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Assessment of Soils Developed on Various Formations in Maroua (Far North, Cameroon) for Production of Compressed Earth Bricks

Bertin Pagna Kagonbé[1*], Bakary Souleymanou[1], Viviane Djaoyang Bakaïné[1], Raphael Essama Boum Belinga[1], Bertrand Tatoh Aziwo[1], Alexis Ngoniri Hamdja[2], Likiby Boubakar[1]

[1]Local Materials Promotion Authority (MIPROMALO), Yaounde, Cameroon
[2]National Institute of Cartography (INC), Yaounde, Cameroon
Email: *kagonbebertin@gmail.com, souleymanou@gmail.com, vivibakian@gmail.com, raphaelbeling2906@yahoo.fr, aziwobertrand@yahoo.com, hamdja.ngonir@gmail.com, likibyboubaka@gmail.com

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Abstract

One of the most important materials in the building industry is earth brick. The current work focuses on the evaluation of Maroua soils and their potential usage in the manufacturing of Compressed earth blocks (CEB). Four sites (Frolina, Goubeou, Mambang, and Djoulgouf) were chosen to conduct this study. One sample was collected at each location. Physico-chemical and mineralogical characteristics were obtained by using particle size, Atterberg limits, X-ray diffraction, and X-ray fluorescence analysis. Results revealed that sand is the most abundant fraction (36.9% - 50.5%) followed by clay (22.1% - 28.4%) and silt (11.3% - 23.8%). They mostly correspond to sandy soils. Liquid and Plastic limits range between 22.6% to 41% and 16.1% to 24.9% respectively and the plasticity index spans from 6.5% to 20.3%. Plasticity is low for Mambang and Djoulgouf and medium for Goubeou and Frolina soils. Mineralogical composition revealed the presence of smectite, kaolinite, and illite as clay minerals, associated with variable amounts of quartz, goethite, and K-feldspars. Geochemical analyses indicate a high silica content (47.1% - 72.8%) followed by alumina (10.9% - 22.8%) and iron (6.4% - 13.2%). The mineralogical, chemical and physical properties of the studied soils revealed that they are suitable for the manufacture of CEB according to the Cameroon Standards of CEB.

Keywords

Soil, Physical Properties, Mineralogy, Geochemistry, CEB, Maroua-Cameroon

1. Introduction

According to [1], soils are a result of the influence of climate, topographic factors, organisms, and parent materials that interact over time. They repeatedly undergo maturity by way of numerous physical, chemical, and biological processes, including weathering with associated erosion [2] [3]. As reported by [4] [5] [6], most minerals in the soil originate from the bedrock, and their spatial distribution is significantly influenced by this bedrock.

Since the outset of civilization, which is thought to have started along the Nile River, earth has been used as a construction material [7]. It has been used effectively in various climatic zones and the mode of usage depends on the type of soil, technical know-how, tools as well as local traditions and customs of the community [7]. Frequently, coarse sand, argillaceous earth, and lime are the principal raw materials used in construction. To prevent cracking during drying of adobe bricks, the natural earth mixtures are frequently adjusted by introducing fibers [8] or another stabilizer. However, in many regions around the world, constructions with adobe bricks have a connotation of poor or bad quality habitations and are often considered second-class building materials for low-income earners [9] [10]. This has led to low acceptance of earth-building materials amongst most social groups which results in earth materials not being widely recognized by authorities in many countries [11]. Indeed, traditional building materials like adobe and CEB are, in fact, affordable, easily accessible, and do not require complex processing before use [12]. Furthermore, the labor required for the construction process is acquired locally, frequently from members of the household, extended family, or the local community which reduces labor costs [9].

In recent years, many countries around the world are facing major challenges relating to shelter and expanding urbanization [13]. This problem seems to be more prevailing in Central Africa and has aggravated over the last three decades owing to high cost and scarcity of building materials [14]. As it has been said, earth could be re-evaluated as compelling options to meet the needs of low-income households [10]. It is an ideal material for sustainable construction in addition to its environmental advantages and cost benefits [15]. Due to the re-discovery of this traditional building material, earthen construction is currently of significant interest to material scientists and civil engineers, and there are numerous researchers studying this subject [16] [17].

