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Geotechnical Assessment of Lateritic Borrow Materials for Road Construction along the Edéa–Kribi Corridor in Cameroon

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Abstract: This paper aimed to evaluate the suitability of lateritic borrow materials for applications in civil engineering, particularly road construction by conducting a geotechnical investigation and mapping of these materials along a 120-kilometer stretch of National Road No. 7 connecting Edéa and Kribi in Cameroon. The fieldwork in this study involved identification of 16 borrow sites and excavation of 64 test pits. Samples were subject to grain-size analysis, Atterberg limits, Modified Proctor compaction tests, and California Bearing Ratio (CBR) testing. Results showed that the soils were predominantly granular, with fine contents ranging from 15% to 28%, liquid limits from 50% to 86.5%, and plasticity indices between 24% and 33.3%. Dry densities ranged from 1.931 to 2.22 g/cm^3, and the CBR values varied between 33% and 49.8%, hence satisfying the requirements for foundation layers under the Experimental Centre for Research and Studies in Construction and Public Works (CEBTP) (1984) specifications. Geographic information system (GIS) mapping and lithological grouping of the borrow sites highlighted spatial variations in geotechnical behavior so as to classify three main lithological categories. These findings highlighted the potential of local lateritic materials as reliable and cost-effective resources for sustainable infrastructure development in tropical regions.

Keywords: Lateritic soils; Geotechnical mapping; Road construction; CBR; Edéa and Kribi; Cameroon; Lithological grouping; Tropical

1 Introduction

Lateritic soils, due to widespread availability and mechanical properties, are extensively used in many tropical developing countries for civil engineering works like road construction in particular. These materials are frequently employed in Cameroon for pavement sub-base and base layers, yet their heterogeneity and unpredictable behavior often result in structural failures of civil infrastructures such as roads, culverts, and buildings. To name a few examples in Cameroon, several structural collapses occurred, such as the failure of a culvert on National Road N°3 at Matomb in year 2016 and multiple building collapses in Douala and Dschang between years 2013 and 2017. Therefore, comprehensive geotechnical investigations are considered indispensable prior to the commencement of construction projects.

Lateritic soils are residual soils formed by intense chemical weathering of metamorphic and igneous rocks under hot and humid climates [1]. The degree of laterization and the engineering properties of these soils vary significantly based on the parent rock, geomorphological context, and pedogenetic processes [2, 3]. As emphasized by the United Nations Educational, Scientific and Cultural Organization [4], the development of geotechnical maps is crucial for supporting sustainable infrastructure development in such adverse environments.

This research focused on the geotechnical mapping of lateritic borrow materials along a 120 km section of National Road N°7, between Edéa and Kribi, located in the Littoral and South Regions of Cameroon. The region is characterized by ferrallitic yellow and reddish soils, underlain by gneissic formations with variable mineralogical compositions [5]. The choice of this corridor is not only motivated by its representativeness of tropical lateritic environments but also by its strategic importance. Serving as a major route for timber and mineral transport from inland production zones, the Edéa–Kribi road directly connects to the deep-sea port of Kribi and has shown recurrent geotechnical challenges requiring scientific assessment.

This research is relevant to recent advances in lateritic soil stabilization. Several studies have shown the effectiveness of cement and lime treatment in improving the geotechnical performance of lateritic soils [6, 7]. These findings underlined the importance of characterizing natural borrow materials, since stabilization techniques can be selectively applied when soils display marginal properties.

In this study, the main objective was to assess the suitability of lateritic materials for civil engineering applications by establishing a geotechnical zoning based on pedological, geological, and geomechanical parameters. In line with the specifications of the Experimental Centre for Research and Studies in Construction and Public Works [8], this study classified and evaluated lateritic soils according to Atterberg limits, grain size distribution, dry densities, water contents, and California Bearing Ratio (CBR) values. In order to ensure durable infrastructure planning, the results could guide construction projects by offering a spatial distribution of borrow quality and quantity.

The location map of the study area is in Figure 1 whereas the geological and soil maps in Figure 2 and Figure 3 provide the spatial and environmental contexts, respectively. These are complemented by the results of geotechnical characterization illustrated in subsequent figures and tables.

