Vol 6, Issue 6, June 2026 www.ijesti.com E-ISSN: 2582-9734
International Journal of Engineering, Science, Technology and Innovation (IJESTI)

Evaluating Stabilized Soil Methods for Durable and Sustainable Rural Road Development: A Comprehensive Research

Ashish Raj
M. Tech. in Transportation Engineering, CBS Group of Institutions, Jhajjar, Haryana.

Vishal Panchal
A.P Civil Department, CBS Group of Institutions, Jhajjar, Haryana.

ABSTRACT

This study evaluates the performance of stabilized soil techniques for sustainable rural road construction. Weak rural road soils often have low strength, high plasticity, and poor load-bearing capacity, leading to early pavement failure and frequent maintenance. The study examines different stabilization methods using lime, cement, fly ash, quarry dust, and lime–fly ash combinations. Results show that stabilized soil improves California Bearing Ratio, compressive strength, compaction, and durability compared with untreated soil. Among the techniques, lime–fly ash stabilization provides the best overall performance. Therefore, soil stabilization is an economical, durable, and eco-friendly solution for rural road development.

Keywords: *Soil Stabilization, Rural Roads, Sustainable Construction, CBR Value, Fly Ash.*

I. INTRODUCTION

Rural roads are the foundation of social and economic development in village areas because they provide basic connectivity between habitations, agricultural fields, markets, schools, health centres, administrative offices, and nearby towns. In developing countries like India, a large portion of the population depends on rural road networks for daily movement, agricultural transportation, employment access, and essential services. However, the construction and maintenance of rural roads remain a major challenge due to weak subgrade soil, poor drainage, seasonal rainfall, limited funds, and high maintenance requirements. Many rural roads are constructed over locally available soil that may not always satisfy the required engineering standards for pavement construction. Such soils may have low California Bearing Ratio value, high plasticity, excessive swelling and shrinkage behaviour, poor compaction characteristics, and low resistance against repeated traffic loading. When untreated weak soil is used in road construction, it may cause premature pavement failure in the form of rutting, settlement, cracking, pothole formation, edge breaking, and surface deformation. These failures not only reduce the service life of the road but also increase transportation cost, travel time, accident risk, and maintenance expenditure. Therefore, improving the engineering properties of local soil has become an important requirement for sustainable rural road construction. Soil stabilization is one of the most practical, economical, and widely accepted techniques used to enhance the performance of weak soil for road pavement applications. It involves the modification of natural soil by mechanical, chemical, or additive-based methods to improve its strength, durability, stability, and load-bearing capacity. Stabilized soil techniques can include the use of lime, cement, fly ash, bitumen, quarry dust, rice husk ash, stone dust, geopolymers, fibres, and other industrial or agricultural by-products. These stabilizers react with soil particles and improve bonding, reduce plasticity, increase density, and enhance resistance to moisture-related damage. Lime stabilization is especially useful for highly plastic clayey soils because it reduces plasticity and improves workability through cation exchange and pozzolanic reactions. Cement stabilization provides higher strength and stiffness by forming cementitious compounds that bind soil particles together. Fly ash, rice husk ash, and other waste materials are also gaining attention because they support the reuse of industrial by-products and reduce the need for conventional construction materials. In rural road projects, the selection of a suitable stabilization technique depends on soil type, traffic intensity, climatic condition, availability of materials, cost, environmental impact, and expected pavement life. Since rural roads often have limited budgets, the use of locally available stabilizers and waste materials becomes highly beneficial. Stabilized soil not only improves pavement performance but also reduces the thickness requirement of pavement layers, minimizes aggregate consumption, decreases construction cost, and improves long-term serviceability. Thus, the performance evaluation of stabilized soil techniques is essential for identifying suitable methods that can provide durable, economical, and environmentally responsible rural road infrastructure.