In Cameroon, the exploitation of soil material involves various actors. Nevertheless, the choice of this material is often based on the user's expertise, which is not sufficient to guarantee the quality building constructions and consequently, good economic returns on real estate investments [18]. In addition, the majority of recent works on the geotechnical properties of Cameroonian soil has been done in humid tropical areas [19]. The soil materials used in the Far North Region of Cameroon are not well known and so far have benefited from only a few geotechnical investigations. The present study, therefore, seeks to assess soils that have been developed on magmatic and metamorphic formations in Maroua for their possible use in compressed earth brick production.

2. Geographical and Geological Setting

Geographically, the studied area extends from latitude 10˚30'N - 10˚42'N and longitude 14˚16'E - 14˚30'E (**Figure 1**). The local climate corresponds to the sudano-sahelian type, with a long dry season from October to May and a short rainy season from June to September [20]. The region's topography consists of the plain and summit landscape morphologies [21]. The Mayo Mizao, Mayo Kaliao, and Mayo Tsanaga rivers are the main rivers in Maroua town and are the most significant seasonal collectors that drain these plains (**Figure 1**).

The types of soils found in this area are vertisols with hydromorphic characteristics, organized into two groups: hydromorphic vertisols with calcareous nodules and vertisols without calcareous nodules [22] (**Figure 2**). Additionally, holomorphic soils, lithosoils, tropical ferruginous soils, and alluvial deposits are also observed [21] [22].

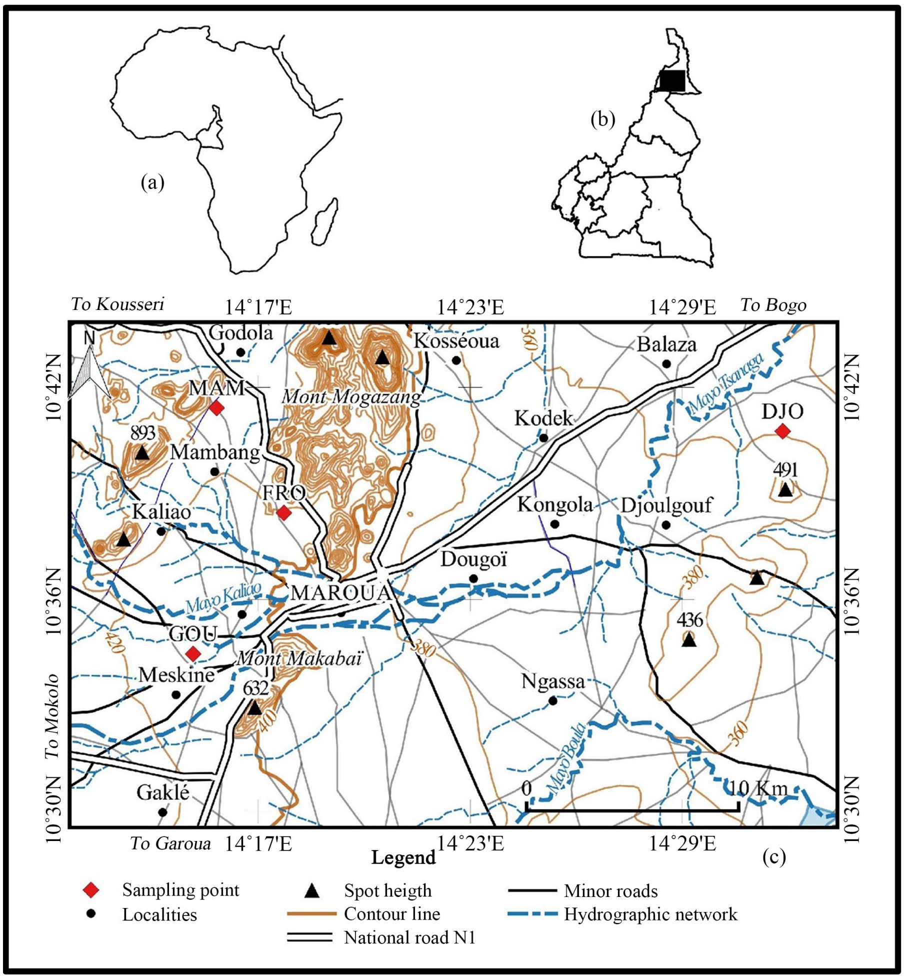

Figure 1. Location Map of the Study Area: (a) Location of Cameroon in Africa, (b) Location of the Far-North Region in Cameroon, (c) limit of the Study Area.