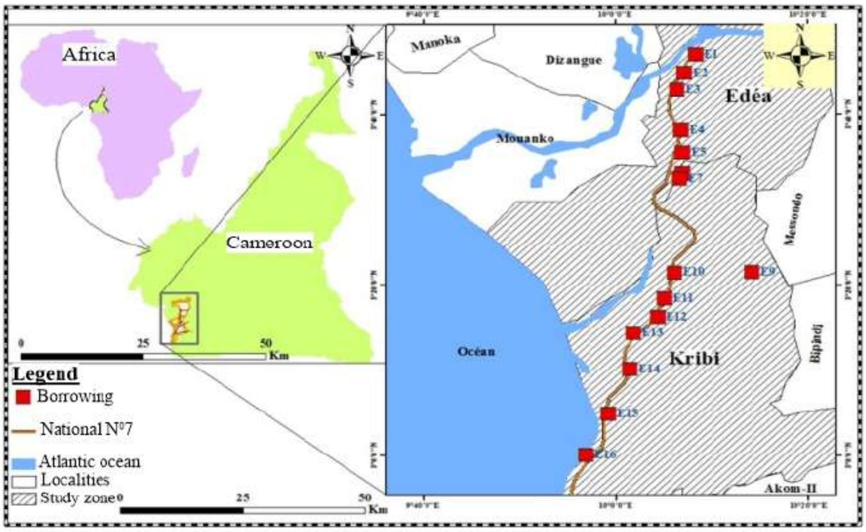

Figure 1. Location map of the study area of Edéa—Kribi [9]

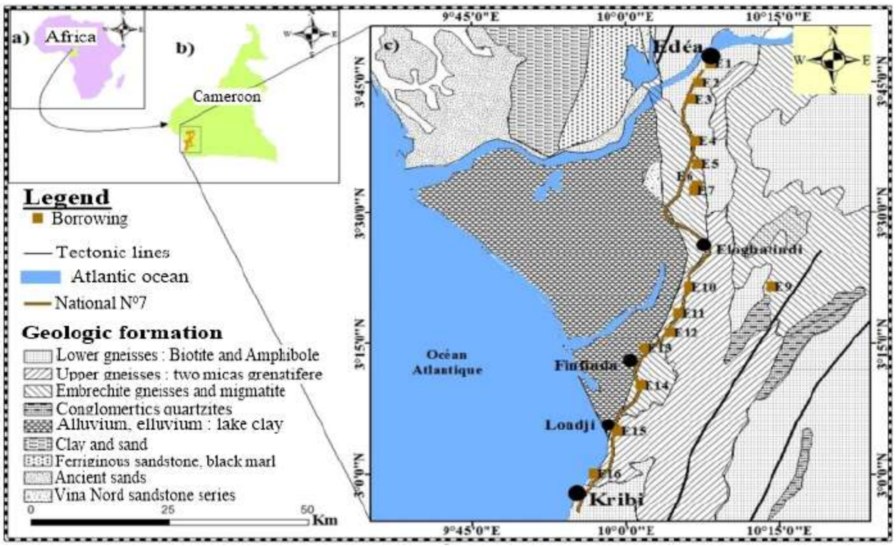

Figure 2. Geological map of the study area [9]

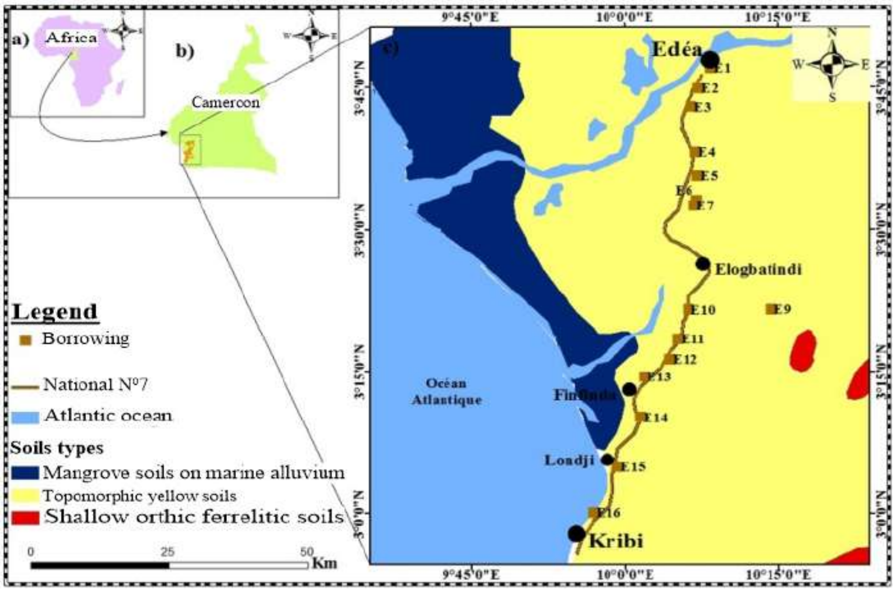

Figure 3. Soil map of the study area [9]

2 Methodology

The study area lies along a 120-kilometer stretch of National Road N°7 between the towns of Edéa and Kribi, spanning the Littoral and South Regions of Cameroon. This zone covers parts of the Sanaga-Maritime and Ocean Divisions and presents a variety of geological and geomorphological contexts. The region is influenced by a humid equatorial climate with average annual temperatures around 26.6℃ in Edéa and 25.7℃ in Kribi, as well as average precipitation exceeding 2000 mm per year. The terrain transitions from low coastal plains near the Atlantic Ocean to higher plateaus and hills inland, with slopes ranging from flat ($< 5°$) to hilly ($> 14°$). The geological basement consists predominantly of gneisses, mica schists, quartzites, and ferruginous sandstones, while the soils are largely ferralitic, yellow to reddish, and occasionally alluvial in nature.

