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RESEARCH ARTICLE

CARTOGRAPHY OF GRANULAR SOILS USED IN ROAD PAVEMENT LAYERS IN BENIN

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Abstract

Civil engineering works require the selection of granular materials and the assessment of their geomechanical characteristics. The lack of relevant geotechnical mapping to facilitate these operations leads to costly and sometimes inconclusive prospecting for each project. The aim of this study was to contribute to the availability of geotechnical mapping in Benin. To this end, and in order to capitalize on the data, the proposed methodological approach is based on the systematic and controlled recording of data produced by laboratories during geotechnical surveys for road construction projects. A web platform called Road Mat was designed to collect the data. It is intended to be constantly evolving in order to improve our knowledge of tropical soils, which are essentially made up of laterites, widely developed residual formations with particularly complex development processes and which are dependent on bedrocks, with a view to better controlling the availability of granular materials. The mapping was carried out by exporting the data to Arcgis 10.8. The geotechnical parameters and data were taken from road surveys covering a total of 3118 km.

Introduction: -

As the population continues to grow, there is a need to connect cities, ports and suburbs. The response to this need is infrastructure development, in particular road links, for which construction and maintenance require the removal of large quantities of materials. While the road industry seeks out and exploits areas where materials can be extracted, these areas are becoming increasingly scarce, alongside the need for agricultural land and urban development. The materials used in the construction of road pavements have specific geomechanical qualities, and geotechnical surveys are carried out upstream during the feasibility phase of each infrastructure development project. Projects vary in length depending on the scale of the project and the information available in different formats. Geotechnical cartographic tools provide a generalised representation of all the components of a geological environment that are important for land development, and for the design, construction and maintenance of civil engineering works and mines (Amraoui, 2023). Geotechnical maps are needed to facilitate access to basic data to support decisions on the feasibility of road projects, and mapping involves collecting and processing the data to be mapped. The development

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of Geographic Information System (GIS) software has facilitated the production of maps by reducing time and cost (Kaâniche et al., 1999).
However, in the case of geotechnical maps, data collection depends largely on the methodology used to collect and process the data. Urban development is booming in several parts of Benin (Houndji, 2024). Such regions are increasingly facing the disappearance of areas where road building materials are extracted, paving the way for a search for new, more distant areas. To prevent and better plan for this situation, the existence of the required documentation would be a great asset. Documentation is available in a number of formats, including physical archives, databases and maps.
However, it is a fact that Benin does not yet have any substantial geotechnical mapping on a national scale, so the development of specific geotechnical maps could have a major impact on geotechnical studies. There are several approaches to acquiring geotechnical data for mapping: systematic inventory of materials (Kasongo et al., 2018), overlaying existing data and new data (Devleeschouwe et al., 2006; Fares, 1994). The aim of this study is to develop two thematic geotechnical maps for each zone, based on a geotechnical database fed with data collected during various geotechnical missions carried out in Benin.

Materials and Methods

The study aims to assess the granular materials that can be used in pavement layers based on characteristic geotechnical parameters. The national road network is made up of seven (07) National Inter-State Roads (RNIE) totalling 2,178 km and thirty-nine (39) National roads (RN) with a total length of 3,898 km.
The study area consists of fifty-nine (59) roads with a total length of 3118.195 km, representing 80% of the national network. It covers all 12 of the country's départements and 59 of the 77 communes. It represents 52% of the national classified road network, estimated at 6076 km. The methodological approach was as follows:
(i) Collection of data sources,
(ii) Classification of soils from the data analysed,
(iii) Creation of a database and thematic maps of materials by region.

Collection of data sources.

Existing documentation was collected from the road administration of the Ministry of Infrastructure and Transport for the period 2006 to 2021. A total of twenty-four (24) pre-project geotechnical study reports of type G1 according to standard NFP 94-500 carried out by the road administration were selected in order to cover the entire study area. The aim is to use the geotechnical data collected during the reconnaissance of natural materials from quarries to estimate their potential use in pavement layers. The material sampling sites were represented by points on a digital terrain model (DTM) from the Geographic National Institut (ING).
Three geographical zones (north, centre and south) have been identified, each with a similar geographical extent (around 150 km). Table 1 shows the number of quarries explored for road construction in each zone. Most of the soils from these quarries belong to the laterite family; these are residual formations rich in iron oxides and hydroxides, with indurated, gravelly or nodular to clayey levels (horizons speckled with kaolinite). These soils are widespread in Benin and are the most commonly used in road construction. All samples were geolocated by the operators.

Table 1. Length of roads and borrow pits by geographical area.

Zones	Road length by geographical area (km)	Number of laterite quarries
South	1160	68
Center	732	45
North	1226	115
Total	3118	228

Soil classification based on analysed data.

