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Mapping and Geotechnical Characterization of Some Local Construction Materials for the Adamawa Region of Cameroon

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Authors' contributions

This work was carried out in collaboration between all authors. Author ZZP designed the study, performed the statistical analysis and wrote the protocol. Author NNA wrote the first draft of the manuscript. Authors NNA and MJR manage literature searches under the guidance of author UCM. Authors NDA and NJ managed fieldworks, geotechnical analyses and mapping. All authors read and approved the final manuscript.

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ABSTRACT

In the Adamawa Region of the Republic of Cameroon, there exist many raw materials for building structures. Various methods of investigation were used to map these raw materials, including knowledge of the spatial distribution, inventory and the estimation of resources and the development of a database which is compatible with georeferenced maps. Geotechnical tests were made on some raw materials including granulometric analysis, Atterberg limits, CBR and Micro Deval tests. The results obtained allowed inventory of 1499 natural local materials sites: 338 sites of materials of plant origin, 76 sites of clays, 113 of sands deposits, 754 sites of lateritic soils and 218 sites with rocks. The geotechnical characteristics of lateritic soils (ferruginous gravel and

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lateritic clay) studied vary with their underneath rock basement, respectively of metamorphic and volcanic origins. Based on their Los Angeles values (LA_{10}<20 to LA_{10}>45), the rocks studied were classified as very poor compared to very good quality materials. Some soils are favorable for building bricks or concrete depending on their geotechnical properties.

Keywords: Local construction materials; mapping; geotechnical characterization; Adamawa region; Cameroon.

1. INTRODUCTION

A material is a natural or artificial substance that man shapes to make objects. So it is a selected base material because of its particular properties for a specific use. The term 'local' refers to two concepts: (i) the origin: that is, the proximity of the place of extraction of the material from its place of use; (ii) the low proportion and / or low financial impact of possible imported inputs necessary for the production of manufactured goods. A local material is therefore any natural substance that is possibly transformed in the country of origin and used in the field of construction [1]. According to [2,3], local materials represent available primary materials or products from their transformation requiring a maximum of 30% imported input. Many will reduce this concept to some based products with land or wood such as clay bricks, tiles and wood used in construction. This simplistic and reductive vision limits the range of materials able to be used in construction and that could be called rightfully local construction materials [2].

In Cameroon, the potential of local recoverable resource is important. These include for example, inorganic materials (laterites, clay, aggregate, limestone, marble, various rocks, etc.), wood and fiber, and manufactured materials (bricks, tiles, various binders, metal materials). The mapping of this local resource for the Adamawa Region of Cameroon was executed by the National Civil Engineering Laboratory (LABOGENIE) under the auspices of the Ministry of Public Works, which is charged with the provision of funds for its execution. This project is initiated basing on the premise that, Cameroon as a whole is endowed with enormous construction materials for public use, which are under exploited and not properly valorized [4]. Thus, if these materials are identified, mapped out, categorized and valorized their use for constructions, local economic conditions will prove very economical and effective. This will assist development planners in their regional development programmes whereby appropriate resources will be assigned to particular areas in respect to their local specificities. According to the reference terms, emphasis was in the use of remotely sensed data and GIS tools which generated a comprehensive inventory of these materials. These tools enabled the overlay of satellite images over existing ordnance survey maps in order to circumscribe the different council areas. In this wise, the potentials of local construction materials for each council area could be identified and mapped out. This article summarizes the results obtained and the basic objectives were to determine the engineering properties of local construction materials of the Adamawa region of Cameroon, to emphasize the importance of their effects on the construction, and to evaluate their uses in geotechnical applications.

2. MORPHOLOGY AND GEOLOGICAL SETTING

The Adamawa region is a vast plateau with gentle slope to the south and steep sides at the north. From south to north, altitudes increase slowly and in a regular manner until around Meiganga where it begins at the Adamawa plateau with elevations between 1000 and 2000 m [5]. The most important mountains are: Guenfalabo, Tchabal Mbabo (2460 m) and Hossere Djinga Nganha (1923 m). On the tectonics plan, the region belongs to the Panafrican belt [6-7]. It is characterized by the presence of many shear zones oriented NE-SW including the Shear Cameroonian Centre [7]. The geological diversity of this region is marked by the presence of granites at the border with Nigeria, metamorphic rocks (micashistes, schist and gneiss) covered with volcanic rocks at East of the Gotel Mountains and northeast of Ngoundéré and sedimentary rocks in Mbéré valley [7-8] (Fig. 1). The detailed geological formations situated on the Ngaoundéré West uplift are given in explanatory notes by [7]. These formations are the main local materials of geological origin of this region.