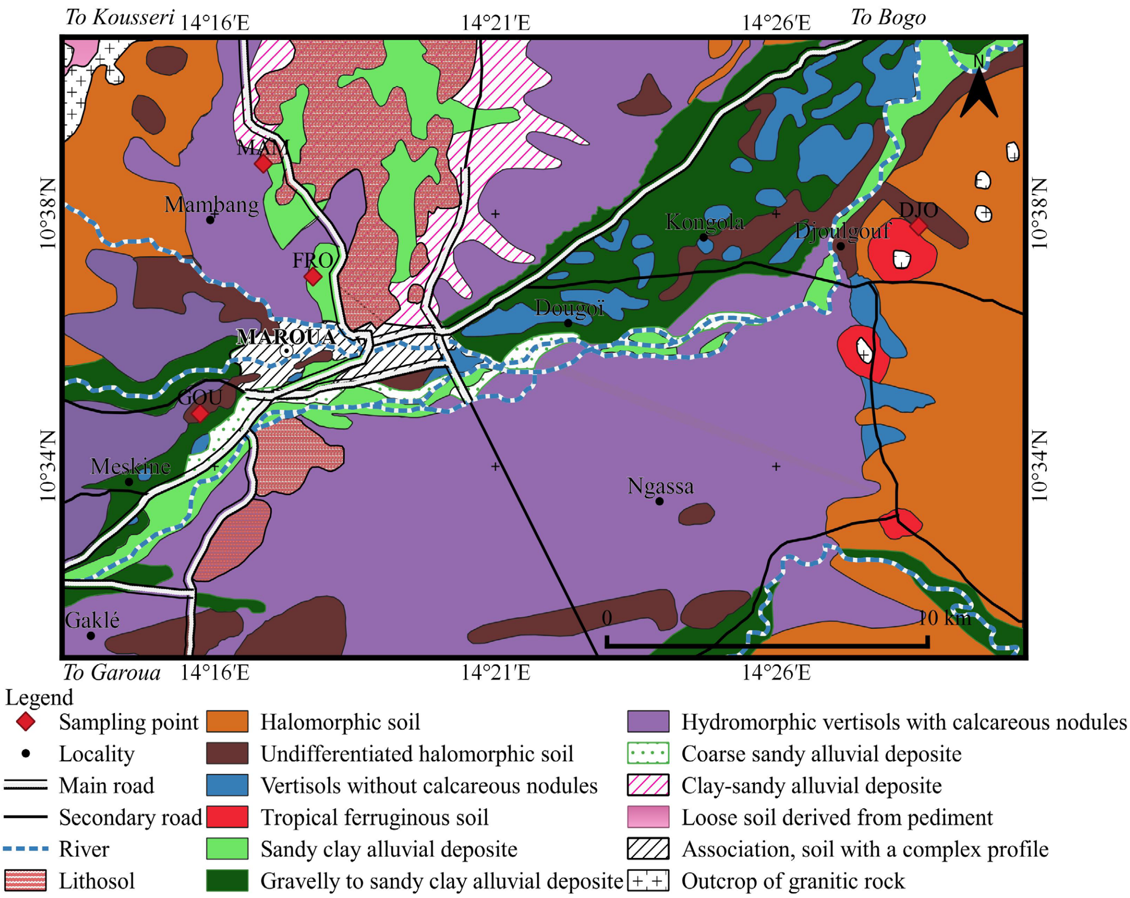

Figure 2. Soil Map of the Study Area, extracted from North Cameroon Soil Map at 1:100,000, Yaounde, ORSTOM.

From a geological point of view, the study area consists globally of volcanic, plutonic, and metamorphic rocks [23] (**Figure 3**). Volcanic rocks are not sufficiently represented in this area, and mainly consist of gabbros, while metamorphic and plutonic rocks are gneisses (**Figure 3**), and granites respectively [23].

3. Material and Methods

3.1. Earth Materials

Depending on their geological context, each town or city uses earth materials from the nearby deposits. As a result, the earth material employed shows various geological and lithological characteristics. Globally, the soils commonly known as "laterite" are the most exploited as raw materials. In general, four main lateritic soil sites can be distinguished in the study area (**Figures 4(a)-(d)**). In Maroua, these soils have been used as an embankment for roadworks and occasionally for compressed earth bricks and adobe production.

