IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 23, Issue 2 Ser. 2 (Mar - Apr 2026), PP 01-07
www.iosrjournals.org

Geotechnical Characterization Of Borrow Materials For Unpaved Roads In Niger: Case Studies From The Tahoua And Agadez Regions.

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Abstract:
In most developing countries, particularly Niger, unpaved roads account for more than 70% of the national road network. Their widespread use is justified by the availability of construction and maintenance materials in the immediate vicinity of project sites. However, these roads have limited durability because of the characteristics of the borrow materials used and the unsealed nature of the roadway.
This study assessed the suitability of these borrow materials for the construction and maintenance of unpaved roads through laboratory testing, including particle-size analysis, Atterberg limits, Proctor compaction tests, and CBR tests.
The results show Class B and C1A1 soils, with liquid limit values generally consistent the recommendations of the CEBTP guide. However, the plasticity index values for 14 of the 15 soil samples are below the CEBTP recommendations. Regarding CBR, only 3 of the 15 samples yielded values below 30, which is below the recommended threshold for traffic volumes exceeding 30 vehicles per day.
This study highlights the significant potential of local materials for the construction of earthen roads in Tahoua and Agadez regions. However, their optimal use requires improvement measures to ensure the stability, durability, and performance of the road infrastructure, as discussed below.
Keyword: *Borow Materials, Unpaved Roads, Geotechnical Characterization*

Date of Submission: 27-03-2026 Date of Acceptance: 07-04-2026

I. Introduction

In developing countries facing multiple sectoral challenges, unpaved roads are frequently constructed to facilitate integration and trade among communities in different areas. The performance of these structures is closely linked to the quality of the fill materials used in their construction and maintenance. The need to ensure the availability of sufficient quantities of materials for projects at reasonable haul distances not exceeding 15 km [3], while meeting the characteristics required by the technical specifications, led to this study, which forms part of the G2 geotechnical mission and pursues three objectives:

- Characterize materials from borrow pits in the three departments of Tahoua and Agadez regions and assess their suitability for the construction of earthen roads;
- Identify and mitigate the consequences of the major geological risks highlighted during the study;
- Formulate technical recommendations for the potential use of these materials in the project under consideration.

A distinctive feature of this study is that it includes data from borrow pits located in at least two different regions, thereby providing a useful dataset for the study area.

Geographical Location of the Study Area

Niger is located at the heart of the West African craton, one of the oldest geological formations in Africa. Its geology is characterized by:

- Very ancient Precambrian formations (crystalline basement).
- Vast Paleozoic to Cenozoic sedimentary basins.
- More recent volcanic formations in certain areas

The Precambrian basement

The crystalline basement (gneiss, granite, schist) is present in the Tahoua and Agadez regions; it does not outcrop extensively and is overlain by a thick sedimentary cover. It occurs at considerable depth, except along the banks of the Niger River.

Sedimentary Formations of the Iullemmeden Basin
Continental Terminal (Tertiary)
This is the dominant formation in the region. Its lithology is as follows:
- Fine to medium-grained sands
- Clayey sandstone
- Clays
- Hardened lateritic layers

Cretaceous and Paleogene formations (at depth)
- Sandstone
- Clays
- Limestones
- Clays

Recent Quaternary Deposits
Along the Niger River and in the valleys (koris), the following are observed:
- Sandy alluvium
- Silt
- Floodplain clays
- Aeolian deposits

The materials used in this study were collected in the Agadez and Tahoua regions, located in northern and northwestern Niger, respectively, both of which are characterized by a Sahelian climate.