A total of 16 lateritic borrow sites were identified along the road axis based on accessibility, areal extent, and absence of surface constraints like settlements or plantations. At each site, four hand-dug pits were excavated to 1 to 2 meters deep with picks and shovels; as a result, 64 pits were dug in total. Soil samples were collected from these pits for laboratory characterization. Field equipment included a handheld Global Positioning System (GPS) receiver for site geolocation, double measuring tapes, sample bags, notebooks, and a pickup vehicle for material transport. Equipment adopted in the laboratory consisted of drying ovens, electronic balances, graduated containers or tares, a sieve column for grain-size analysis, Casagrande apparatus for Atterberg limits, pycnometers, Proctor and the CBR molds with corresponding rammers and compaction apparatus, as well as a computer installed with spreadsheet and Geographic Information System (GIS) software.

The geotechnical volume of each borrow site was estimated by calculating the product of its areal extent and the average thickness of the lateritic layer. Site boundaries were mapped using Arc Geographic Information System (ArcGIS) based on the GPS coordinates, and thickness was inferred from pit observations. The volume was thus obtained using the formula $V = A \times E$, where, A represents the surface area and E the mean thickness of the gravelly horizon.

Laboratory testing followed the established French national standards (NFP) for civil engineering and included both physical and mechanical analysis. The natural water content was determined by drying soil samples at 105℃ and calculating the moisture loss as a percentage of dry mass. Atterberg limits were obtained using the Casagrande cup and rolling methods on soil fractions passing a .4 mm sieve, providing values for the liquid limit w_L, plastic limit w_P, and plasticity index IP = w_L - w_P. Grain-size analysis was performed by first washing samples through a .08 mm sieve to remove fines, drying and then sieving them through a series of increasingly fine mesh sizes. The percentage retained and passed at each sieve was calculated, and granulometric curves were plotted (Figure 4–Figure 9).

The Modified Proctor test was conducted to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the lateritic soils. This involved compacting soil samples in five layers at increasing moisture contents and plotting the dry density as a function of moisture. The CBR test assessed soil strength under the compaction at 95% of the MDD, following four-day water immersion. A cylindrical plunger was used to penetrate the compacted samples, while the force required at penetrations of 2.5 mm and 5 mm was recorded. The CBR value was calculated using the standard formula CBR_{25} = 100 × F_{25} / 13,35 or CBR_{50} = 100 × F_{50} / 20 with reference forces of 13.35 kN and 20 kN, respectively.

- F_{25}: Force (in kN) at 2.5 mm of penetration;
- F_{50}: Force (in kN) at 5 mm of penetration.

Finally, soil samples were classified in accordance with the Highway Research Board (HRB) system, which considers grain-size distribution and plasticity indices. The classification categories ranged from A-1 to A-7, with group indices calculated to assess material quality and suitability for use in different pavement layers. This systematic approach allowed the characterization of the mechanical suitability of lateritic soils as subgrade, sub-base, and base materials for civil engineering infrastructure, based on both local standards [8] and international guidelines.

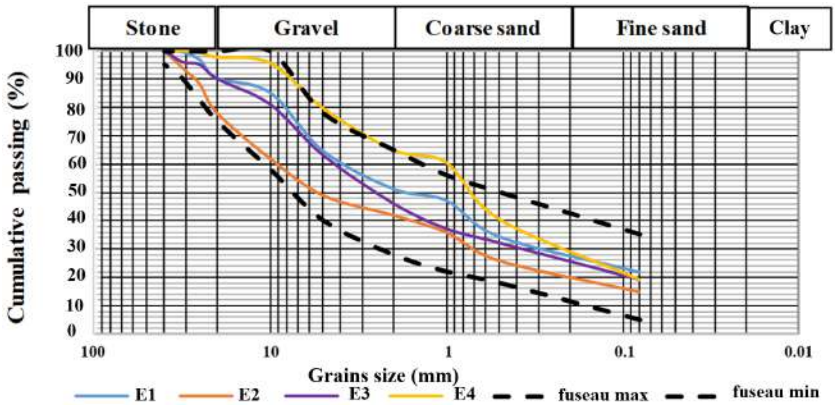

Figure 4. Grain-size distribution curves for group 1 borrow sites–foundation layers