The files collected indicate that, in most cases, the samples were subjected to the usual tests in accordance with the standards in effect for road construction, namely: a particle size analysis (NF P 94-056); measurements of Atterberg

limits (NF P94-051); and modified Proctor (NF P94-093) and CBR (NF P94-078) tests. The following parameters are determined from these tests:
- sieve 2 mm and sieve 0.08 mm (f) for particle size analysis;
- The liquidity limit and the plasticity index (PI) for the Atterberg limits;
- Maximum dry density and optimum moisture content for the Modified Proctor Optimum (OPM)
- CBR index at 95% OPM for bearing capacity.

Various soil classification systems exist. In this study, we used the classification proposed by CEBTP (AHISSOU & al.,2024; ISSIAKOU, 2017, Bagarre, 1990), which takes greater account of borrow materials, made up of loose laterites or lateritic gravels, which are less rich in fines. It proposes three classes G1, G2 and G3 according to geotechnical parameters, the thresholds of which are defined below:
- G1, if f <= 15% for IP<16 and f*IP<250 when IP>16;
- G2, if 15%<f<25%, and 250<f*IP<600 when IP>24;
- G3 if 25%<f<35%, and 600<f*IP<1000 when IP>28;

Materials with a high proportion of fines (f>35%) are excluded for road techniques and are noted as not classified (NC).

As fare as bearing capacityconrcers, borrow materials are classified into three categories as follows (Bagarre, 1990):
- 5<CBR<30, materials accepted as subgrade; noted P1
- 30<CBR>80, materials used as sub-base; P2
- CBR>80 materials accepted as base course, noted P3.

Depending on the level of traffic, materials P3 and P2 are respectively acceptable as base and sub-base layers for road pavements. Material P1 is suitable for sub-base.

Creation Of a Database And Thematic Maps By Region.

The database was developed in the following stages
- needs analysis
- data modelling;
- database schema design
- database development using software.

The following steps were taken to produce the maps: processing to determine the parameters to be mapped, exporting the data, and producing the maps using ARCGIS 10.8 software, which can be used to create, manage, analyse and display geospatial data in a variety of contexts, including building and civil engineering, town planning, the environment, transport, etc. The material test sites were represented by points on a digital terrain model (DTM) from the geographic national Institut. The coordinates were transformed into Decimal Degrees (DD) in the WGS 84/ UTM 31 N reference frame and checked to ensure that the points were correct. Soil classes determined according to the CEBTP classification and bearing capacity classes are displayed for each zone.

Results.

Figure 1 shows the conceptual diagram developed using MySQL Workbench software to bank and process the data, classifying it according to physical and bearing capacity data. 228 families of geospatial data have been stored in the database.

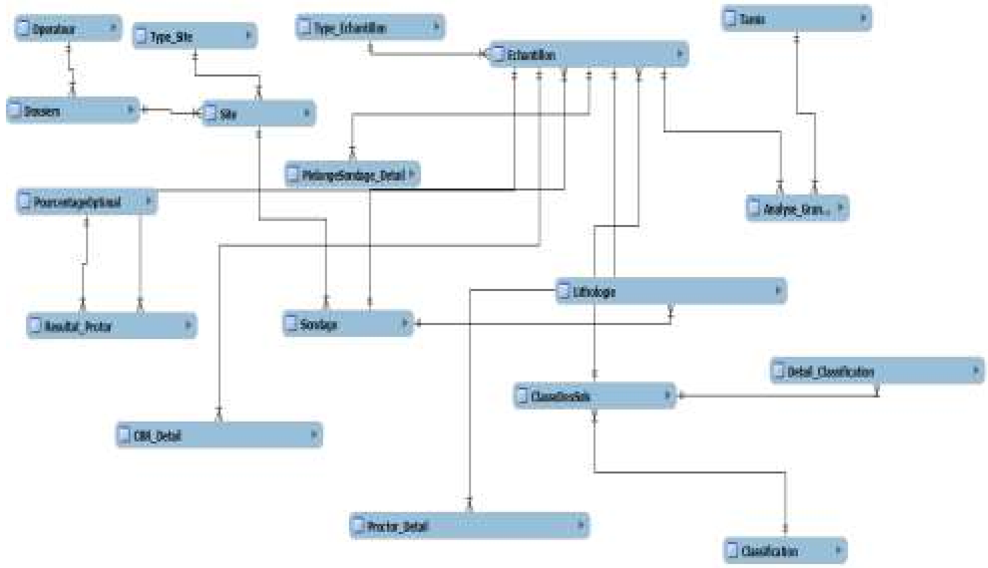

Figure 1. conceptual diagram developed

Tables 2 and 3 show the determination of the soil and CBR classes in the southern and central zones based on the percentage of fine (f), plasticity index (PI) and CBR data.