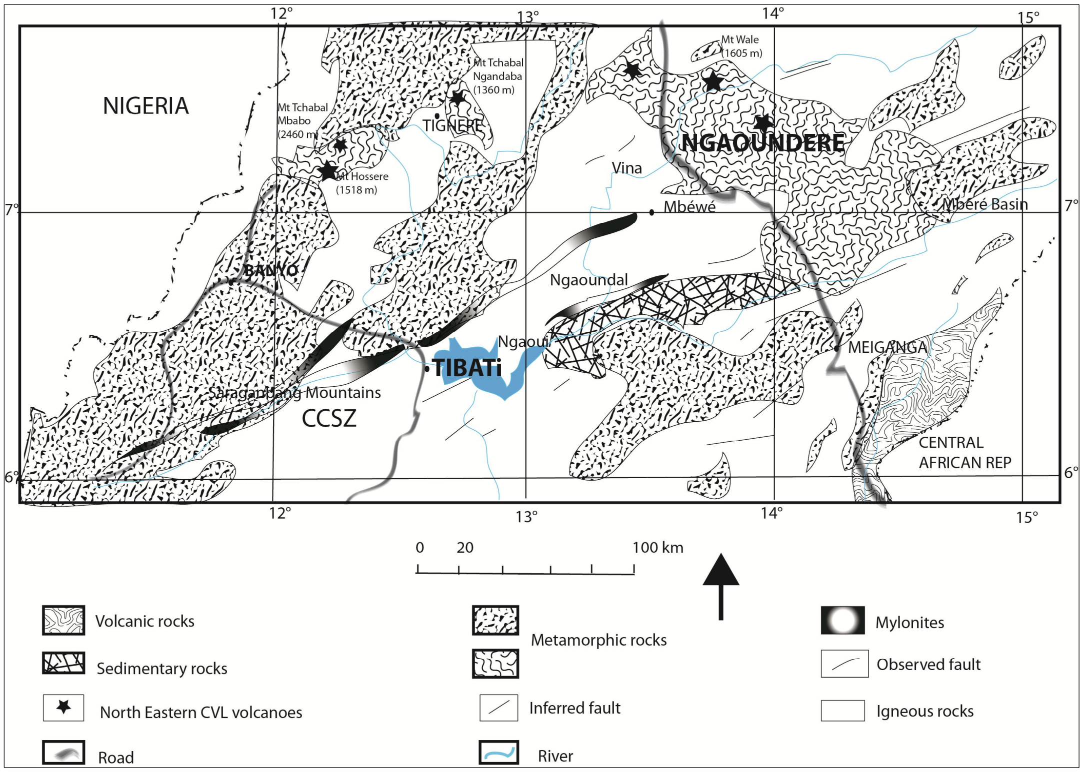

Fig. 1. Geological map of Adamawa region (in [8])

3. METHODS AND TECHNIQUES

3.1 Data Collection

Two different means were used to acquire the data needed for this project. Firstly, there was documentary consultation where the results of previous works, especially the scientific publications on pedology and geology for the Adamawa were consulted. Secondly there was the use of remote sensed data. With this, multi-band, multi-date and multi-spectral SPOT 5 satellite images were provided by the Ministry of Public Works. These images had been purchased from the ASTRIUM Group, an enterprise based in France. The images ranged from 2005 to 2010 and in order to resolve the problem of the infra red band, SPOT 4 satellite image with a resolution of 10 m grouping 91 scenes in one mosaic was added free of charge to the package commanded.

3.2 Image Treatment and Interpretation

Surfaces of at least 100 m^2 that were preliminarily identified basing on pre-knowledge of the region served as references for sampling and classification with the Erdas computer software. Using image enhancements, iteration and the different adaptive filters for respective purposes (Lee, Frost, Gamma, Kuan) to interpret both surface and subsoil characteristics, three classified images were obtained–vegetal, pedological and geological formations. To validate these classifications, an intensive fieldwork was organized which lasted for 65 days. During the fieldwork, verifications of the different formations revealed by the image treatment had to be made, pits were dug using pick axes and spades to determine the thickness of some superficial formations, quarry positions, natural and planted forests (eucalyptus forest), Indian and raffia bamboo sites, outcrops of granitic and plutonic rocks were all located with the use of GPS. For accuracy purposes, control points were taken so as to geo-reference the existing ordnance survey maps that bears the administrative units of the region. These points were taken in localities that evenly spread across the region.

Having the ordnance survey maps geo-referenced, the treated and validated satellite images in raster layers were then converted to vector layers in order to have them opened in the ArcGIS software. In the ArcGIS, the treated image was then superimposed on the geo-referenced survey map that contained all the administrative units of the region. This was done following the different types of local construction materials identified in the region. To this effect, the vector layers of geological, pedological and vegetal formations were overlaid on the survey map one after the other so as to easily map out and determine the volumes of construction materials in each council area.

3.3 The Search and Location of the Sites of Local Construction Materials

Basing on field observations and the use of empirical methods of investigations, all the different types of local materials were sampled and all the exploitation sites located with use of GPS. In the field, the following sites were identified and located. They included: sites of pedological, geological and plant origins.

3.4 The Estimation of the Average Volumes of Soil and Rock Formations

This consisted of determining the limits of each material type, the total surface area of that material type (done in square meters) within ArcGIS and the average altitude using contours. The average volumes of the materials that can be extracted (Vm) is a function of the average force (Fm) and the surface (S) following this equation:

$$Vm = Fm \, x \, S$$

With Fm in meters, S in square meters and Vm in cubic meters.

3.5 Geotechnical Analyses

The geotechnical tests were done at LABOGENIE on 43 samples only pedological (04 samples of clay, 10 samples of sand and 29 samples of laterite) and geological (10 samples of rocks).

3.5.1 Physical characterization of soils and rocks

Pedological samples collected during field trips were subjected to standard laboratory analysis like particle size analyses (sieving and sedimentation) according ASTM norm D-422, Sand Equivalence (ES), water content (Wnat), Atterberg limits according ASTM norm D-4318, Californian Bearing Ratio (CBR), and stabilization with CPJ 35 cement (4%, 6% and 8%) following Cameroonian standards (CN 102-114, 2008). The HBR classification was deducted from their granulometric analysis. For rocks, Los Angeles (LA) test and 4 days Water Micro Deval (WMD) were done.