3.2. Sample Collection

Fieldwork was conducted during the dry season and consisted mainly in describing the environmental setting. Four localities (Frolina, Goubeou, Mambang, and Djoulgouf), were further retained for detailed investigation and one sample

(FRO GOU MAM and DJO respectively) was collected per locality (**Table 1**). Sample codes are based on the initials of the name of the area from which they were collected. According to the Munsell Color Chart [24], GOU, MAM, and DJO soils have a reddish brown color (10YR 6/6 and 10YR 5/6; (**Figure 4**) while

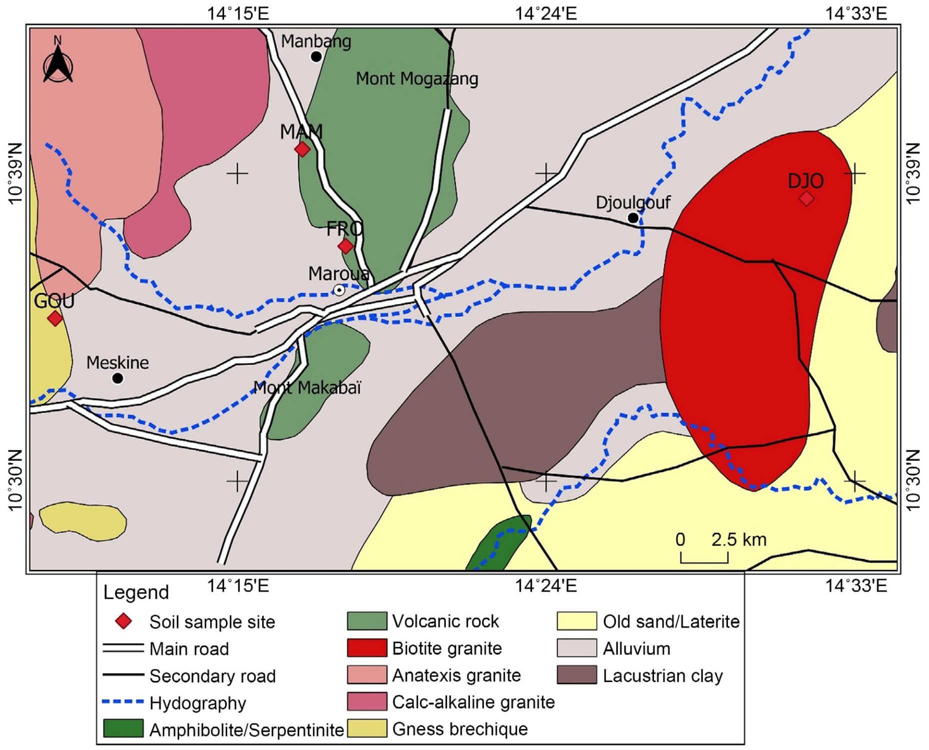

Figure 3. Geologic Map of the Study Area extracted from Geological reconnaissance map of the Federal Republic of Cameroon: sheet NC 33 Number E62.

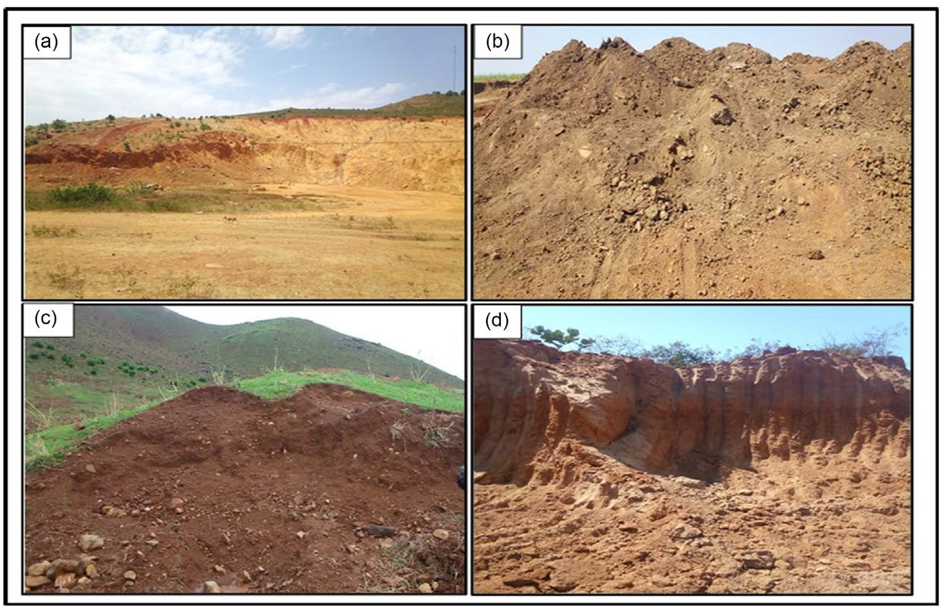

Figure 4. Field photos of investigated soils: (a) Frolina, (b) Goubeou, (c) Mambang and (d) Djoulgouf.