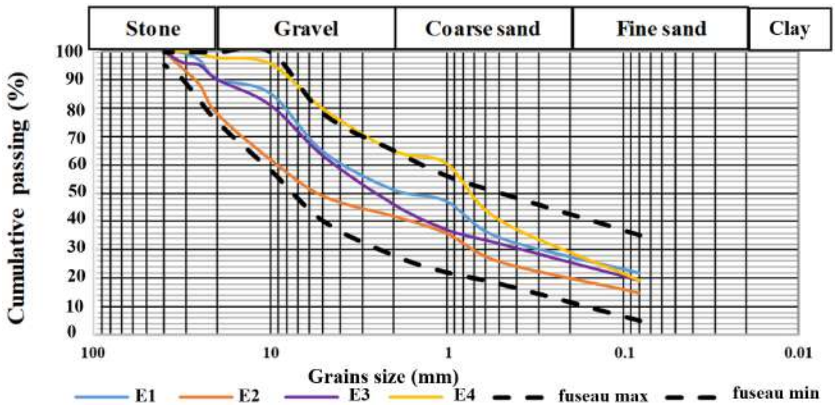

Figure 5. Grain-size distribution curves for group 1 borrow sites–base layers

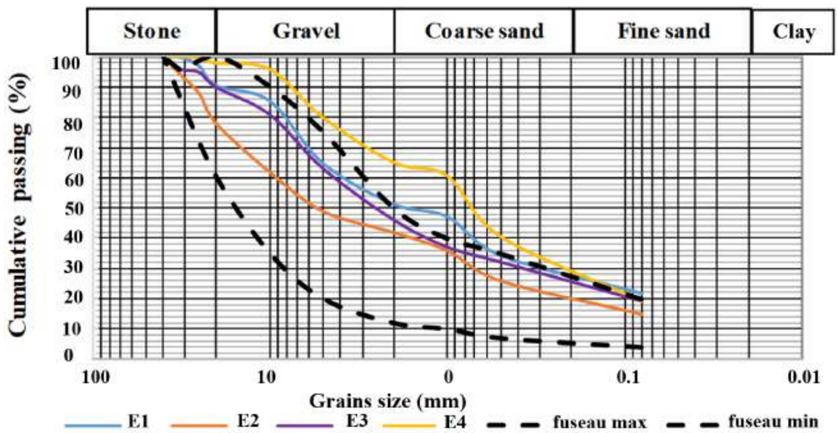

Figure 6. Grain-size distribution curves for group 2 borrow sites–foundation layers

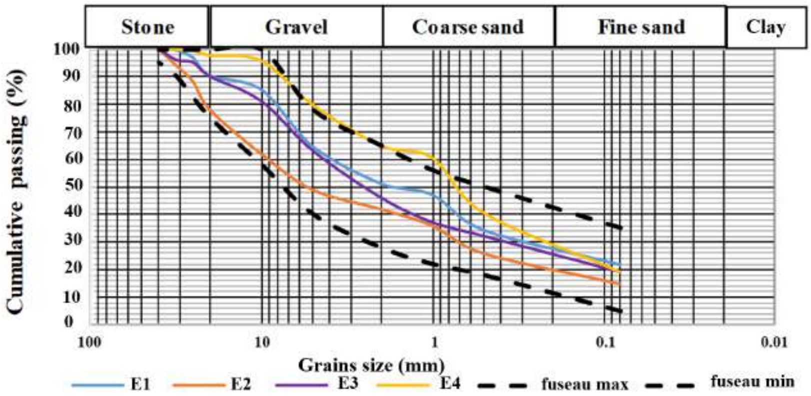

Figure 7. Grain-size distribution curves for group 2 borrow sites–base layers

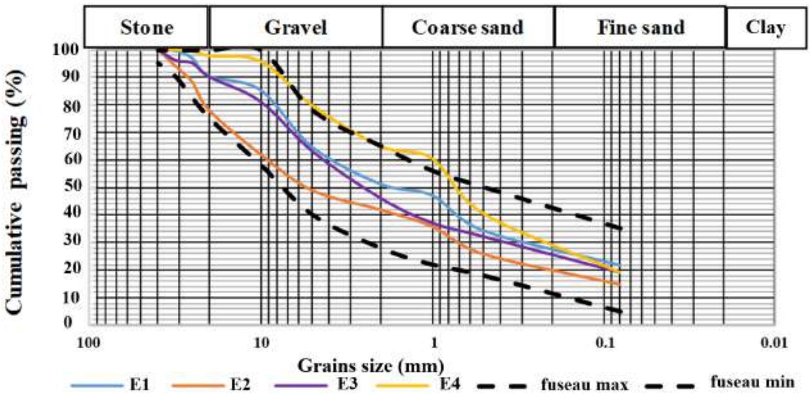

Figure 8. Grain-size distribution curves for group 3 borrow sites–foundation layers