3.5.2 Stabilization and production of blocks

Two types of stabilization were done (firing at 950°C on clay or adding cement on lateritic soil) in order to improve the physical and chemical characteristics, thus giving the blocks great resistance [9,10]. Before the production of Compressed Earth Blocks, the organic matter in each soil was removed, followed by drying the samples in the oven at 105°C for 48 hours; then, particles less than 2 mm were used for making the blocks. The soil/cement ratio was done according to the following mixture: a bag of cement (50 kg 42 litres) respectively for 16 wheelbarrows of soil (stabilization at 4%), for 11 wheelbarrows of earth (stabilization at 6%) and 8 wheelbarrows of earth (stabilization at 8%).

To test their fusibility, clay soils were homogenized with a ball mill. After that, plaster molds were used to speed up drying to a water content of 7-8%. Test specimens (8 cm x 4 cm x 1.8 cm) were prepared using 10 KN hydraulic press, after, firing at 950°C.

3.5.3 Quality control of blocks

Only water absorption ratio test (Abs) using to the ASTM norm C373-72 allowed us to have an idea on the quality of blocks produced.

4. RESULTS AND DISCUSSION

A number of local construction materials were identified and mapped out in the Adamawa region which differs to an extent from one council area to the other. Figs. 2, 3 and 4 illustrate the spatial distributions of vegetation, soil and rock formations in the Adamawa Region. Table 4 shows spatial representation and some characteristics of local construction materials in the Adamawa region.

4.1 Spatial Distribution of Vegetation in the Adamawa Region

All the types of vegetation identified in the region are represented in all the divisions but the division with the most natural vegetation is Vina with about 24.55% of natural vegetation in the whole region, following Djerem (21.87%), Faro and Deo (21.51%), Mbere (20.03%) and Mayo Banyo (12.20%). Fig. 2 and Table 1 present different types of vegetation observed: dense forest (0.28%), thicket (16.46%), light forest/wooded savana (19.63%), shrubby savana (61.42%), grassy savana (2.2%). The architecture of huts constructed in this region respects some geometry in the spacing of the local construction materials used [4]. For example, the rafters often in conical form are supported by strong eucalyptus pegs. The roof, made up of grass, covers the whole building. Most of the wood used is untreated thereby being vulnerable to insect attack, humidity and rotting [4].

4.2 Spatial Distribution of Pedological Local Construction Materials

The pedological local construction materials (Fig. 3) found in the Adamawa region includes the following from the most important to the least:

The lateritic soils subdivided into ferruginous gravel and lateritic clay soils (Tables 2 and 3).

The ferruginous gravel soils (Table 2) provided specially from weathering of metamorphic rocks. They cover a surface estimated at 31 860 km^2, being about 49.65% of the local construction materials of the region. The alteration profile of this type of soils is constituted from top to bottom - gravel with fragments and hardpan bloc - hardpans. The first two levels provided from successive mechanical degradation of underneath hardpans.

The lateritic clay soils (Table 3) are developed on volcanic rocks. They either result from the weathering of volcanic rocks or from the destruction of lateritic hardpans. They are few and cover only 844 km^2, being a little more than 1% of the soils in the Adamawa Region. The average volume of the lateritic soils is 2.3 Km^3 for an average thickness around 2 m. These lateritic clay soils in HBR classification belong to A-7-5(16), A-7-5(19), A-7-6(4), A-7-6(13), A-7-6(19), and A-7-6(20) classes. The percentage of