The topic “Performance Evaluation of Stabilized Soil Techniques for Sustainable Rural Road Construction” focuses on assessing how different soil stabilization methods improve the engineering behaviour of soil used in rural road pavements. The concept of sustainability in rural road construction is not limited to environmental protection only; it also includes economic efficiency, durability, local resource utilization, low maintenance demand, and social benefit. Traditional road construction generally depends on large quantities of natural aggregates, borrow soil, and energy-intensive materials. Excessive extraction of aggregates and soil from natural sources causes environmental degradation, land disturbance, increased carbon emissions, and depletion of non-renewable resources. In this context, stabilized soil techniques provide a sustainable alternative by improving locally available soil and reducing dependence on costly imported materials. The use of industrial by-products such as fly ash, quarry dust, slag, and cement kiln dust also helps in waste management and supports circular economy principles. Similarly, agricultural wastes such as rice husk ash and coir fibre can be used to enhance soil properties while reducing disposal problems. Performance evaluation of stabilized soil usually includes laboratory tests and field-based observations to compare untreated soil with treated soil. Important tests such as grain size analysis, Atterberg limits, Standard Proctor compaction test, California Bearing Ratio test, Unconfined Compressive Strength test, permeability test, durability test, and wet-dry cycle test help in determining the suitability of stabilized soil for pavement construction. The CBR test is particularly important for rural roads because it indicates the load-bearing capacity of subgrade soil. A higher CBR value means that the soil can support traffic loads more effectively and may require a thinner pavement layer. Similarly, compressive strength and durability tests help in understanding the resistance of stabilized soil against deformation, moisture variation, and long-term traffic stress. The evaluation of stabilized soil techniques also helps engineers identify the optimum percentage of stabilizer required to achieve desired strength without unnecessary increase in cost. For example, excessive use of cement may increase strength but also raise construction cost and carbon emissions. On the other hand, a balanced combination of lime and fly ash may provide adequate strength, improved plasticity control, and better sustainability. Therefore, the comparative study of different stabilization methods becomes necessary to select the most appropriate technique for specific rural road conditions. In sustainable rural road construction, the main aim is to build roads that are strong, durable, affordable, and environmentally safe. Stabilized soil techniques contribute to this aim by improving weak subgrade soil, reducing pavement failure, extending road service life, and lowering maintenance frequency. Better rural roads improve agricultural supply chains, enhance access to education and healthcare, generate employment opportunities, and support overall rural development. Hence, performance evaluation of stabilized soil techniques is highly significant for developing cost-effective and sustainable rural road infrastructure. This study provides a useful framework for understanding the role of soil stabilization in improving pavement performance and promoting sustainable construction practices in rural areas.

II. RESEARCH BACKGROUND

Mgaya et al. (2026) had presented a structured literature review on the potential use of synthetic nonwoven waste materials as soil reinforcement agents in geotechnical engineering, in response to the growing environmental concerns associated with plastic-based nonwoven waste and the increasing demand for sustainable ground improvement techniques. Following the PRISMA 2020 framework, the authors had initially identified 54 publications, of which 15 studies were selected for detailed review based on the inclusion criteria. The review findings had consistently indicated that the incorporation of small proportions of synthetic nonwoven fibers (0.2–1.5% by dry soil weight) significantly improved important geotechnical properties of soil. It had been reported that unconfined compressive strength increased by up to 64%, California Bearing Ratio (CBR) values improved substantially, plasticity index decreased, and swelling potential was notably reduced. These improvements had been attributed to mechanisms such as mechanical interlocking, frictional resistance, and crack-bridging effects within the soil matrix. The study had concluded that synthetic nonwoven waste materials represented a technically effective and environmentally sustainable alternative to conventional chemical stabilizers, particularly for subgrade and embankment applications, while also supporting circular economy principles. However, the authors had noted the lack of research in the Tanzanian context and had recommended further experimental studies to assess locally available materials and develop practical design guidelines.

