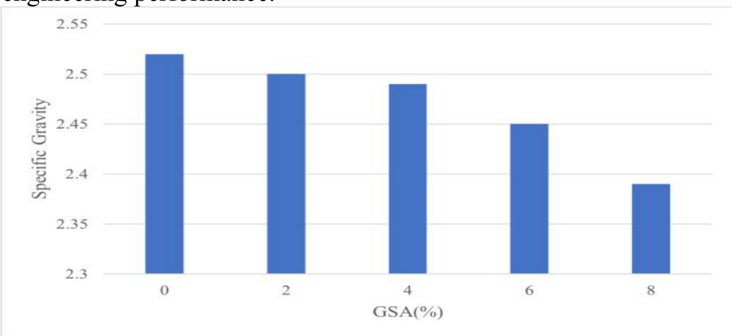

Fig. 2: Graph of Specific gravity against variations of GSA percentages

The obtained value is consistent with previously reported values for lateritic soils in Nigeria, which typically range between 2.4 and 2.7, and confirms the suitability of the soil for stabilization studies (Bowles, 1996; Ubi et al., 2022).The obtained value is consistent with previously reported values for lateritic soils in Nigeria and confirms the suitability of the soil for stabilization studies.

3.2 Influence of Groundnut Shell Ash on Compaction Characteristics

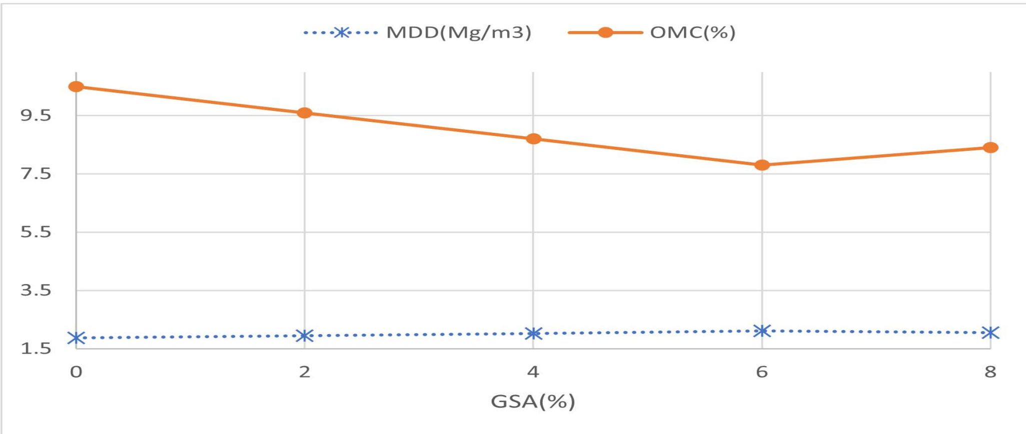

Fig. 3: Graph of Compaction characteristics against GSA percentages

As shown in Fig. 3, the maximum dry density increased progressively from 1.88 Mg/m³ (0 % GSA) to a peak of 2.15 Mg/m³ at 6 % GSA, while the optimum moisture content decreased from 10.5 % to 7.8 %. These trends are attributed to the filler effect of fine GSA particles and the onset of pozzolanic reactions forming calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) gels that improve particle packing (Little, 1995; Adetayo et al., 2021).

The observed optimum at 6 % GSA and the magnitude of improvement (≈14 % increase in MDD) are in excellent agreement with Ubi et al. (2022) and Adeniyi et al. (2025), who reported peak MDD values of 2.12–2.18 Mg/m³ at the same stabiliser content for lateritic soils from the South-South and South-West regions. This validation confirms that 6 % GSA provides the optimal balance for field compaction in tropical environments.