Table 1. Macroscopic characteristics of studied soils.

Samples	Soil Provenance	Coordinates	Color (dry)	Textural Class	Structure	Rock Fragment /nodule	Parent rock/ Special Feature
FRO	Frolina	14.29 E 10.64 N 424 m	Reddish yellow (7.5YR 7/8)	Sandy silt	Massive	1%	Gabbro/ Relict bedrock
GOU	Goubeou	14.25 E 10.57 N 426 m	Yellowish Brown (10YR5/6)	Sandy clayey	Massive	15%	Gneiss/ Ferruginous concretion Quartz grains
MAM	Mambang	14.25 E 10.69 N 600 m	Reddish brown (2.5YR5/4)	Sandy clayey	Massive	15%	Gabbro/ Angular blocky Relict bedrock
DJO	Djoulgouf	14. 52 E 10.68 N 360 m	Reddish brown (2.5YR5/4)	Sandy clayey	Massive	8%	Granite/ Ferruginous concretion Angular quartz grains

FRO soil has a reddish yellowish color (7.5YR 7/8, **Figure 4**). With exception to FRO, the consistency of the soils when dry is slightly hard and very noticeable within the gravel and coarse fraction. The nature of the weathering profiles is sandy silty (FRO), and sandy clayey (GOU, MAM, and DJO). The lower weathering horizon presents a more or less preserved structure of the parent rock. The matrix is remarkably characterized by the presence of nodules and angular fragments of the parent rock, usually made up of quartz crystals that resisted weathering. The nodular horizon of Djoulgouf soil is made up of ferruginous concretions. Where they occur, these nodules decrease from the top to the bottom of the weathering mantle.

3.3. Experimental Methods

Particle size distribution, Atterberg limits (PL, LL, and PI), and natural water content were done at the Local Materials Promotion Authority in Yaounde, Cameroon. Dry sieving was used for the soil fraction greater than 80 µm while gravity sedimentation was applied on the soil fraction lesser than 80 µm in accordance with the ASTM D-422 standard [25]. The degree of plasticity was achieved through the determination of Atterberg's limits using the Casagrande apparatus [26], following the ASTM norm [27]. The plasticity index was mathematically deduced as the arithmetic difference between plasticity and liquidity limit [26]. The natural water content was assessed by two weights, the first for the dry sample and the second after drying in the oven at 105˚C for 24 hours. Moore and Reynolds's [28] method for X-ray powder diffraction (Berlin, Germany) was used to determine the mineralogical composition of the soils. X-ray diffractometer model D8 Advance from Bruker was used to identify, the mineral phases. It was configured with CuKα radiation (λCu = 1.54056 Å) at a step scan of 0.02˚ with a timer having a counting step size of 0.45 seconds operating at a voltage of 40 kV and an electric current of 40 mA. For powdered samples, measurements were conducted in continuous scanning mode with a step size of 0.01 (2θ), a counting time of 0.25 s, and a range of 2˚ - 70˚. The chemical composition was obtained using a Philips XRFSPW1404k spectrometer at the geochemistry unit of "Cimenteries du Cameroun". They employed the molten pearl technique. The method recommended by [29] was used to determine the Chemical Index of Alteration (CIA) of the studied soils as follows: CIA = $Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O) \times 100$.

4. Results and Discussion

4.1. Physical Properties

The result Results reported in **Table 2** show that the studied soils have a large proportion of sand, ranging from 36.9% to 50.5%, followed by clay (22.1% - 28.4%) and silt fractions (11.3% - 23.8%). Compared to the FRO, GOU, and DJO materials, the MAM material has a higher clay content. However, the soils developed on magmatic rocks have a higher clay fraction. Sand content in GOU material is below the limit suggested by the Cameroonian standard [30] but the proportion of gravel and clay is over the limit. According to [31] gravel is a stable material and its properties are hardly altered in the existence of water, meanwhile, sand in a dry state exhibits significant mechanical internal friction. When the soil is compacted during CEB production, the clay fractions will act as binders and may be moisture-sensitive [32]. The grading curves of the studied soils are reported in **Figure 5** alongside the particle size envelope of soil materials used for the production of compressed earth bricks [30]. It may happen that some which do not fall within the recommended zones still give acceptable results in practice. The MAM, FRO, and DJO materials all fall within the sandy clayey field on the Belgian triangular diagram for soil textures [33], however, the GOU material falls inside the heavy sandy clay field (**Figure 6**).