Kanalli et al., (2026) investigated the stabilization of clayey soil using mine waste (MW) and granulated blast furnace slag (GBFS) to enhance its suitability for pavement applications in northern Karnataka, India, where soils were known for high compressibility and low bearing capacity. Initially, MW was added in varying proportions (0–50%) to the soil, which was reported to improve compaction characteristics, increasing the maximum dry unit weight from 16.38 to 19.71 kN/m³ and the California bearing ratio (CBR) from 2.3 to 5.6%, although the resulting strength remained insufficient for high-volume roads. Subsequently, GBFS was incorporated (0–50%) into the optimum soil-MW mix (60:40), and the addition of 30% GBFS was found to increase the soaked CBR to 10%, significantly enhancing soil strength. Two pavement structures were designed and analyzed using finite element modeling through IITPAVE and ABAQUS, with Pavement-II, containing a cement-treated base, demonstrating lower compressive and tensile strains than Pavement-I. Life cycle cost analysis indicated a 36.91% reduction in total costs for Pavement-II, while life cycle assessment showed a 61.32% decrease in carbon footprint, highlighting both economic and environmental benefits, and promoting sustainable pavement construction using locally available waste materials.

Jamnongwong et al. (2025) investigated the potential use of dam sediments, typically considered waste, as sustainable materials for road construction by stabilizing them with eucalyptus ash (EA) and cement. They noted that EA, recognized for its pozzolanic activity, was blended with cement to enhance both the mechanical strength and environmental performance of the sediments. Destructive tests, including unconfined compressive strength and California bearing ratio, indicated that a 10% EA-cement blend significantly improved mechanical properties, with the unconfined compressive strength reaching 2.25 MPa, nearly five times higher than that of untreated sediments. Nondestructive free-free resonance tests corroborated these findings by showing increased wave velocities, reflecting greater material stiffness and strength. Microstructural analysis revealed the formation of calcium silicate hydrate gels, which contributed to matrix densification and stronger interparticle bonding. Leaching tests demonstrated that heavy metal concentrations in the stabilized samples were well below regulatory thresholds, and groundwater quality assessments confirmed chemical and microbiological safety. Cost analysis further suggested that using EA-cement-stabilized sediments could be 5.7 times more cost-effective than conventional materials. Overall, they concluded that the mechanical, microstructural, environmental, and economic outcomes supported the use of EA-cement-stabilized dam sediments as a sustainable and viable alternative in road construction.

Primusz et al. (2025) investigated the potential of on-site mixed stabilization of cohesive soils in Hungary, which was traditionally considered only as soil improvement rather than a structural pavement layer, and whose bearing capacity was typically disregarded in pavement design. They hypothesized that for low-volume roads constructed on cohesive soils, lime or lime–cement stabilization could serve as an alternative to granular base layers. A case study was conducted to validate this hypothesis and the proposed research methodology. The study evaluated the efficacy of lime stabilization across eight experimental road sections, comparing structural and economic performance against crushed stone base layers reinforced with geo-synthetics. The results indicated that the elastic moduli of the lime-stabilized layers ranged from 120 to 180 MPa, closely approaching the 200–280 MPa observed for crushed stone bases. The findings suggested that lime stabilization provided comparable load-bearing capacity while being more cost-effective. Additionally, this approach was reported to enhance sustainability by utilizing local soils, reducing dependence on imported materials, lowering transport costs, and minimizing carbon emissions, thereby offering a durable and environmentally friendly alternative for resilient road construction.

Chinkhuntha et al., (2024) investigated the engineering properties of Red Clay Soils (RCS) in tropical regions, noting that their high compressibility, creep rates, plasticity, low strength, and swelling potential often rendered them unsuitable for road construction. The study examined the potential of stabilizing RCS using Bluegum Sawdust Ash (BSDA) and Sisal Fiber (SF) to develop a cost-effective and environmentally sustainable material for low-volume roadways. Experiments were conducted on both unstabilized and stabilized soil samples to assess physical properties, including Atterberg limits, compaction, Unconfined Compressive Strength (UCS), and California Bearing Ratio (CBR). BSDA was incorporated in increments from 2% to 10%, with 6% identified as optimal, which led to a reduction in the Plasticity Index from 20.78% to 10.90% and substantial improvements in UCS and CBR values. The inclusion of SF further enhanced stabilization, increasing the soaked CBR to 28.12% and UCS to 736.011 kN/m^3. The study concluded that this triphasic approach of combining RCS, BSDA, and SF provided a sustainable and economical solution for road subbase construction.