3.3 Effect of Groundnut Shell Ash on Atterberg Limits

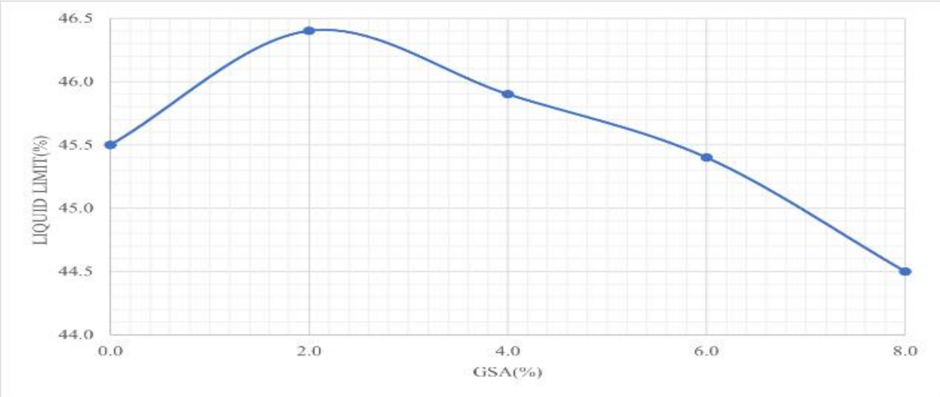

Fig. 4: Variation of Liquid Limit with GSA Content

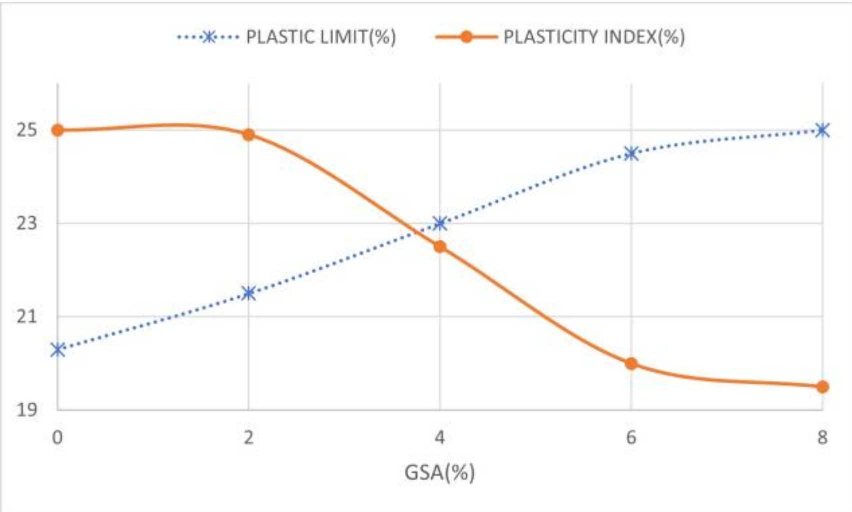

Fig. 5: Variation of Plastic Limit (PL)

The liquid limit rose marginally from 45.5 % to 46.4 % at 2 % GSA before decreasing to 44.5 % at 8 % GSA. More significantly, the plasticity index reduced steadily from 25 % to 20 % at 6 % GSA. According to Fig.s 4 and 5, the liquid limit decreased slightly at higher GSA contents, while the plasticity index reduced steadily from 25 % to 20 % at 6 % GSA. The reduction in plasticity is explained by the flocculation and agglomeration of clay particles as well as the formation of cementitious compounds that restrict water adsorption and improve soil stability (Bell, 1996; Adetayo et al., 2021).

These changes are consistent with findings by Adetayo et al. (2021) and Adeniyi et al. (2025), who documented 4–7 % reductions in plasticity index at 6 % GSA. The validated improvement enhances volume stability and reduces the risk of shrinkage cracking in pavement subgrades.

3.4 California Bearing Ratio (CBR)

The California Bearing Ratio (CBR) test was conducted to evaluate the load-bearing capacity of the stabilized soil mixtures under both soaked and unsoaked conditions.