Table 2. Geotechnical properties of the studied soil and Cameroonian standard for compressed earth blocks.

Sample	FRO	GOU	MAM	DJO	NC 102 - 114, 2006
Particle size distribution					
Gravel Φ > 2 mm (%)	3.6	26.1	10.4	14.2	0 - 25
Sand 2 > Φ > 0.02 mm (%)	50.5	37.0	37.6	36.9	55 - 75
Silt 0.02 > Φ > 0.002 mm (%)	23.8	11.3	23.6	21.7	10 - 25
Clay Φ < 0.002 mm (%)	22.1	25.6	28.4	27.2	10 - 15
Atterberg limits					
Liquid limit (Ll) (%)	30.9	41.0	40.0	22.6	25 - 30
Plastic limit (Pl) (%)	22.0	24.9	19.7	16.1	20 - 35
Plasticity Index (Pi) (%)	8.9	16.1	20.3	6.5	2 - 30
Moisture content (%)	5.1	2.8	2.8	2.8	/
Organic matter (%)	7.3	4.7	9.7	2.4	

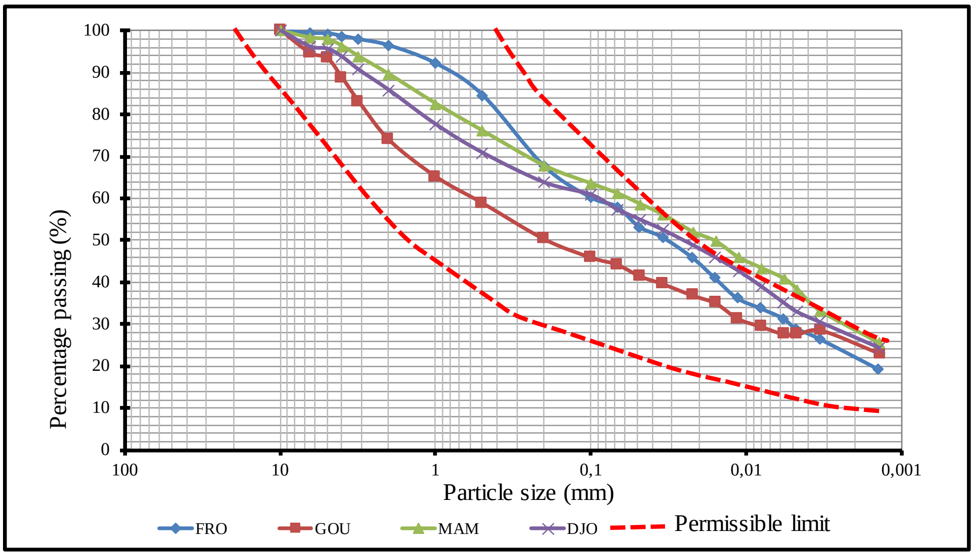

Figure 5. Particle size distribution curves of the studied soils plotted alongside the grading envelope of soils materials used for the production of CEB [30].

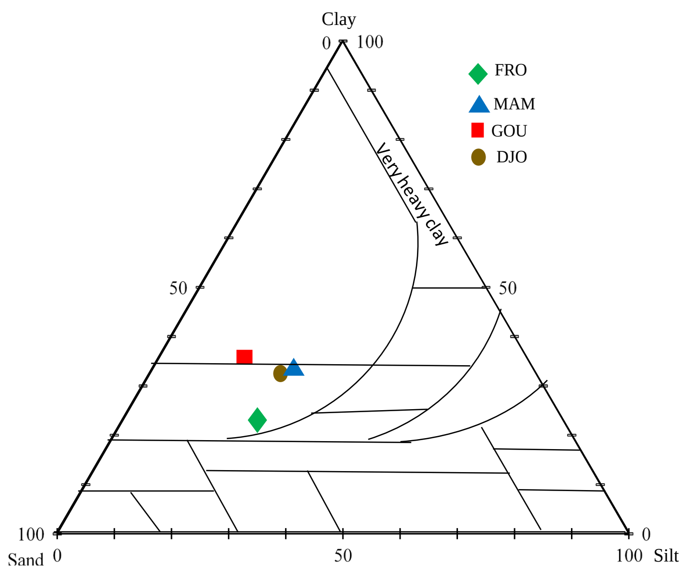

Figure 6. Belgian Texture Diagram proposed by [33] of the Studied Soils.