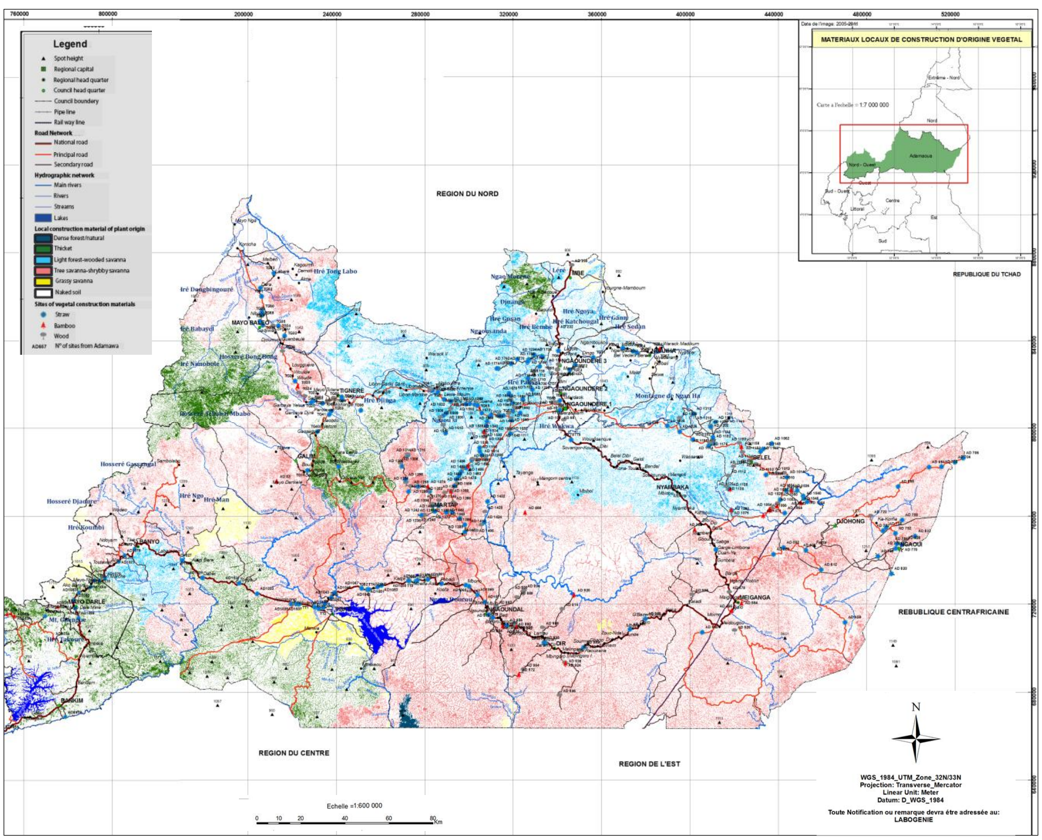

Fig. 2. Spatial distribution of vegetation types in the Adamawa region

fines particles is comprises between 57 and 93%. The plasticity index (PI) varies between 22 and 33 with liquidity limits between 52 and 71%. According to the HBR classification system, these samples are inorganic clays of high plasticity.

For ferruginous graves soils, they belong to A-2-7(0), A-2-7(1), A-2-7(2), A-2-7(4), A-2-7(6) and A-2-7(14). The CBR values are between 14 to 120. The percentage of fines particles is between 11 and 39 with the plasticity index between 19 and 28. The graves with CBR>100 can be considered like a very good materials which can be used in pavement layers, plate form, fondation and base layers for the traffic T1 to T5. These graves are found in Djadji (Galim), Mardaock and Bidjoro (Ngaoundere 2). Those with 70>CBR>30 can be used in embankments, shape layers and foundation in T1 to T3 traffics. It is found in Mayo Voure and Pasadouse (Galim) and selbe Darang (Ngaoundere 2). The gravels with CBR>30 can be used in embankments, shape layers and the production of compressed earth blocks. The types of mud houses constructed with lateritic soils are made up of thatches that are filled with mud. The walls of these houses are constructed with sun dried bricks placed on one another and held together by laterite and clay mortar. To overcome inconveniences (long term disadvantages especially due to erosion and alternation of the dry and rainy seasons), the walls of some of these house scan be plastered with concrete or reinforced by concrete pillars [4].

The *clayey sand soils* and *sandy clays soils* represent arena (Table 3). The derived specially from weathering of granite. They can be light purple, reddish, yellowish or whitish in color. They cover a surface estimated at 26 653 km^2 being around 42% of the pedological local construction materials of the region. Their overburden average thick is around 10.09 m involving an average volume of 47.48 km^3 of potential exploitable materials. Geotechnical and physical data show that the percentage of fines grains is between 43 and 83 %. Their plasticity index (PI) varies between 14 to 62 with liquidity limits around 23 to 76%. In the HBR classification, these soils belong to A-2-4 (0), A-2-7 (0), A-7-5(6), A-7-5(8), A-7-5(9), A-7-5(17), A-7-6(11), A-7-6(12), and A-7-6(20) classes. These samples are inorganic clays of low to high plasticity. Some clayey soils studied are favorable to the production of baked bricks and tiles (Table 3).

The *hardpan* in slab and the bauxite constitute the level of ferruginous gravel or the rich level in alumine respectively. Lateritic hardpans according to [11,12] are hard soils. They are overburden being a long period of erosion. They occupy an estimated area of bout 3 000 km^2 and 410 km^2, being respectively a little less than 5 and 1 % of the pedological local construction materials of the region. The average volume estimated is 624 340 647 m^3 with a thickness about 0.5 m. The hardening or concretionary development after the iron enrichment seems to proceed by a number of mechanisms including chemical precipitation, loss of water of crystallization (dehydration) and the development of a continuous fabric of cementing materials [11]. Finally, the precise climatic conditions, the global morphology, the parent rock facies, the mineralogy and the geochemistry define the distinctive criteria used to explain the genesis of that type of superficial formation [11].

According to [12] the confidence with which “laterite” can be used for road construction is diminished largely because the term may apply to a material with a range of geotechnical properties. Unfortunately, laterites have not been used to their fullest extent in the upper (base and sub base) layers of low volume paved roads in the African region for a number of reasons such as the variability in their engineering properties and their failure to meet traditional specifications. For example, these materials commonly exhibit gaps in the grading curve (e.g. in the sand coarse fraction); high plasticity indices (15-20) and soaked CBR values lower than the minimum of 80 per cent normally specified [12]. As a result, other more expensive options are adopted such as hauling over long distances other natural gravels which meet the traditional specifications; stabilizing the laterites with cement and lime or using crushed stone for the base.

The *alluvial sand* (616 km^2) has been found of flats in river beds (Table 4). The geotechnical data of these sand show that they belong to A-2-4(0) class in the HBR classification. Their piston sand equivalents (ES) varies between 44 to 98. The percentage of fines particles is between 0.4 to 32%. These results mean that they are being clean, average clean and very clean. The very clean sand (ES>70) are those of rivers from the localities of Mayo Dankali, Mayo Ngoukor and Mayo Djarandi in Faro and Deo department, of

Falfa, Mayo Kantalan, Lainga, Mayo Ngaoudai, Sassa Bersi, Ndom Benoue and Karna Petel in Vina department. This very clean sand can be use in making concrete blocks. However, the lack of fines clay particles can conduct plasticity false of that concrete which can be eliminate by increasing the quantity of water. The clean sands (70>ES>60) are those of river from the Tchabal Baouro locality in Vina department. This sand is suitable for high quality concretes. The average clean sand (60>ES>35) are those from Galim in Faro and Deo department and Ngaoundere 1 in Vina department. The poor clean sands (ES<35) are those of Kontcha in Faro and Deo department. The low percentage of fine clay in some samples of sands studied is ideal for high-quality concretes while some present a risk of withdrawal or swelling (Table 3). Unfortunately, the almost total absence of fine clay may cause a fault plasticity of concrete that it will take catch up by increasing the dosage of water.