Pooni et al., (2023) highlighted that unsealed roads formed a crucial component for the growth and development of many countries, where low traffic volumes and economic constraints often precluded the construction of higher-class paved roads, rendering them prone to distress. They noted that prior research had indicated that targeted application of additives and specific techniques could enhance the engineering and geotechnical properties of unsealed pavements. The study presented a comprehensive, up-to-date literature review on methods to improve unsealed road durability, categorizing the literature into non-chemical and chemical additive techniques. The authors discussed these techniques to provide a critical overview of their stabilisation mechanisms, properties, performance, durability, and suitability for unsealed roads. The review emphasized a shift toward sustainable stabilisation methods that minimized disruption to existing pavement practices, contingent on a thorough understanding of stabilisation approaches and long-term performance data, thereby capturing the prevailing state-of-knowledge in unsealed road pavements.

Kulkarni and Mandal (2022) investigated the stabilization of weak soils for road infrastructure, emphasizing that proper stabilization of such soils using innovative technologies could enable their use as sub-base materials in low-volume road construction, replacing conventional granular sub-bases. They carried out experiments on silty sand stabilized with nano zinc oxide (ZnO) and cement, applying 1%, 1.5%, and 2% of nano ZnO in combination with 2%, 4%, and 6% cement, respectively. The study examined the effects on proctor compaction, California Bearing Ratio (CBR), unconfined compressive strength (UCS), and Atterberg limits. It was reported that soaked CBR values increased substantially—by 158.5%, 311.9%, and 365.3%—when 1.5% nano ZnO was combined with 2%, 4%, and 6% cement. UCS values were found to improve markedly with curing time, while Atterberg limits indicated a reduction in soil plasticity at optimized proportions. SEM analyses confirmed the microstructural changes supporting these improvements. TCLP tests demonstrated that heavy metal concentrations in leachate remained within permissible limits. Strain analysis using IITPAVE suggested that the mix containing 1.5% nano ZnO and 6% cement was optimal, meeting criteria for chemically stabilized sub-base courses for low-volume roads.

Dhar and Hussain (2021) investigated the potential of lime to enhance the strength and bearing capacity of subgrade soils. They examined the effects of soil type, varying lime percentages (3, 5, 7, and 9%), and curing durations (0, 7, 14, and 28 days) on soil engineering properties through laboratory tests including linear shrinkage, unconfined compressive strength (UCS), split-tensile strength (STS), and California bearing ratio (CBR). Their findings suggested that soils with higher clay fractions required relatively greater lime content to modify physicochemical characteristics. Lime addition was observed to reduce linear shrinkage while increasing UCS, STS, and CBR values, although beyond an optimum lime content, an opposite trend was noted. Strength improvement of lime-stabilized soil was further enhanced with curing time. Microstructural analyses using FESEM, XRD, and FTIR indicated the formation of cementitious compounds, confirming changes in soil morphology. Soils with high plasticity indices yielded lower strength for specific lime contents and curing durations. Notably, 3% lime treatment achieved the 7-day target UCS of 345 kPa, and CBR values at optimum lime met subbase requirements for low-traffic rural roads, potentially reducing pavement thickness and construction costs.