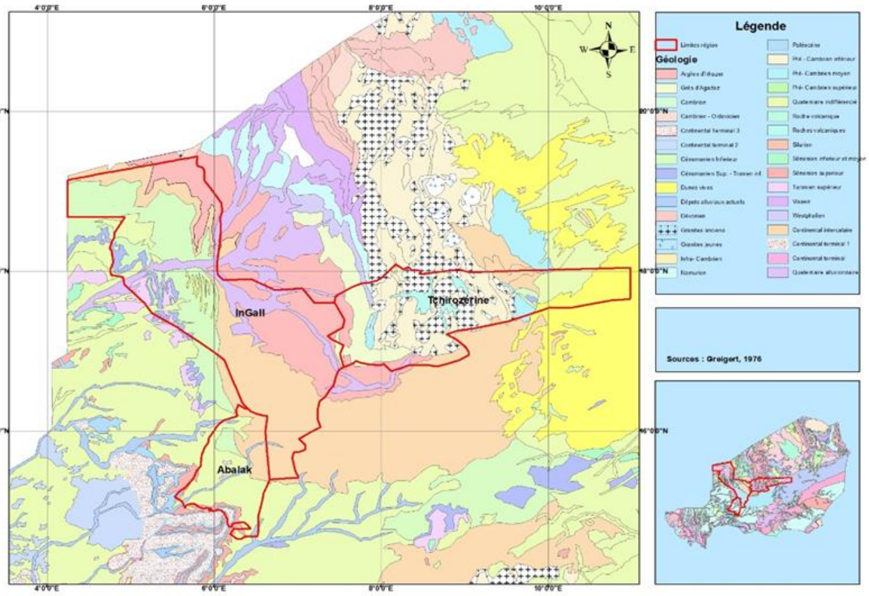

Figure 1: Study area sources Greigert, 1976

II. Material And Methods

Material sampling was carried out in accordance with EN ISO 14688-1, using a Garmin GPS device as the primary tool for locating the sampling sites. [10]

Sieve analysis was performed in accordance with NF P18-560, using a heating chamber, a set of sieves, and an electronic balance as the main test equipment. [8]

Atterberg limit testing was performed in accordance with NF P94-051, using a grooving tool, a precision balance accurate to 0.001 g, and a Casagrande device with its base. [6]

The modified Proctor test was carried out in accordance with NF P94-093, using an heating chamber, a modified Proctor rammer, and a graduated mold as the principal equipment. [9]

Finally, the CBR test was conducted in accordance with NF P94-078, using the following main equipment: a displacement comparator, a cylindrical piston with a cross-sectional area of 19.35 cm², and a universal press fitted with a cylindrical plunger. [7]

Procedure methodology

a) Sampling Campaign

Prior to field deployment, a survey plan for the investigation points is prepared. This plan includes the GPS locations of the boreholes, the borehole diameter, the sterile overburden thickness, and the layout of the investigation points together with their characteristics (depth and deposit thickness). The search for clay deposits is based on 1:200,000-scale maps, supplemented by surveys of local communities and the relevant technical services in the region. Once identified, the borrow sites are georeferenced using GPS coordinates, after which manual test pits are excavated. These pits are due to a depth sufficient to penetrate the exploitable layers. Geotechnical logs of the encountered materials are prepared, and the thickness of each penetrated layer is measured. As part of this study, a total of fifteen (15) borrow sites were investigated, and samples were collected for laboratory testing. Composite samples were then prepared from homogeneous test pits to allow comprehensive laboratory analysis. [11]

b) Identification Tests

Identification tests, including sieve analysis, were carried out in accordance with NF P18-560. A 3 000 g sample was taken from each surveyed site and subjected to dry sieving in order to establish the particle-size distribution curve, which shows the variation in the percentage by weight retained as a function of sieve opening, and to classify the soil geotechnically. [8]

c) Atterberg Limit Tests

Atterberg's tests are used to determine the range of plastic behavior of the material as a function of water content, namely the Atterberg limits, were performed on the soil fraction passing the 0.400 mm sieve in accordance with NF P94-051. These parameters are defined by the consistency state of the soil and include the liquid limit (WL) and the plastic limit (WP), from which the plasticity index (IP) is derived. [6]

$IP = WL - WP$

d) Modified Proctor

To monitor fill placement and determine the compaction conditions of the borrow materials as a function of water content and a given compaction energy, the Proctor test was performed on the collected samples in accordance with NF P94-093 to determine the optimum moisture content (Wopt) and the maximum dry density (γd max). [9]

e) Immersed CBR

To determine the bearing capacity of the borrow materials, which reflects the ability of the material to support a load without excessive deformation, the California Bearing Ratio (CBR) after four days of immersion was determined experimentally in accordance with NF P94-078. [7]

III. Result

This section presents the results of the particle-size analysis, Atterberg limits, modified Proctor test, and CBR bearing-capacity test for all the borrow pits investigated. In accordance with the specific requirements of the CEBTP, the validation of borrow materials suitable for earthen roads is based primarily on three geotechnical criterias, namely:

- Grain-size analysis, with particular attention to the allowable percentage of fines
- % passing an 80 µm sieve < 30%
- Grain size ranges into three ranges with a preference for range 2

Table 1 Grain size range for the wearing course [3]

Diameters	% Passed		
	1	2	3
40 mm			100
20 mm	100	100	85 – 100
10 mm	70 – 100	65 – 100	35 - 100
5 mm	50 – 90	45 – 85	40 – 95
2 mm	30 – 60	30 – 68	23 – 77
1 mm	25 – 50	25 – 55	18 – 62
0,5 mm	20 – 40	20 – 48	15 - 54
0,2 mm	15 – 35	15 – 37	12 – 43
80 µ	10 - 30	12 - 32	10 - 38

Analysis of the product f × IP

- f × IP < 100: Acceptable soil

- 100 < f × IP ≤ 200: Average soil
- f × IP > 200 Poor soil

Atterberg limits, specifically regarding the plasticity index (IP),
- LL ≤ 40 in dry tropical climates [3]
- 15 ≤ IP ≤ 25 [3]

And the CBR index:
- CBR ≥ 30 if heavy truck traffic exceeds 30 vehicles/day [3]
- CBR ≥ 20 for heavy truck traffic of less than 30 vehicles/day. [3]

a) Presentation of the results from the borrow materials sites in the Abalak Department, Tahoua Region

Table 1: Summary of the results from the borrow materials site tests in the Abalak Department, Tahoua Region.

Borrow material	Modified Proctor Test (NF P 94-093)		CBR Load-Bearing Capacity (NFP94-078)	Atterberg Limits (NFP 94-051)		Particle Size Analysis NF P18-560	GTR Classification	f x IP
	γdmax	ωopm	CBR at 95%	LL	PI	% < 80 µm		
1	1,74	14.7	35	29	14.1	3.7	B4	52.17
2	1,66	14,3	26	25,8	19,6	1,9	B4	37,24
3	1,748	9	44	27,1	12,9	1,4	B3	18,19
4	1,645	10,8	35	27,1	13	13	B6	169
5	1,796	7,3	32	26,8	13,4	2,8	B3	37,52

According to the GTR classification, the soils of the borrow pits in the Abalak department fall within classes B3, B4, and B6, with soil quality ranging from acceptable to average.

The Abalak-INGAL Route, borrow 1, is classified as B4, with acceptable soil quality, and meets the granulometric specifications for range No. 3.

The Abalak-INGAL Route, borrow 2, is classified as B4, with acceptable soil quality, and meets the granulometric specifications for range No. 3.

The Abalak-INGAL Route, borrow 3, is classified as B3, with acceptable soil quality, and meets the granulometric for range No. 3.

The Abalak–INGAL Route 4 is classified as B6 with average soil quality and meets the granulometric specifications of range No. 3.

The Abalak-INGAL Route, borrow 5, is classified as B3, with acceptable soil quality, and meets the granulometric specifications for range No. 3.

For the Abalak-INGAL route, borrows 1 to 5 have LL values of 29, 25.8, 27.1, 27.1, and 26.8, respectively. All of these values comply with the recommendations of the CEBTP guide.

For the Abalak-INGAL route, borrows 1 to 5 have IP values of 14.1, 19.6, 12.9, 13, and 13.4, respectively. Of these results, only Borrow 2 complies fully with the recommendation of the CEBTP guide.

For traffic volumes below 30 vehicles/day, a CBR value of at least 20 is required; this condition is met by all Borrows 1 to 5 of the Abalak-INGAL route, with CBR values of 35, 26, 44, 35, and 32, respectively.

However, for traffic volumes exceeding 30 vehicles/day, a CBR value of at least 30 is required; this condition is met by most borrows along the Abalak-INGAL corridor, except Borrow 2, which has a CBR value of 26.

b) Presentation of the results from the borrow materials sites in the Ingal Department, Agadez Region.

Table 2: Summary of the results from the borrow materials site tests in the Ingal Department, Agadez Region.