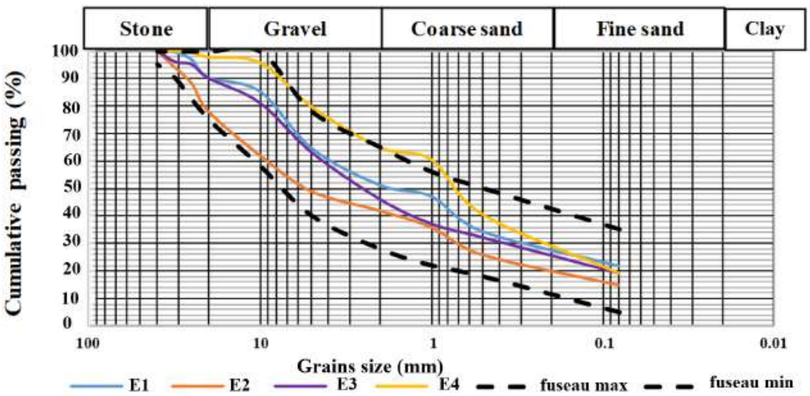

Figure 9. Grain-size distribution curves for group 3 borrow sites–base layers

3 Results

The geotechnical characterization of the 16 lateritic borrow sites between Edéa and Kribi yielded comprehensive physical and mechanical properties, which were grouped into three lithological categories based on the composition of parent rock. Results of grain-size distribution indicated that the soils under study were predominantly granular, with fine contents ranging between 15% and 28%, falling below the 35% threshold for fine soils defined by the HRB system. This suggested that these materials could be considered coarse-grained and suitable for civil engineering applications such as subgrade and foundation layers.

The average percentage of particles passing through the 2 mm sieve ranged from 42% to 65.5%, while those passing the 5 mm sieve varied from 49% to 83.4%. These results were illustrated in the granulometric distribution curves, presented below for each group of borrow sites. Group 1, with yellowish lateritic gravels, showed well-graded curves suitable for both sub-base and foundation layers (Figure 4 and Figure 5). Group 2, composed of slightly reddish gravels, also exhibited acceptable gradation (Figure 6 and Figure 7). Group 3, with strongly reddish lateritic materials, demonstrated denser gradation curves appropriate for load-bearing layers (Figure 8 and Figure 9).

The Atterberg limits showed that the liquid limits varied between 50% and 86.5%, while the plasticity indices ranged from 24% to 33.3%. According to Casagrande's plasticity chart, these values place the soils in the category of medium to high plasticity clays, which may slightly affect their workability during construction but remain within acceptable ranges for lateritic materials used in road construction. These results are summarized in Table 1.

The compaction characteristics derived from the Modified Proctor test indicated that the maximum dry densities ranged between 1.931 g/cm^3 and 2.22 g/cm^3, while the optimum moisture contents (OMC) varied from 10% to 17%. These values confirmed the suitability of these soils for compaction under standard field conditions. The corresponding CBR values, measured at 95% of the OMC after 4-day soaking, ranged from 33% to 49.8%, hence classifying these soils as having medium to good bearing capacity for foundation and base layers based on the specifications [8]. The results are summarized in Table 2.

In addition to laboratory tests, the GIS mapping and field observations enabled the classification of borrow sites into three geotechnical groups based on the mineralogical composition of the underlying parent rocks. The first group included borrow sites developed on biotite–amphibole–pyroxene–sillimanite–hypersthene gneiss (Figure 10); the second on embrechite and migmatitic gneiss (Figure 11); and the third on two–mica grenantiferous gneiss (Figure 12). Each group exhibited slightly different mechanical responses, suggesting that mineralogy subtly influenced geotechnical behavior.

Table 1. Atterberg limits for lateritic borrow materials

Average of Wells	**Natural Water Content w (% nat.)**	**Atterberg Limits (LA) and Related Indices for Moisture Content**			
		Liquid Limit w_L (%)	**Plastic Limit w_P (%)**	**Plasticity Index (IP) (%)**	**Consistency Index (IC) (%)**
E1	12.7	58.4	33.9	24.5	3.6
E2	14.0	68.0	37.0	31.0	3.9
E3	15.0	57.0	31.0	26.0	2.8
E4	26.3	77.0	45.8	31.2	1.9
E5	20.0	66.1	37.9	28.2	2.3
E6	16.7	77.6	48.2	29.4	3.6
E7	21.1	68.2	40.1	28.1	2.2
E8	14.8	86.5	53.2	33.3	4.8
E9	14.4	70.4	39.3	31.1	3.9
E10	11.0	50.0	26.0	24.0	3.5
Ell	13.9	61.6	37.6	24.0	3.4
E12	20.0	59.0	30.0	29.0	2.0
E13	14.9	60.5	34.6	25.9	3.1
E14	17.6	69.1	43.1	26.0	2.9
E15	15.0	71.0	42.0	29.0	3.7
El6	19.6	73.0	45.9	27.1	2.7