4.3 Geological Formations for Local Construction Materials

Geological formations of the Adamawa Region (Table 5) comprise of sedimentary rocks - 3 297 km^2, being 5% of all the rocks in the region; volcanic rocks - 7 838 km^2, being 12.35% of all the rocks in the region, plutonic rocks - 29 830 km^2, being 47.02% of all the rocks in the region, and metamorphic rocks - 22 476 km^2, being 35.43% of all the rocks in the region (Fig. 4). The average volume of accessible and exploitable rocks is 75.26 Km^3. Each particular rock type is characterized by its minerals, texture fabric, bonding strength and macro and micro structure.

Table 1. Spatial representation of local construction materials in the Adamawa region

Type of formation	DJEREM	Faro and Deo	Mayo banyo	Mbere	Vina	Total in the region (km^2)	Percentage in the region (%)	Average volume (km^3)
Vegetation								
Dense forest	69	-	-	-	-	69	0.28	-
Thicket	955	1 645	1 314	-	177	4 091	16.46	-
Light forest /wooded savanna	-	830	257	-	3 790	4 877	19.63	-
Tree savanna/shrubby savanna	4 116	2 870	1 344	4 919	2 011	15 260	61.42	-
Grassy savanna	293	-	117	17	121	548	2.21	-
Total/department (km^2)	5 433	5 345	3 032	4 936	6 100	24 845	-	-
Percentage/department (%)	21.87	21.51	12.20	20.03	24.55	-	-	-
Pedological								
Clay sand soil	5 219	3 973	2 831	8 302	6 066	26 391	41.30	47.48
Harpan	345	330	1 054	391	928	3 048	4.77	0.6
Bauxite	402	-	-	-	8	418	0.65	-
Lateritic clay	-	218	24	324	520	1 086	1.70	0.9
Ferruginous gravel soils	6 845	11 556	4 144	4 756	4 559	31 860	49.86	0.38
Soils under sedimentary rocks	-	-	-	384	-	384	0.60	-
Alluvial and plain sand	183	95	153	87	193	711	1.11	0.50
Total/department (km^2)	13 002	16 172	8 206	14 244	12 274	63 898		-
Percentage/department (%)	20.35	25.31	12.84	22.29	19.21	26 391	41.30	-
Geological								
Sedimentary rocks	557	68	-	1 045	1 608	3278	5.21	
Volcanic rocks	-	1 299	-	280	5 780	7359	11,70	
Plutonic rocks	7 764	5 192	2 473	7 984	6 430	29 843	47.45	75.26
Metamorphic rocks	3 935	3 949	6 259	5 097	3 171	22 411	35.63	
Total/department (km^2)	12 256	10 508	8 732	14 406	16 989	62 891	-	-
Percentage/department (%)	19.49	16.71	13.88	22.91	27.01	3 278	5.21	-

Table 2. Characteristics of some lateritic soils

Lateritic soils																			
N°	X (E)	Y (N)	Nature of material	Department	Council	S (m^2)	Ep (m)	V (m^3)	HRB	W_l	I_p	% F	Wnat	CBR	Abs 4%	Abs 6%	Abs 8%	Stability	Possible use
AD 541	307683	718218	Reddish lateritic grave	Djerem	Ngaoundal	283 350	1.3	368 355	A-2-7 (1)	56.2	23.5	20.9	1.9	57	-	-	-	-	A
AD 625	220216	787018	Laterite	Faro et Déo	Galim Tignère	1 270 441	2.5	3 176 103	A-7-6(20)	61.1	31.4	79.1	24.6	18	23.1	22.8	20.3	Good	B
AD 626	218772	791159	Laterite	Faro et Déo	Galim Tignère	2 006 273	2	4 012 546	A-7-5(16)	54.5	22.8	91.2	35.6	19	-	-	22.2	Good	B
AD 669	195184	882933	Sand soil	Faro et Déo	Kontcha	1 212 528	1.2	1 455 034	A-2-6(0)	26.3	11.3	39.3	2.,4		8.,8	8.5	8	Good	B
AD 1012	428931	741086	Brownish laterite	Mbéré	Meiganga	4 457 550	1	4 457 550	A-7-5 (16)	56.6	24.9	66.7	44.6	12	-	-	-	-	C
AD 1034	411474	798301	Sand soil	Vina	Bélel	3 226 992	0.83	2 678 403	A-2-7(3)	69.7	26.5	34.5	4.6	31	-	-	-	-	
AD 1184	353713	869072	Lateritic grave	Vina	Mbe	470011	0.35	164 504	A-2-6(0)	33.8	16	22.,2	8.7			9.1		Good	B
AD 1227	342482	812201	Lateritic grave	Vina	Ngaoundéré 2	11 235 446	1.2	13 482 535	A-2-7(2)	53	22.2	31.8	8.8	120	-	-	-	-	D
AD 1236	341604	815287	Reddish laterite	Vina	Ngaoundéré 2	427954	1.40	599 136	A-2-6(19)	56.6	31.1	76	38.3	-	-	23.9		Good	B