Table 2. Soil and CBR classes in the southern zone.

Quarries	Percentage of fine, f	Plasticity index, IP	CBR	Soils class (G1/G2/G3)	CBR class
Bolorounfè 1	12	10,01	30	G1	P1
Bolorounfè 2	13,26	15,66	65	G1	P2
Egbé	9,83	13	45	G1	P2
Evega 1	10,36	13,28	61	G1	P2
Evega 2	13,77	13,78	62	G1	P2
Houngomè 1	12,59	13,09	77	G1	P2
Houngomè 2	17,78	19,61	48	G2	P2
Gangnigon 1	13,51	14,44	60	G1	P2
Gangnigon 2	13,51	8,68	44	G1	P2
Igbo-Ola 1	17,38	18,01	35	G2	P2
Igbo-Ola 2	13,43	13,01	42	G1	P2
Kpankoun	13,05	13,67	30	G1	P2
Missèbo	12,25	6,45	65	G1	P2
Odometa 1	14,08	14,33	45	G1	P2
R9EG1	12	8	61	G1	P2
EG2	16	12	62	G1	P2

Table 3.class of soil and CBR in the central zone.

Quarries	Percentage of fine, f	Plasticity index, IP	CBR	Soils class (G1/G2/G3)	CBR class (P1/P2/P3)
R1 EG1 PK 9+500 C/D	09	07	74	G1	P2
EG2 PK 17+700 C/D	07	07	60	G1	P2
EG3 PK 26+350 C/D	03	07	52	G1	P2
EG4PK 53+850 C/G	20	06	60	G2	P2
EG5 PK 59+000 C/D	05	06	68	G1	P2
EG6 PK 94+500 C/D	09	06	70	G1	P2
EG7PK151+500	21	08	60	G2	P2
EG8PK159+000	10	06	60	G1	P2
EG9 PK173+500C/D	12	07	93	G1	P3
EG 9a PK176+600C/G	17	06	65	G2	P2
EG10 PK195+300 C/D	12	07	86	G1	P3
EG11 PK202+200C/D	22	07	81	G2	P3
EG11a 208+300C/G	09	07	45	G1	P2
EG 12 209+300C/D	12	06	58	G1	P2
EG13 219+100C/D	10	06	67	G1	P2
EG14 228+300C/G	16	09	88	G2	P3
EG15 252+700C/G	16	06	65	G2	P2
EG16 (PKC/G)	11	8	65	G1	P2
2 EG17 (PK 2+00 C/G)	13	10	61	G1	P2
EG18 3 (PK C/G)	18	14	60	G2	P2