Borrow material	Modified Proctor Test (NF P 94-093)		CBR Load-Bearing Capacity (NFP94-078)	Atterberg Limits (NFP 94-051)		Particle Size Analysis NF P18-560	GTR Classification	f x IP
	γdmax	ωopm	CBR at 95%	LL	PI	% < 80 µm		
1	1,726	15,2	41	28,1	13,6	10,3	C1A1	140,08
2	1,854	10,9	45	26,7	11	11,6	C1A1	127,6
3	1,702	8,2	21	25,6	9,8	6,8	B4	66,64
4	1,851	10,3	40	26,3	9,6	4,8	B4	46,08
5	1,812	11,1	28	30,8	13,8	10,3	B4	142,14

According to the GTR classification, the soils of the borrow pits in the Ingal department fall within classes B4, and C1A1, with soil quality ranging from acceptable to average.

The INGAL-Agadez Route, borrow 1, is classified as C1A1, with average soil quality, and meets the specifications for Zone No. 3.

The INGAL-Agadez Route, borrow 2, is classified as C1A1, with average soil quality, and meets the specifications for Zone No. 3.

The INGAL-Agadez Route, borrow 3, is classified as B4, with acceptable soil quality, and meets the specifications for Zone No. 3.

The INGAL-Agadez Route, borrow 4, is classified as B4 with acceptable soil quality, and meets the specifications for Zone No. 3.

The INGAL-Agadez Route, borrow 5, is classified as B4, with average soil quality, and meets the specifications for Zone No. 3.

For the INGAL-Agadez route, borrows 1 to 5 have LL values of 28.1, 26.7, 25.6, 26.3, and 30.8, respectively. All of these values comply with the recommendations of the CEBTP guide.

For the INGAL-Agadez route, borrows 1 to 5 have IP values of 13.6, 11, 9.8, 9.6, and 13.8, respectively. All of these values lie near the lower limit of the recommendations in the CEBTP guide.

For traffic volumes below 30 vehicles/day, a CBR value of at least 20 is required; this condition is met by all Borrows 1 to 5 of the INGAL-Agadez route, with CBR values of 41, 45, 21, 40, and 28, respectively.

However, for traffic volumes exceeding 30 vehicles/day, a CBR value of at least 30 is required; this condition is met by most borrows along the INGAL-Agadez corridor, except Borrows 3 and 5, which have CBR values of 21 and 28.

c)Presentation of the results from the borrow materials sites in the Tchiro Department, Agadez Region.

Table 3: Summary of the results from the borrow materials site tests in the Tchiro Department, Agadez Region.

Borrow material	Modified Proctor Test (NF P 94-093)		CBR Load-Bearing Capacity (NFP94-078)	Atterberg Limits (NFP 94-051)		Particle Size Analysis NF P18-560	GTR Classification	f x IP
	γdmax	ωopm	CBR at 95%	LL	PI	% < 80 µm		
1	1,592	8,6	35	31,8	12,7	15	B6	190,5
2	1,741	12,4	45	24,9	12,9	6,6	B4	85,14
3	1,699	8,6	47	35,1	13	4,3	B2	55,9
4	1,636	11,1	33	27,1	13,7	13,4	B6	183,58
5	1,768	13,6	52	25,8	12,1	8,9	B4	107,69

According to the GTR classification, the soils along the bypass routes in the Tchiro department fall within classes B2, B4, and B6, with soil quality ranging from acceptable to average.

The Agadez-Arlit bypass route, borrow 1, is classified as B6, with average soil quality, and meets the specifications for Zone No. 3.

The Agadez-Arlit Route, borrow 2, is classified as B4, with acceptable soil quality, and meets the specifications for Zone No. 3.

The Agadez-Arlit Route, borrow 3, is classified as B2, with acceptable soil quality, and meets the specifications for Zone No. 3.

The Agadez-Arlit Route, borrow 4, is classified as B6, with average soil quality, and meets the specifications for Zone No. 3.

The Agadez-Arlit Route, borrow 5, is classified as B4, with average soil quality, and meets the specifications for Zone No. 3.

For the Agadez-Arlit route, borrows 1 to 5 have LL values of 31.8, 24.9, 35.1, 27.1, and 25.8, respectively. All of these values comply with the recommendations of the CEBTP guide.