Table 2. Modified Proctor and CBR test results

Average of Wells	**Maximum Dry Density (MDD) γ_d (t/m^3)**	**Water Content w (%)**	**California Bearing Ratio (CBR) at 95% of the MDD**
E1	2.172	10.3	35.8
E2	2.066	10.0	40.0
E3	1.994	13.0	40.0
E4	1.943	17.0	33.1
E5	1.995	13.2	36.5
E6	1.954	13.3	37.0
E7	2.22	11.7	36.0
E8	1.956	14.2	36.2
E9	2.062	13.0	42.7
E10	2.079	10.0	44.0
Ell	2.138	11.3	42.3
E12	1.931	14.0	33.0
E13	2.054	12.9	41.5
E14	2.016	12.7	35.9
E15	1.975	13.0	40.0
E16	1.955	13.5	36.2

When compared against the specifications [8], most of the tested borrow materials met or exceeded the recommended criteria for use in subgrade and foundation layers. Only a few samples, which displayed marginally low CBR or high plasticity, would require stabilization for application in high-traffic roads. Table 3 presents a comparative synthesis of the three groups, in terms of geotechnical performance relative to the specifications [8].

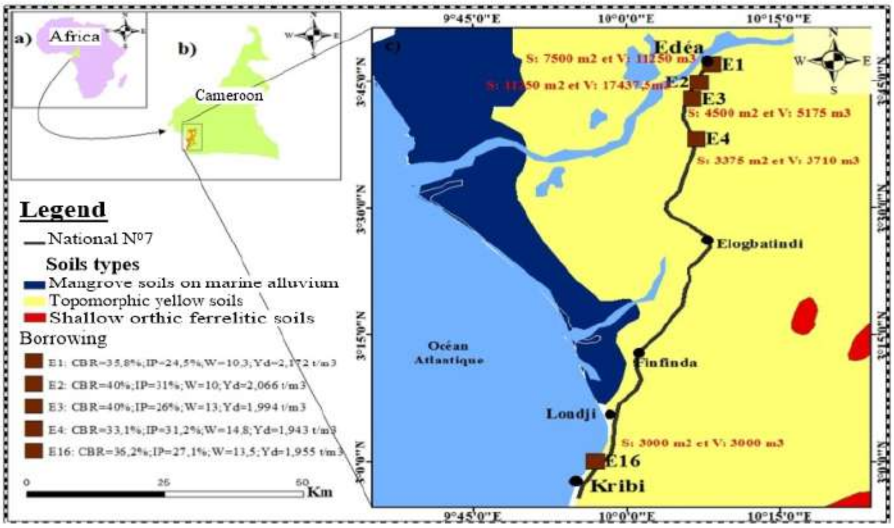

Figure 10. Geotechnical characteristics of borrow sites on biotite–amphibole gneiss

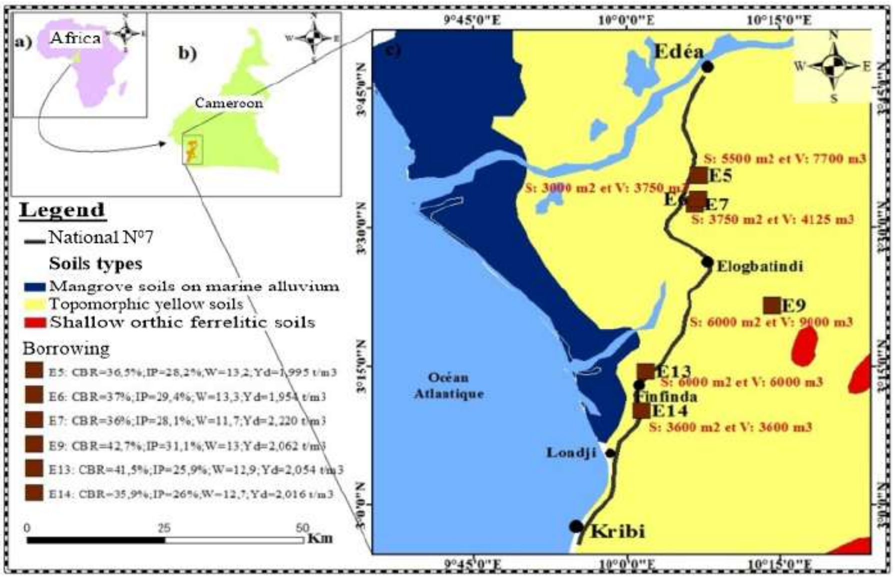

Figure 11. Geotechnical characteristics of borrow sites on embrechite–migmatitic gneiss