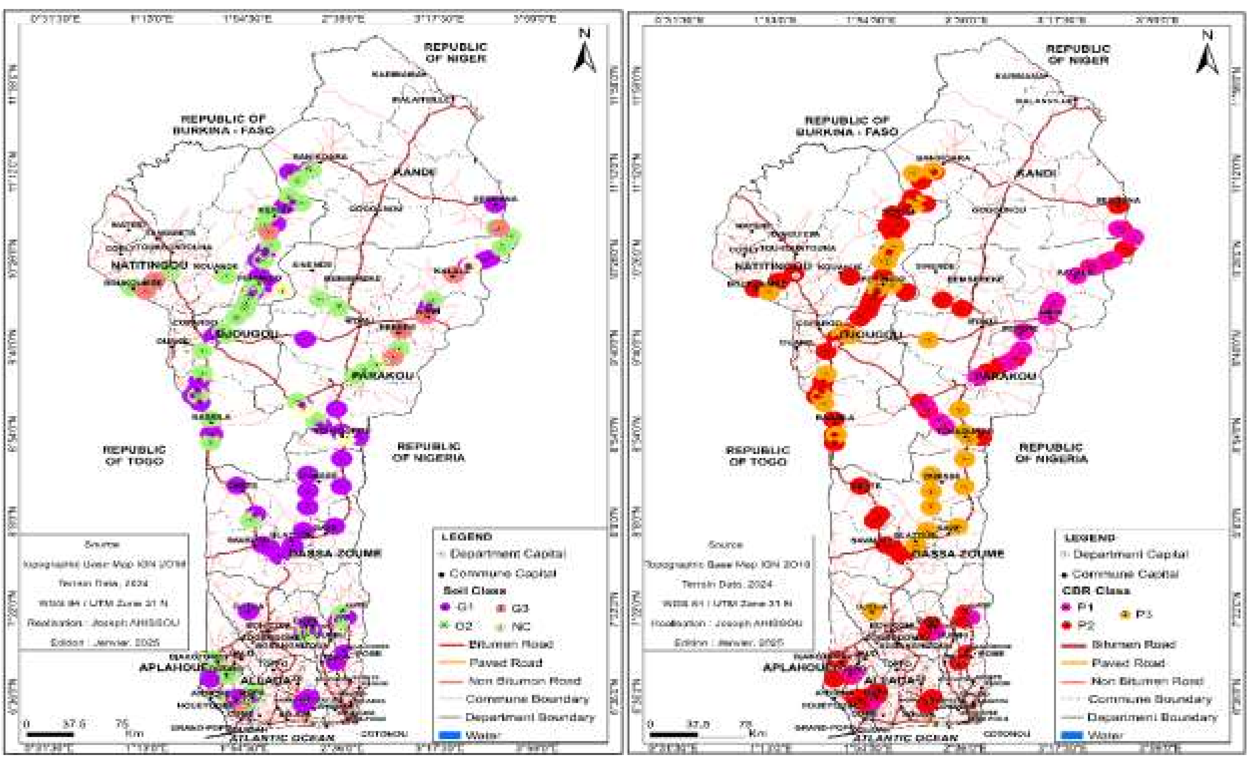

Figure 2. (a) thematic maps from south to north of the soil class, (b) bearing capacity class

Figure 2 shows all the road networks but only provide the results for those considered in the study.

These figures show thematic maps from south to north of the soil class (left) and bearing capacity class (right) of lateritic soils for each zone.

As mentioned above, 52% of the national road network was taken into account in this study. It covers
- to the South, the regions of Bopa, Houeyogbé Dogbo, Aplahoué, Zinvié, Covè, Ouinhi, Adjaouèrè and Kétou;
- to the Centre, in the regions of DassaZoumè, Glazoué, Savalou, Bantè, Savè, Ouèssè and Ouinhi;
- in the North, the regions of Bassila, Tchaourou, Parakou, Pérèrè, Nikki, Kalallé, Sègbana, Djougou; Ouaké, Pehunco, Kérou, Banikoara, Natitingou, Boukombé.

Discussion.

An overview shows that there is no clear relationship between soil classes and bearing capacity. By way of illustration, a material classified as G1 can be of bearing capacity classes P1, P2 and P3, as is the case respectively for Kalalé (North zone), Bantè (Centre zone) and Djidja (South zone).
Closer examination shows that soil class G1 is the most common, followed by G2. Class G3 is exceptional. The distribution is as follows
- in the south, a mixture of G1 and G2
- in the centre mainly G1 and
- in the North a mixed G1-G2 with some G3 (north-east section), with a few areas of unclassified material symbolising material with a very high fines content.

As for bearing capacity, the three classes are fairly evenly represented, but their distributions vary. The following are observed:
- in the southern zone, mainly class P1, more occasionally class P2 and only one class P3 to the north-west of Abomey,
- In the Center, the western section is class P2 and the other eastern section is class P3. They are clearly differentiated.
- In the North, the distribution indicates class P1 on the eastern section, the Parakou-Pèrèrè-Nikki-Kalalé axis, and a mix of P2 and P3 on the parallel western section.

For example, G2 materials generally have a bearing capacity of P2 or P1, while G3 materials often have a bearing capacity of P1. There seems to be a link between the geological map and the bearing capacity data. To the north-east of Parakou, in the Kandi basin, class P3 dominates, with a higher frequency of G3 soils (which, it should be remembered, are the least common in the area studied). Soils are in fact dependent on geomorphology and geological context. This hypothesis merits further investigation, by studying the precise mineralogical nature of lateritic soils and their relationship with the underlying parent rock and also with the climatic and geomorphological history of the region on a geological scale. The landscape of West Africa is characterised by numerous peneplains and networks of hills, the result of alteration and erosion of the basement since at least the Paleocene (60 million years ago), which is continental (Marame-Mbengue et al. 2024).

Conclusion.

This study exploited the geotechnical data collected in the 3118 km of road studies carried out. After being analysed and sorted, this geospatial data was stored in a database called ROAD MAT. The data was processed to determine soil classes and bearing capacity classes in accordance with CEBTP.These two indicators have been mapped by geographical zone: south, centre and north. These maps are a first step in the transition to digital format of the geotechnical data available from borrow materials that previously existed in physical format; they can already help to reduce the cost of road studies. In this way, the process of acquiring and processing geotechnical data in Benin can be dematerialised at national level.
There is still existing data to be taken into account on the axes not considered. While the study highlights the performance of lateritic soils, mainly by means of the bearing capacity indicator, a detailed mineralogical study would show the interrelationships between surface materials and the parent rock. Statistical and geostatistical work also needs to be undertaken to make even greater use of this database, using multi-criteria analysis to rank the major

properties used to determine bearing capacity. It would also be easy to create and computerise a road health log based on relevant criteria, in order to improve the management and longevity of existing roads.

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