Volume-5, Issue-3, pp-85-92
www.naujcve.com
Research Paper Open Access

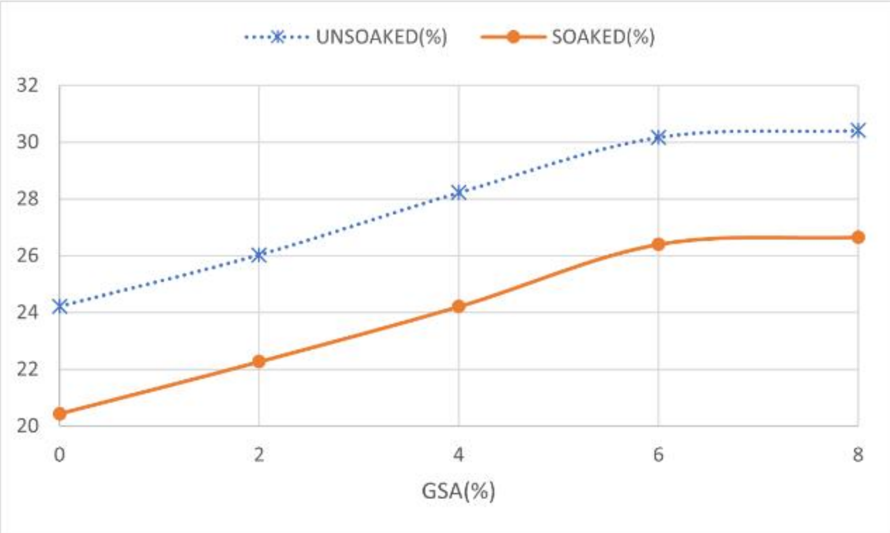

Fig. 6: Variations of CBR with GSA content in soaked and unsoaked conditions

3.4.1 Unsoaked CBR

As shown in Fig. 6, the unsoaked CBR values increased from 24.21 % for the untreated soil to 30.17 % at 6 % GSA, with a marginal increase to 30.41 % at 8 % GSA.

This progressive improvement indicates that the addition of GSA significantly enhances the soil's resistance to penetration and deformation under traffic loads. As shown in Fig. 6, the increase in unsoaked CBR is primarily attributed to the formation of cementitious compounds produced during pozzolanic reactions between the soil and GSA, which improve particle interlocking and reduce void spaces within the soil matrix (Adeniyi et al., 2025; Faluyi et al., 2024).

3.4.2 Soaked CBR

Fig. 6 shows that the soaked CBR values increased from 20.44 % for the untreated soil to 26.40 % at 6 % GSA, with a slight increase to 26.65 % at 8 % GSA.

The improvement in soaked CBR indicates that GSA stabilization enhances the soil's resistance to moisture-induced softening. The cementitious products formed during the pozzolanic reaction help maintain structural integrity even under saturated conditions.

The relatively small difference between soaked and unsoaked CBR values at higher GSA contents suggests improved moisture resistance and reduced susceptibility to water-induced weakening, which is particularly beneficial for pavement subgrades exposed to seasonal rainfall in tropical regions (Mezie et al., 2023; Adeniyi et al., 2025).

3.5 Optimum Groundnut Shell Ash Content

Collectively, the peak improvements in MDD, OMC, plasticity index, and both soaked/unsoaked CBR occurred at 6 % GSA. Beyond this percentage, marginal or reverse trends were observed, consistent with excessive unreacted ash particles disrupting the soil matrix (Adetayo et al., 2021). The results therefore confirm 6 % GSA as the optimum stabiliser content for the Ikpayongu lateritic soil, aligning closely with optimum values reported across multiple Nigerian studies (Ubi et al., 2022; Adeniyi et al., 2025). This corroboration strengthens the generalisability of the findings for sustainable road construction in tropical regions. The geotechnical improvements observed in this study demonstrate the practical viability of groundnut shell ash (GSA) as a sustainable stabiliser for lateritic subgrade soils in Nigeria. The 14 % increase in maximum dry density (to 2.15 Mg/m³) and 26 % reduction in optimum moisture content (to 7.8 %) at 6 % GSA significantly enhance field compaction efficiency. These values align closely with those reported by Ubi et al. (2022), Adeniyi et al. (2025), and Adam (2025) for lateritic soils in the South-South, South-West, and Edo regions, confirming that 6 % GSA consistently optimises particle packing and reduces moisture demand under tropical conditions. For contractors in Benue State, this translates to easier achievement of required field densities with less water and shorter construction time.