A: A Used for embankments, subgrade and foundation of pavement traffic T1 to T3; B: Favorable to the production of compressed earth blocks; C: Used for embankments and forms layers.
D: Very good material. Used for embankments in the pavement layers: deck, foundation and base of T1 to T5 traffic after all possible corrections, making rammed earth, widening and shoulder.
X: Longitude; Y: Latitude; S: Surface, Ep: thickness; V: Volume; HRB: Highway Research Board (Soil classification); Wl: Liquid limit; IP: Plasticity index; %F: Percentage of fines particles; Want: Water content CBR: Californian Bearing Ratio; Abs 4%: Water absorption at 4% of stabilization

Table 3. Characteristics of some analyzed clayey soils

N°	Nature	Department	Locality	X (E)	Y (N)	Ep (m)	S (m^2)	V (m^3)	HRB	Wl	Ip	% F	Wnat	Abs(%)	VBS	Resonance at 950°C	Coloration after firing	Cohesion	Use
AD 345	Lateritic clay	Faro et Déo	Mbabo	196540	802313	1,29	526 641	679 367	A-2-7(4)	71,1	34,1	61	30,6	34,6	1,46	Mate	Red brick	Low	E -
AD 346	Clay	Faro et Déo	Road Wogomdou - Mbabo	197563	802985	1,50	761 482	1 142 223	A-7-5(20)	60,4	30,3	93,7	21,9	18,6	4,2	Metallic sound	Pale brown	Good	F -
AD 347	Sandy clay	Faro et Déo	Galim	220702	784063	1,50	1 160 255	1 740 383	A-2-7(4)	63,8	33,7	81,7	24,2	19	1,83	Mate	Yellow red	Medium	E -
AD 348	Clay	Faro et Déo	between Kontcha - Pawati	194960	880467	1,50	598 952	898 428	A-7-5(19)	60	26,9	74,8	20,1	11,2	10,13	Metallic sound	Red brick	Good	F -
AD 349	Sandy clay	Faro et Déo	Alme	211480	869145	0,50	756 466	378 233	-	-	-	-	-	16	6	Mate	Red brick	Medium	E -

N°	Nature	Department	Locality	X (E)	Y (N)	Ep (m)	S (m^2)	V (m^3)	HRB	Wl	Ip	% F	Wnat	Abs(%)	VBS	Resonance at 950°C	Coloration after firing	Cohesion	Use
AD 350	Gray clay	Faro et Déo	Mayo Baleo centre	205778	847878	1,50	608 293	912 440	-	-	-	-	-	15,6	6	Lightly Metallic	Red brick	Medium	F -
AD 351	Clay	Faro et Déo	Between Sadeck - Garbaya	223328	807820	1,29	430 695	555 597	-	-	-	-	-	21,8	2,67	Metallic	Light pink	Good	F -

E - Not favorable to the production of baked bricks and tiles
F -Favorable to the production of baked bricks and tiles
VBS: Methylen blue value

Table 4. Characteristics of alluvial sands

Alluvial sand						ES_P	%F	Quality of material	Possible use
N°	**X (E)**	**Y (N)**	**Nature of material**	**Department**	**Council**				
AD 422	220142	783659	Alluvial sand of Mayo Voure	Faro et Déo	Galim	45	6,2	Clayey sand	Risk of withdrawal or swelling, reject for quality concrete
AD 439	215116	837049	Fine sand	Faro et Déo	Mayo Baléo	90	0.4	Very clean sand	In the manufacture of various types of concrete, etc ... the almost total absence of fine clay may cause a fault plasticity of concrete that it will take catch up by increasing the dosage of water.
AD 451	753655	667462	Micaceous fine sand with smma galets of quatrz	Mayo Banyo	Bankim	60	2.5	Not clean sand	Risk of withdrawal or swelling, reject for quality concrete
AD 515	343088	801132	Alluvional coarse sand of Laïnga	Vina	Ngaoundéré 1	73	32,1	Clean sand	The low percentage of fine clay is ideal for high-quality concretes.
AD 516	347593	804995	Alluvional coarse sand of Mayo Ngaoudaï	Vina	Ngaoundéré 1	90,3	1,3	Very clean sand	Risk of withdrawal or swelling, reject for quality concrete

ESp: Piston Sand Equivalence

Table 5. Characteristics of some geological formations

Geological formation						V (m^3)	LA 10	LA 6	MDH 10	MDH 6	Quality of material	Possible use
N°	X (E)	Y (N)	Nature of material	Department	Council							
AD 1285	306433	715224	Plutonic rock (Granite)	Djerem	Ngaoundal	435 562 080	11	13	7	10	Very good to good (10/14) et good to medium (6/10)	Gravel Class A -
AD 1289	184720	731080	Metamorphic rock (Gneiss and Quartzite)	Djerem	Tibati	451 015 800	27		9	11	Mediumto weak	Gravel Category D -
AD 1325	193594	873415	Metamorphic rock (Massif of gneiss)	Faro et Déo	Mayo Baléo	199 587 160	20	25	9	14	Good to medium	Gravel Class B -
AD 1455	380856	833270	Volcanic rock (chaotic cast basalt)	Vina	Nganha	452 469 920	13	14	5	10	Very good to good	Gravel Class A -
AD 1483	342752	802210	Volcanic rock (Scories)	Vina	Ngaoundéré 1	-	37	38	33	33	Moyen à faible	Gravel Category D -
AD 1489	342310	834477	Volcanic rock (phonolitic cone)	Vina	Ngaoundéré 3	301 689 640	20	23	10	14	Good to medium	Gravel Category B for the 10/14 class -

Gravel class A: Suitable in bonding layers, base, foundation of traffic roadways (T1-T2-T3-T4-T5), in reinforcing layer and coating of T1 to T5 trafficking pavement. The manufacturing of masoned stones, as gambions, aggregates of different types of concrete, drainage layers, etc ...