Hinga (2021) investigated the potential of stabilizing red clay soil in Kenya’s central highlands, traditionally considered unsuitable for road construction, by using natural gravel and hydrated lime to produce an efficient, affordable, and sustainable material for low-volume roads in Nyeri County. The study involved blending red clay with natural gravel in six admixtures at 20% increments from 0 to 100%, with predetermined amounts of hydrated lime added to each mix. Advanced mineralogical and chemical analyses revealed that red soil and gravel were primarily composed of silica at 40.7% and 50.8%, respectively, while hydrated lime contained 72.5% calcium oxide, and kaolinite was identified as the dominant clay mineral in the soil. Gravel was classified as stone Class A after toughness testing. Standard procedures were applied to test particle size, specific gravity, consistency limits, activity, free swell, compaction, and California Bearing Ratio (CBR) on three specimens per admixture. The results indicated that both red soil and gravel were well-graded and classified as laterite soil and lateritic gravel. Specific gravity decreased slightly with increasing gravel and lime content, while lime addition (ranging from 2.2% to 4.7%) reduced consistency limits. Red soil showed a liquid limit of 74.3% and a plasticity index of 30.1%, differing notably from natural gravel. Free swell indices varied from 0 to 6.3%, peaking at 12.7% in soil-gravel-lime mixes, reflecting the influence of the stabilizers on soil behavior.

Rosales et al. (2020) investigated soil stabilization techniques and proposed the use of commercial nanomaterials, specifically silicate-based solutions, to enhance the technical properties and bearing capacity of expansive soils. They conducted a physico-chemical characterization of the nanomaterial and subsequently prepared various mixtures of expansive soil, selected soil, and artificial gravel with quicklime and the nanomaterial to assess improvements in soil performance. Their study reported that both compressive strength and the California Bearing Ratio (CBR) index increased considerably with the addition of nanomaterials. A full-scale application was performed on two sections of stabilized road, which were compared to a control section, revealing that the use of nanomaterials allowed a 30 cm reduction in the control section thickness, thereby decreasing quicklime usage and simplifying mechanical preparation. The authors concluded that commercial nanomaterials enhanced the performance of the stabilized sub-base layer and, through life cycle assessment, demonstrated a reduction in the environmental impact associated with conventional soil stabilization methods.

III. METHODOLOGY

The methodology of the study “Performance Evaluation of Stabilized Soil Techniques for Sustainable Rural Road Construction” was designed to evaluate the improvement in soil properties after using different stabilization materials. First, soil samples were collected from selected rural road construction sites. The collected samples were cleaned, dried, and prepared for laboratory testing. The basic properties of untreated soil were determined through tests such as grain size analysis, specific gravity test, Atterberg limits test, Standard Proctor compaction test, California Bearing Ratio test, and Unconfined Compressive Strength test. These tests helped to identify the natural strength, plasticity, compaction behaviour, and load-bearing capacity of the soil. After testing the untreated soil, different stabilizing materials such as lime, cement, fly ash, quarry dust, and a combination of lime and fly ash were mixed with the soil in selected proportions. Each stabilized soil sample was properly mixed with water and compacted according to standard laboratory procedures. The prepared samples were then tested again to evaluate changes in Maximum Dry Density, Optimum Moisture Content, CBR value, UCS value, and Plasticity Index. The results of stabilized soil were compared with untreated soil to determine the improvement in strength and durability. The performance of each stabilization technique was analysed on the basis of strength gain, plasticity reduction, compaction improvement, cost-effectiveness, and sustainability. Special attention was given to the use of locally available and waste materials because they reduce construction cost and environmental impact. Finally, the most suitable stabilization method was identified for sustainable rural road construction based on overall engineering performance and practical applicability.