While the liquid limit and plastic limit values range from 22.6% to 41% and 16.1% to 24.9%, respectively, the plasticity index varies between 6.5% and 20.3% (**Table 2**). The DJO material has the lowest plasticity index and liquid limit. All the studied samples have plasticity indices and liquid limit values that are within the range considered acceptable by the Cameroonian Standard for producing CEB [30]. On comparing the liquidity limit values of the studied soils with those prescribed by the Cameroonian standard for CEB (25% - 30%), the DJO and FRO material is suitable for CEB manufacture (**Table 2**). Based on the clay workability chart (**Figure 7**), the MAM and DJO materials are low-plasticity silts, whereas those from GOU and FRO are medium-plasticity clays. This could be due to the type and amount of clay in the soil [34] [35].

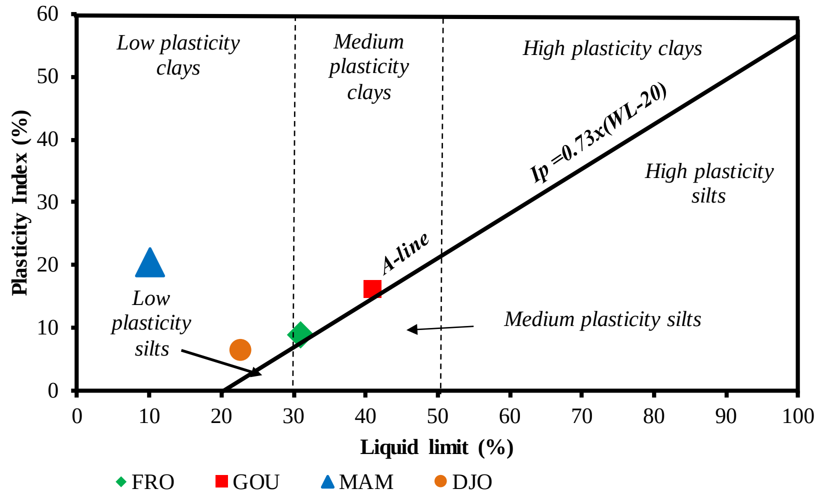

Figure 7. Casagrande's plasticity chart of studied soils.

The natural water contents of the studied soils range globally from 2.8% to 5.1% (**Table 2**). Compared to the materials from MAM, DJO, and GOU (2.8%), the FRO material has higher water content (5.1%). The water retention capacity in soil materials depends highly on the content of fine elements [36], and is correlated to the dry season of soil sampling. According to [37], the natural water content in fine-grained soil influences its engineering behavior given that expansive clay absorbs water between its thin layers, lowering the compressive strength at the ideal moisture content.

4.2. Mineralogical Characteristics

Quartz and K-feldspar represent non-clay minerals, whereas the spectra show distinctive reflection peaks related to smectite, kaolinite, illite, and goethite minerals (**Figure 8**). Only FRO and MAM materials contained smectite (14.66 Å), which is completely absent in materials from GOU and DJO. In accordance with [38] study on differential weathering of granite in the tropical area, the smectite observed in FRO and MAM materials suggests bisiallitisation as the chemical process operating at the bottom of the soil profile. The presence of smectite at least partly explains why these materials have a plasticity index higher than those of MAIM and DJO materials. Indeed, the plasticity of soil is also greatly improved by the presence of illite [39]. In addition, goethite (2.98 Å) and kaolinite peaks (7.06 Å) are seen in all of the studied samples. According to [21], kaolinite is indicative of the high degree of weathering of the soils and on the other hand, suggests that monosiallitisation is a crystallochemical process. Goethite's presence could be explained by the relative concentration of mafic minerals with a high Ti_2O and Fe_2O_3 content during weathering [21]. All samples contain the minerals quartz (4.25 Å, 3.34 Å, 3.24 Å, 2.45 Å, 2.28 Å, 2.12 Å, 1.97Å, 1.81 Å, 1.66 Å, 1.54 Å, 1.45 Å, and 1.37 Å) as well as k-feldspar (3.24 Å). The presence of quartz in these soils is attributed to the mineral assemblage of the parent rock and its high resistance to weathering [40].