Gravel class B: Suitable in bonding layers, base, foundation pavement traffics (T1-T2-T3), layered reinforcement and coating roads of traffic T1 to T5. The manufacturing of masoned stones, as gambions, aggregates of different types of concrete, drainage layers, etc...

Gravel class D: Suitable in bonding layers, base, foundation pavement traffics (T1-T2-T3). The manufacturing of masoned stones, as gambions, aggregates of different types of concrete, drainage layers, etc ...

Gravel class B for the 10/14 class: Suitable in bonding layers, base, foundation, trafficking pavement (T1-T2-T3-T4) in reinforcing layer and coating of traffic roadways T1 T5. The manufacturing of masoned stones, as gambions, aggregates of different types of concrete, drainage layers, etc ... and Category C for 6/10 class, used in tie layers, base, foundation of traffic roadways (T1-T2-T3).

LA10 : Los Angeles on gravels of granular class 10mm; MDH 6 : Micro Deval on gravels of granular class 6 mm

Sedimentary rocks are constituted by metamorphic conglomerate and sandstones. They are localized in Kontcha basin, Djerem ditch near Ngaou Hills in Ngouandal municipality, Mbere ditch crossing some localities: Nyambaka, Meiganga, Belel, Djohong following a south south west - nord nord east orientated band constitute the greatest variation in strength and behavior. In general, the minerals of sedimentary rocks are usually softer and their assemblage is generally weaker than the igneous rocks. In these rocks the minerals are not interlocking but are cemented together with inter-granular matrix material. They usually contain bedding and lamination or other sedimentation structures and, therefore, may exhibit significant anisotropy in physical properties depending upon the degree of their development. This group of rocks therefore creates many problems and challenges in rock construction [13,14].

Volcanic rocks belong to the volcanic formations of the Cameroon Volcanic Line. They are constituted of basalt, trachyte and phonolite. They are found at department of Faro and Deo (Galim Tignere, Mayo Baleo, Tignere), Mayo Banyo (Banyo), Mbere (Meiganga, Djohong), and Vina (Belel, Nganha, Nyambaka, Ngaoundere 1, 2 and 3).

Plutonic rocks are mostly coarse grain granite of pink or white feldspaths. They are identified in the form of north north east - south south west elongated bands at the western region of the limit of Nigeria republic, either in the central and southern part of the Adamawa region. Volcanic and plutonic rocks tend to be massive with high strength. Their minerals are of a dense interfingering nature resulting in only slight, if any, directional differences in mechanical properties of the rock. These rocks constitute few problems in rock construction when fresh [13,14].

Metamorphic rocks constitute the substratum of the Region. They are orthogneiss, gneiss, schists and quartzites. They are also from a north north east - south south west elongated bands in altenance with the plutonic rocks. These types of rocks show a great variety in structure and composition and properties. The metamorphism has often resulted in hard minerals and high intact rock strength; however, the preferred orientation of platy (sheet) minerals due to shearing movements results in considerable directional differences in mechanical properties. Particularly the micaceous and chloritic schists are generally the most outstanding with respect to anisotropy [13,14].