Table 3. Comparison of borrow materials in line with the standards [8] for foundation layers

Features	CBR at 95%	γ_d (g/cm^3) at the OMC	IP (%)	Passing (%) .08 mm
Average characteristics of group 1 borrowing	37.02	2.026	27.96	20
Average characteristics of group 2 borrowing	37.97	2.037	28.86	21.77
Average characteristics of group 3 borrowing	39.83	2.031	26.5	21.75
Difference between group 1 and group 2	.95	.011	.9	1.77
Difference between group 2 and group 3	1.86	.006	2.36	.02
Difference between group 1 and group 3	2.81	.005	1.46	1.75
CEBTP (1984) Specification for the foundation layer	$\geq$ 30	$\geq$ 1.80	$\leq$ **25**	$\leq$ **35**
CEBTP (1984) Specification for the base layer	$\geq$ 80	$\geq$ 1.9	$\leq$ 15	$\leq$ **20**

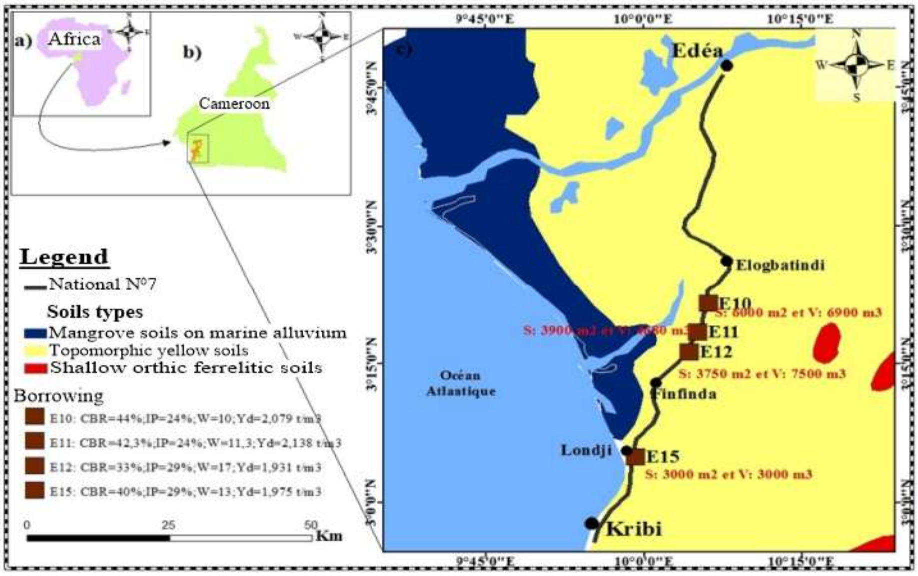

Figure 12. Geotechnical characteristics of borrow sites on grenantiferous two–mica gneiss

Overall, the geotechnical data showed that the lateritic materials available along the Edéa–Kribi axis exhibited favorable properties, namely appropriate gradation, acceptable compaction behavior, and sufficient load-bearing capacity for road construction. The minor variability observed across different geological zones suggested that localized treatment or selection might be necessary in some sections, though the resources are generally adequate for civil engineering needs.

4 Discussion

The geotechnical results obtained from the lateritic borrow sites between Edéa and Kribi confirmed the overall suitability of these materials for civil engineering purposes, particularly in road construction. The grain-size distribution curves fell within the recommended gradation envelopes of the standards [8] for both foundation and base layers applied in low to medium traffic roads. This was in agreement with earlier studies conducted in West and Central Africa, where natural lateritic gravels have been successfully used in similar climatic and geological contexts [7, 10].

The relatively low, 15–28%, of the fine content observed in the samples helped classify the soils as coarse-grained according to the HRB classification system. This favorable particle-size composition enhances permeability and reduces swelling potential, both of which are crucial for ensuring long-term pavement stability under cyclic loading and wet tropical conditions [11]. Similar to studies in Burkina Faso, Mali, and Nigeria [12–18], the Edéa–Kribi lateritic soils showed similar granulometric properties, thus reinforcing their potential for widespread use in road works across the region.

The plasticity indices, although moderately high at 24–33.3%, remained within the acceptable range defined by the CEBTP for lateritic subgrades and sub-bases. This plasticity was largely influenced by the degree of laterization and clay fraction present in the soil matrix, which in turn depended on the intensity of weathering and the parent lithology. Borrow sites developed on different lithological units showed slight variations in plasticity and dry densities; therefore, geological setting appeared to play a role in geotechnical behavior.