The California Bearing Ratio (CBR) results provide even stronger evidence for pavement design optimisation. The unsoaked CBR rose by 25 % to 30.17 % and the soaked CBR by 29 % to 26.40 % at 6 % GSA. Such strength gains are comparable to the 25 to 48 % CBR improvements documented by Ubi et al. (2022), Adeniyi et al. (2025), and Adam (2025). More importantly, the present study's soaked CBR value exceeds the minimum 25 % threshold recommended for low- to medium-traffic roads in Nigeria (Federal Ministry of Works, 2013). This allows designers to reduce the thickness of overlying base and subbase layers, potentially lowering overall pavement construction costs by 15 to 25 % compared with untreated or cement-stabilised sections (a cost-saving magnitude also highlighted by Adetayo et al., 2021; Mezie et al., 2023).

The reduction in plasticity index (from 25 % to 20 %) further strengthens subgrade performance by minimising shrink-swell potential and moisture-induced softening. This improvement, validated by Adetayo et al. (2021) and Mezie et al. (2023), is particularly beneficial in Benue State, where seasonal rainfall frequently saturates subgrades.

IV. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study evaluated the effectiveness of groundnut shell ash (GSA) as a stabilizing agent for improving the geotechnical properties of lateritic soil intended for road subgrade applications. Laboratory analyses showed that the natural soil, classified as A-2-6 (AASHTO) and SC (USCS), exhibited moderate engineering properties but required stabilization to enhance its performance under traffic loading and varying moisture conditions. The inclusion of GSA significantly influenced the soil behaviour by improving compaction characteristics, reducing plasticity, and increasing the load-bearing capacity of the soil. Maximum dry density increased while optimum moisture content decreased with increasing GSA content up to an optimum level, indicating improved particle packing and soil structure. Similarly, the California Bearing Ratio values increased under both soaked and unsoaked conditions, demonstrating enhanced resistance to deformation and improved subgrade strength. Among the tested mixtures, an optimum GSA content of approximately 6% by dry weight of soil produced the most favourable combination of compaction and strength characteristics. The results therefore demonstrate that groundnut shell ash is an effective and sustainable stabilizing material capable of improving the engineering performance of lateritic soils, while also promoting the beneficial reuse of agricultural waste materials for cost-effective and environmentally responsible road construction.

5.2 Recommendations

The following recommendations are proposed:

1.Further research should be conducted under field conditions to evaluate the long-term performance of GSA-stabilized lateritic soils in actual pavement structures. Field trials would provide more reliable information on durability, compaction behaviour, and performance under real traffic loading and environmental conditions.
2.Additional studies should investigate the durability characteristics of GSA-stabilized soils, particularly their resistance to cyclic wetting and drying, freeze–thaw effects, and long-term strength development.
3.Investigations should be carried out on the combined use of groundnut shell ash with conventional stabilizers such as cement or lime in order to determine whether synergistic effects can further improve soil strength and durability.

REFERENCES

[1]Adam, H. (2025). Performance of groundnut shell ash as supplementary material to cement in stabilizing lateritic soil. International Journal of Multidisciplinary and Current Educational Research, 8(1), 1–17.