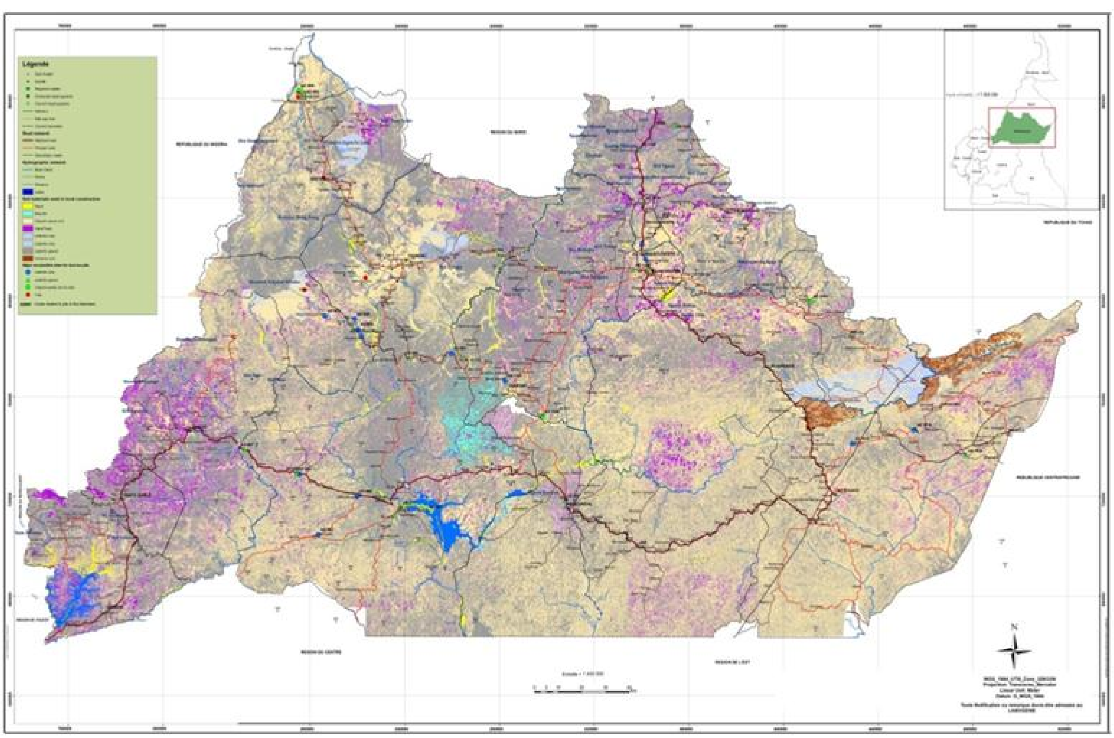

Fig. 3. Spatial distribution of pedological soils in the Adamawa region

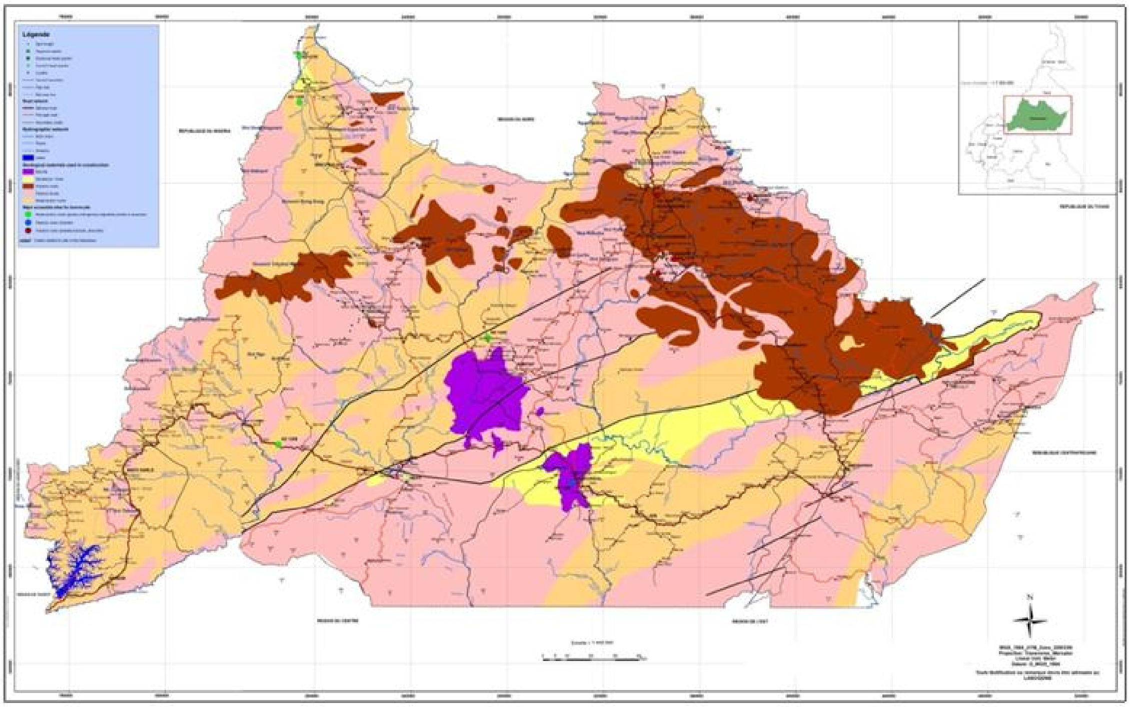

Fig. 4. Spatial distribution of geological types of Adamawa region

Based on their Los Angeles values, these rocks can be constituted of:

i. Very good quality materials ($LA_{10}<20$), gravels of category A and B, localized at Mahanga, Ngora, Ngarbaya Djire, Woulde, Djoumvoli and Mayo Nga in Faro et Deo department. They can be also used as foundation layer, base layer, coating layers, building roads for traffic 1-5, drainage layers, masonery stones, gabions, and production of hydraulic concretes.
ii. Good quality materials ($20<LA_{10}>35$), gravels of category C, found in Mabonsou, Mayo Badji, Gada Mayo, Djombi, Meure Groua, Hossere Ganti, Gourwalt, Sirgou and Demotin Faro et Deo department, Mount Ngaouhora, Naboune, Hossere Lere and Sassa in Vina department. Their uses are possible in coating layers and foundation layers of traffics 1-3.
iii. Poor quality materials ($45<LA_{10}>35$), gravels of category E, localized in Mayo Voure, "Tournant de deux morts", Bect 1 in Faro and Deo department, and Lac Tison in Vina department.
iv. Very poor materials ($LA_{10}>45$), gravels of category F. They are found at Yelwa and Galadi in Faro and Deo department. Their uses are possible in backfill material, masonery stones and gabions.

5. CONCLUSION

The raw materials of the Adamawa region include different types of raw materials (vegetation, pedological and geological) easily exploitable for building industries.

- Plant materials are constituted by a dense forest (0.28%), fodder (16.46%), and light forest/wooded savanna (19.63%), shrub savanna (61.42%), and herbaceous savanna (2.2%).
- The pedological local construction materials are constituted of lateritic soils subdivided into ferruginous gravel and lateritic clay soils, the clayey sand soils and sandy clays soils with the percentage of fines grains is between 43 and 83%, and also hardpan and alluvial sand (616 km^2).
- Geological formations include volcanic rocks, metamorphic rocks which constitute the substratum and plutonic rocks with mostly coarse grain granite and feldspars.

Sands with their sand equivalents between 23 and 98 are very clean, clean, average clean and poor clean sands. It can be uses for production of many types of concrete regarding their equivalent sand values. Graves regarding their CBR values, percentage of fines particles, granular corrections and other stabilization methods can be used as backfill material of coating layers for land road or protected taking into account the requested traffic. Rocks of the Adamawa region constitute being very good quality, being good quality and even poor quality regarding their Los Angeles and Micro Deval values wet.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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