IV. RESULT

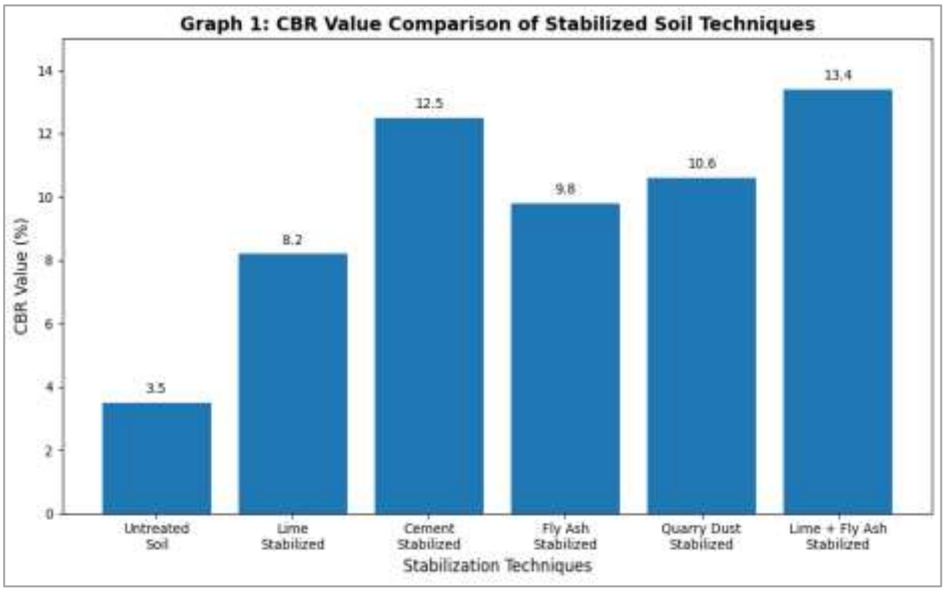
The performance evaluation of stabilized soil techniques showed that untreated soil had poor engineering properties and was not suitable for durable rural road construction without improvement. The natural soil showed low bearing capacity, higher plasticity, and weak resistance against load and moisture variation. After stabilization, clear improvement was observed in California Bearing Ratio, Unconfined Compressive Strength, Maximum Dry Density, and plasticity characteristics. Among the selected techniques, lime stabilization improved soil workability and reduced plasticity, while cement stabilization produced higher strength and stiffness. Fly ash and quarry dust stabilization also improved soil performance and supported sustainable road construction by using waste or locally available materials. The combined use of lime and fly ash showed the best overall performance because it improved strength, reduced plasticity, and provided better durability in a more sustainable way.

Table: Performance Evaluation of Different Stabilized Soil Techniques

Stabilization Technique	CBR Value (%)	UCS Value (kN/m²)	Maximum Dry Density (g/cc)	Plasticity Index (%)	Performance Level
Untreated Soil	3.5	110	1.68	24.0	Poor
Lime Stabilized Soil	8.2	245	1.74	14.5	Good
Cement Stabilized Soil	12.5	390	1.82	16.0	Very Good
Fly Ash Stabilized Soil	9.8	285	1.76	18.2	Good
Quarry Dust Stabilized Soil	10.6	310	1.80	17.5	Very Good
Lime + Fly Ash Stabilized Soil	13.4	420	1.84	12.8	Excellent

The result indicates that the CBR value increased from 3.5% in untreated soil to 13.4% in lime + fly ash stabilized soil, showing a major improvement in load-bearing capacity. Similarly, the UCS value increased from 110 kN/m² to 420 kN/m², which confirms better compressive strength and resistance against deformation. The Maximum Dry Density also improved after stabilization, indicating better compaction and soil particle arrangement. The Plasticity Index decreased significantly, especially in lime and lime + fly ash treated soil, showing improved stability and reduced swelling-shrinkage behaviour. Therefore, the overall results prove that stabilized soil techniques can improve weak soil performance and support sustainable rural road construction.

Bar Graph



The bar graph shows that untreated soil has the lowest CBR value of 3.5%, which indicates poor load-bearing capacity. After stabilization, the CBR value increases in all cases. The highest improvement is observed in lime + fly ash stabilized soil, with a CBR value of 13.4%, followed by cement stabilized soil at 12.5%. This shows that combined stabilization techniques can provide better strength and durability for sustainable rural road construction.