[2]Adeniyi, I. A., Olabiyi, Y. A., &Ogundalu, A. O. (2025). The effect of groundnut shell ash on the geotechnical properties of lateritic soils. LAUTECH Journal of Civil and Environmental Studies (LAUJOCES), 14(1), 45–58. https://laujoces.org/article_download/vol_14/issue_1/Paper_5.pdf

[3]Adetayo, O., Amu, O. O., &Adetayo, A. A. (2021). Effect of groundnut shell ash on laterite soils stabilized with lime for civil structures. International Journal of Engineering Research and Technology, 10(5), 1–12.

[4]Alhassan, M. (2008). Potentials of rice husk ash for soil stabilization. AU Journal of Technology, 11(4), 246–250.

[5]American Society for Testing and Materials. (2017). ASTM D2166: Standard test method for unconfined compressive strength of cohesive soil. ASTM International.

[6]American Society for Testing and Materials. (2017). ASTM D4318: Standard test methods for liquid limit, plastic limit, and plasticity index of soils. ASTM International.

[7]American Society for Testing and Materials. (2017). ASTM D698: Standard test methods for laboratory compaction characteristics of soil using standard effort. ASTM International.
[8]Amu, O. O., Adetuberu, A. A., &Ibitoye, A. B. (2011). Stabilization of lateritic soil with cement and groundnut shell ash. International Journal of Engineering Science and Technology, 3(6), 528–535.
[9]Amu, O. O., Owokade, O. S., &Shomoye, O. I. (2021). Potentials of coconut shell and husk ash on the geotechnical properties of lateritic soil for road construction. International Journal of Engineering Science and Technology, 3(6), 87–102.
[10]Bell, F. G. (1996). Lime stabilization of clay minerals and soils. Engineering Geology, 42(4), 223–237.
[11]Bowles, J. E. (1996). Foundation analysis and design (5th ed.). McGraw-Hill.
[12]Das, B. M., &Sivakugan, N. (2018). Principles of foundation engineering (9th ed.). Cengage Learning.
[13]Faluyi, S. O., Amu, O. O., &Olontuyi, I. O. (2024). Geotechnical characteristics of lime and groundnut shell ash (GSA) stabilised soils for road building in Southwestern Nigeria. Research Square. (Preprint) https://doi.org/10.21203/rs.3.rs-XXXXXXX/v1
[14]Federal Ministry of Works. (2013). Highway manual part 1: Design, volume III: Pavement and materials design. Federal Ministry of Works.
[15]Little, D. N. (1995). Handbook for stabilization of pavement subgrades and base courses with lime. Iowa State University Press.
[16]Mezie, E. O., Ezeokonkwo, J. C., Ugwu, O. O., &Nwakaire, C. M. (2023). Effects of partial replacement of cement and lime with some agrowaste ashes on the geotechnical behaviour of lateritic soil. Saudi Journal of Civil Engineering, 7(4), 115–126. https://saudijournals.com/media/articles/SJCE_74_115-126.pdf
[17]Oluremi, J. R., Adedokun, S. I., &Osinubi, K. J. (2012). Stabilization of lateritic soils with agricultural waste ash. Electronic Journal of Geotechnical Engineering, 17, 447–457.
[18]Osinubi, K. J., &Nwaiwu, C. M. O. (2006). Design of compacted lateritic soil liners and covers. Journal of Geotechnical and Geoenvironmental Engineering, 132(2), 203–213.
[19]Osinubi, K. J., Eberemu, A. O., Yohanna, P., & Etim, R. K. (2020). Reliability estimate of CBR of black cotton soil stabilized with cement kiln dust and random inclusion of sisal fiber. Journal of Testing and Evaluation, 48(1), 1–21. https://doi.org/10.1520/JTE20180295
[20]Rahman, M. A. (1987). Effect of cement-rice husk ash mixtures on geotechnical properties of lateritic soils. Soils and Foundations, 27(2), 61–65.
[21]Ubi, S. E., Nyak, E. E., &Agbor, R. B. (2022). Enhancement of soil stability with groundnut shell ash. Journal of Civil Engineering Research, 12(1), 1–7. https://doi.org/10.5923/j.jce.20221201.01