For the Agadez-Arlit route, borrows 1 to 5 have IP values of 12.7, 12.9, 13, 13.7, and 12.1, respectively. All of these values lie near the lower limit of the CEBTP guide recommendations.

For traffic volumes exceeding 30 vehicles/day, a CBR value of at least 30 is required; this condition is met by all Borrows 1 to 5 of the Agadez-Arlit route, with CBR values of 35, 45, 47, 33, and 52, respectively. Consequently, the requirement for traffic volumes below 30 vehicles/day (CBR ≥ 20) is also satisfied.

IV. Discussion

Analysis of the geotechnical properties of the materials surveyed in the Abalak, Ingal, and Tchiro departments reveals variability in plasticity parameters and intrinsic mechanical properties related to the Sahelian geological context, while confirming the potential of these deposits for road construction.

Most of the samples studied have a liquid limit (LL < 40%), in accordance with the CEBTP (1984) specifications for dry zones. However, the plasticity index (PI) is often below the optimal range of 15 to 25, with most values close to the lower bound of that interval.

This low plasticity was also reported by P'KLA et al. (2016) and MAMAH et al. (2025) for lateritic and silty soils in West Africa. Studies have shown that an IP value that is too low exposes the wearing course to rapid disintegration under the combined effects of traffic and wind erosion, promoting the corrugation phenomenon typical of Sahelian roads (School of Engineering, 2015).

For the values observed in Abalak, although they are the highest in the study and are very close to the upper limit, they likely provide better relative soil cohesion but still require vigilance with respect to slaking, a risk highlighted by Nizeyimana (2020) in similar tropical contexts.

The bearing-capacity test results show that materials from the Tchiro region (33 ≤ CBR ≤ 52) perform significantly better than those from Abalak and Ingal. According to the CEBTP guide (1984), the Tchiro deposits are suitable for supporting traffic >30 vehicles/day. However, in the Abalak and Ingal areas, where some CBR values are below 30 vehicles/day, their use should be limited to low-traffic roads or to subbase layers.

These results corroborate the work of DIOP (2022) on lateritic gravels in Senegal, showing that bearing capacity is closely linked to the granular fraction and compaction energy. The correlation observed here between maximum dry density (γdmax) and CBR is a classic indicator of the stability of both natural and anthropogenic soils in road engineering (MDPI, 2020).

The GTR classification shows that the soils studied are predominantly Class B and C1A1 materials, i.e., sandy-gravelly soils with varying fines contents. Given the lack of cohesion observed and the associated risks, cement stabilization is recommended. As suggested by SALEY et al. (2023), improving the characteristics of these marginal deposits, particularly those with low IP values, through treatment with hydraulic road binders appears to be a promising approach to increasing the durability of unpaved roads in Niger while reducing the transportation costs mentioned by Tayebi and Triki (2026).

V. Conclusion

This study characterized the geotechnical properties of fifteen (15) borrow pits located in the Abalak, Ingal, and Tchiro departments. The objective was to assess their suitability for use as base-course material for unpaved roads, which are vital infrastructure for improving access to the Tahoua and Agadez regions.

Laboratory investigations led to the following main conclusions:

The investigated deposits generally exhibit good mechanical performance, particularly in the Tchiro department, where CBR values greater than 30 permit their use under moderate to heavy traffic according to CEBTP criteria.

A deficiency in plastic fines was identified in several deposits in Abalak and Ingal (IP < 15). Although these materials are load-bearing, they present a high risk of premature disintegration and dust generation, requiring either rigorous selection or technical improvement.

The predominance of Classes B and C1A1 confirms that these are sandy-gravelly soils whose durability will depend primarily on the quality of in situ compaction.

To optimize the service life of unpaved roads in Niger, it is recommended to:

- Prioritize material blending (screening or addition of fine aggregates) for subgrades with a plasticity index outside the target range.
- Extend this study through durability (erosion) and water-sensitivity tests, taking into account Sahelian climatic variations.
- For the most heavily trafficked borrows, consider stabilization using cement or local alternative binders (industrial byproducts or plant-based stabilizers) to reduce recurring maintenance costs.

In summary, while local materials in Niger offer real opportunities for the national road network, their use must be accompanied by rigorous geotechnical monitoring and by construction techniques adapted to the specific characteristics of each deposit.

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