Based on the Modified Proctor tests, the compaction parameters marked by dry densities between 1.931 and 2.22 g/cm^3, and the OMC between 10% and 17%, indicated that the soils could be efficiently compacted with conventional field equipment. These values align with reference data from previous studies [13, 19] in similar tropical environments, indicating that lateritic gravels in this density range typically provide good load-bearing capacity with minimal post-construction settlement.

The CBR indices of 33–49.8% confirmed that these materials met the minimum requirement of 30% for use in foundation layers under the guidelines [8]. While these values were slightly below the recommended 60–80% for untreated base layers, they could still offer sufficient performance for light to medium traffic classes. In zones where the CBR values fell closer to 30%, localized stabilization with lime or cement could help enhance performance as demonstrated in the research by Millogo et al. [7].

Furthermore, the spatial analysis with the GIS allowed development of geotechnical maps that could provide valuable information for planners and engineers. These maps showed the lateral variation of geotechnical properties in relation to geomorphological and geological settings. The classification into three lithological groups offered practical guidance for selecting borrow areas based on anticipated performance and engineering requirements. Beyond their scientific contribution, such maps could serve as decision-making tools for infrastructure planning and policy. By integrating the GIS-based geotechnical mapping into road construction projects, authorities could optimize the selection of borrow pits, reduce the costs associated with inadequate materials, and mitigate the environmental impact of exploiting uncontrolled borrow sites. This policy-oriented approach increased the sustainability and efficiency of infrastructure development.

The geotechnical properties of lateritic soils in the Edéa–Kribi corridor exhibit a strong correlation with parent lithology, degree of weathering, and pedogenic processes. These factors are combined to produce materials, while variable, generally suitable for civil engineering with minimal treatment. The classification based on the HRB and the comparison with the specifications [8] further validated the practical relevance of these borrow sites for infrastructure development in southern Cameroon.

5 Conclusions

This study aimed to evaluate the geotechnical suitability of lateritic borrow materials along the Edéa–Kribi corridor for applications in civil engineering, in particular road construction. Through a combination of field investigations, laboratory analyses, and the GIS-based mapping, thorough knowledge of the physical and mechanical behavior of these materials was developed. The results demonstrated that the majority of the lateritic soils identified along this 120-kilometer corridor exhibited favorable geotechnical properties consistent with regional and international standards for subgrade and foundation layers.

The granulometric analysis confirmed that these soils were generally coarse-grained, with fine contents well below the 35% threshold defined by the HRB classification. Their gradation curves fit within the recommended CEBTP envelopes, hence indicating suitability for both sub-base and foundation layers. The Atterberg limits revealed that moderate plasticity, though slightly elevated, remained acceptable for roadwork applications in tropical environments. Compaction tests yielded dry densities and optimum moisture contents compatible with field compaction practices, while the CBR values ranged from 33% to 49.8%, surpassing the minimum requirement for foundation layers and indicating a generally good bearing capacity.

From a policy perspective, the integration of the GIS maps and infrastructure planning undergone in this study could facilitate decision-makers to optimize borrow pit selection, minimize construction costs, and reduce the environmental impact of exploiting uncontrolled borrow sites. The GIS-based zoning and lithological grouping of borrow sites into three categories provided practical insights into the spatial variability of soil properties. This classification is particularly useful for identifying areas with optimal geotechnical potential and for guiding the selection of borrow pits. The findings in this study also provided a scientific basis for more sustainable management of resources for road construction works in Cameroon and similar tropical contexts. With proper site selection, compaction control, and occasional stabilization, the lateritic borrow materials of the Edéa–Kribi corridor could effectively support the construction of durable roads and structures, hence constituting a valuable resource for civil engineering works. Future work should focus on monitoring the long-term performance of these materials under real traffic and climatic conditions, and further integrating geotechnical cartography into national infrastructure policies.

Author Contributions

Conceptualization, J.V.K. and M.R.D.M.; methodology, J.V.K. and M.R.D.M.; software, B.V.F.N.N., T.B.S.T., and E.D.T.N.; validation, J.V.K.; formal analysis, J.V.K. and M.R.D.M.; investigation, J.V.K., M.R.D.M., B.V.F.N.N., T.B.S.T., and E.D.T.N.; resources, J.V.K.; data curation, J.V.K., M.R.D.M., B.V.F.N.N., T.B.S.T., and E.D.T.N.; writing—original draft preparation, J.V.K.; writing–review and editing, J.V.K., M.R.D.M.; visualization, J.V.K.; supervision, J.V.K.; project administration, J.V.K. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest.

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