V. CONCLUSION

The study concluded that stabilized soil techniques are highly effective for improving the performance of weak soil used in sustainable rural road construction. Untreated soil generally has low bearing capacity, high plasticity, poor compaction characteristics, and weak resistance against moisture and repeated traffic loads. Due to these limitations, roads constructed on untreated soil may suffer from early failure, rutting, cracking, settlement, and frequent maintenance problems. Soil stabilization helps to overcome these issues by improving strength, durability, density, and overall pavement stability. The results showed that all stabilization techniques improved the engineering properties of soil when compared with untreated soil. Lime stabilization was effective in reducing plasticity and improving soil workability, especially for clayey soil. Cement stabilization provided high compressive strength and better stiffness. Fly ash and quarry dust stabilization also improved soil performance while supporting sustainable construction by reusing waste or locally available materials. Among all techniques, the combination of lime and fly ash showed the best overall performance because it achieved the highest CBR value, better UCS value, reduced plasticity, and improved durability. Therefore, it can be concluded that stabilized soil techniques are suitable, economical, and sustainable solutions for rural road construction. These techniques reduce the need for natural aggregates, lower maintenance costs, improve road life, and promote the use of waste materials. Sustainable rural roads developed through soil stabilization can provide better connectivity, improve transportation facilities, support agricultural movement, and contribute to rural development. Hence, proper selection of stabilizing materials based on soil type, cost, availability, and environmental impact is essential for constructing strong, durable, and eco-friendly rural roads.

REFERENCES

1. Mgaya, J. J., Chengula, D. H., & Kifanyi, G. E. (2026) Sustainable Utilization of Synthetic Nonwoven Waste Materials (NWM) for Improving Clay Soils in Rural Road Construction in Tanzania: A Review Paper.
2. Kanalli, S. A., Badiger, M. H., Jaiswal, P., Naagesh, S., Ganesh, K., & Koppa, N. (2026). Stabilization of Clayey Soil Using Mine and Industrial Waste: Economic and Environmental Benefits of Bituminous Concrete Pavement with Cement-Treated Base. *International Journal of Pavement Research and Technology*, 1-24.
3. Jamnongwong, M., Wongvatana, N., Noorak, A., Jongpradist, P., Chaiprakaikeow, S., & Jamsawang, P. (2025). Mechanical and Environmental Performance of Cement-Eucalyptus Ash Stabilized Dam Sediments for Sustainable Road Construction. *International Journal of Geosynthetics and Ground Engineering*, *11*(3), 31.
4. Primusz, P., Kisfaludi, B., Tóth, C., & Péterfalvi, J. (2025). Comparing Load-Bearing Capacity and Cost of Lime-Stabilized and Granular Road Bases for Rural Road Pavements. *Construction Materials*, *5*(4), 74.
5. Chinkhuntha, W., Owayo, A., & Ambassah, N. (2024). Performance evaluation of red clay soils stabilized with bluegum sawdust ash and sisal fiber as low-volume road sub-base materials. *Engineering, Technology & Applied Science Research*, *14*(6), 18105-18113.
6. Pooni, J., Robert, D., Giustozzi, F., Gunasekara, C., & Setunge, S. (2023). A review on soil stabilisation of unsealed road pavements from an Australian perspective. *Road Materials and Pavement Design*, *24*(4), 1005-1049.
7. Kulkarni, P. P., & Mandal, J. N. (2022). Evaluation of strength characteristics of soil stabilized with nano zinc oxide—cement mixes for low volume road applications. *International Journal of Geosynthetics and Ground Engineering*, *8*(1), 7.
8. Dhar, S., & Hussain, M. (2021). The strength and microstructural behavior of lime stabilized subgrade soil in road construction. *International Journal of Geotechnical Engineering*.
9. Hinga, G. N. (2021). *Performance of Red Soil Stabilized with Gravel and Lime in Construction of Low-Volume Roads in Nyeri County, Kenya* (Doctoral dissertation, Civil Enginnering, Jkuat).
10. Rosales, J., Agrela, F., Marcobal, J. R., Diaz-López, J. L., Cuenca-Moyano, G. M., Caballero, Á., & Cabrera, M. (2020). Use of nanomaterials in the stabilization of expansive soils into a road real-scale application. *Materials*, *13*(14), 3058.