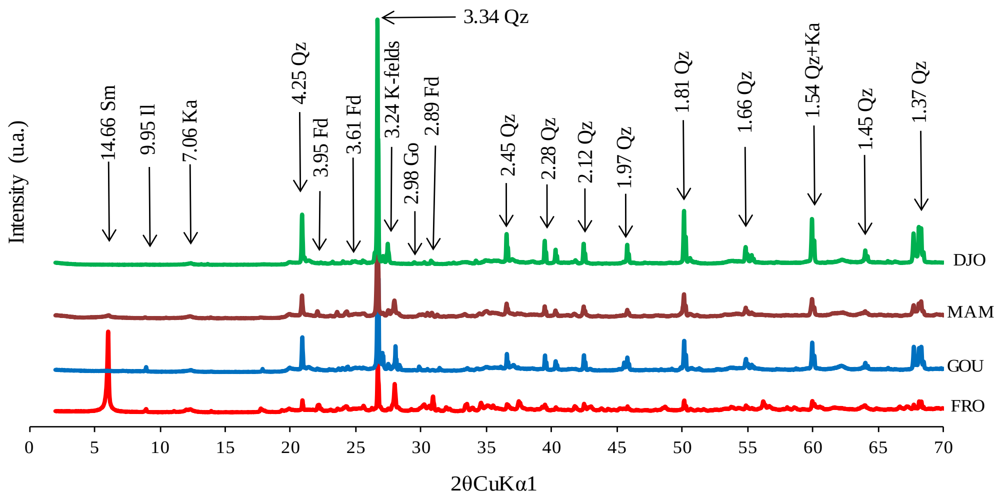

Figure 8. X-Ray Diffractograms of Studied Soil: Sm: Smectite, Ka: Kaolinite, Il: Illite, Go: Goethite Qz: Quartz, K-Felds: K-Feldspar.

4.3. Geochemical Composition

SiO_2 content is high (47.1% - 72.8%) followed by Al_2O_3 (10.9% - 22.8%) and Fe_2O_3 (6.4% - 13.2%) (**Table 3**). SiO_2 reflects the presence of quartz and aluminosilicates [41]. The content of Al_2O_3 within a clay particle depends on the intensity of hydrolysis [42]. Moreover, the amounts of Fe_2O_3 associated with TiO_2 (1.7% - 4.2%) detected in all samples are related to goethite, while potassium is related to the presence of illite and k-feldspars [43]. The concentration of CaO, MgO, Na_2O, K_2O, and TiO_2 elements is relatively low (0.1% - 6.3%). The highest value of CaO (6.3%) was recorded in FRO material (**Table 3**). Chahi *et al.* [43] suggest that the CaO mostly in soil material implies the existence of carbonates and sulfates. TiO_2, K_2O, and Na_2O are the least for the soil developed on basalts with lower percentages of weathered minerals relative to the other soils. MnO and P_2O_5 are present in negligible quantities (<0.2%) often lower than the detection limit in some samples. The LOI value ranges from 3.6% to 8.3% and the higher values were recorded in the MAM material (**Table 3**). Sample GOU has low LOI (3.64%), which is likely due to a faster rate of disintegration and decreased biological activity. The higher LOI value observed in MAM indicates that the biological activity and the clay content have increased [34]. FRO and MAM which are soils formed on basalt, had the highest LOI. It is related to vegetation and the water regime [41] and according to [44] investigation, the increase of LOI in the soil is linked to the existence of kaolinite and mica. According to [45], the strength characteristics of cement-soil blocks are significantly influenced by the amount of organic matter in the soil as a whole. SiO_2/Al_2O_3 ratio ranges and 2.1 to 6.7. The relatively high SiO_2/Al_2O_3 ratios observed in the studied soils are related to a different degree of weathering and reflect the presence of 2:1-type clays [21]. CIA values ranged from 64.9% and 77.4%, and according to [29], the parent rocks of these soils had undergone intermediate weathering.

Table 3. Chemical composition of the studied soils.

Sample code	FRO	GOU	MAM	DJO
SiO_2	47.1	58.5	49.3	72.8
Al_2O_3	22.8	19.9	16.4	10.9
Fe_2O_3	13.2	10.2	12.0	6.4
CaO	6.3	0.2	5.7	0.5
MgO	2.0	0.5	3.1	0.3
Na_2O	0.6	3.2	2.7	0.8
K_2O	1.9	2.4	0.5	3.0
TiO_2	0.1	0.3	1.4	0.5
MnO	0.0	0.1	0.2	0.1
P_2O_5	0.0	0.2	0.1	00
LOI	5.8	3.6	8.3	4.5
Total	100	99.0	99.7	99.8
SiO_2/Al_2O_3	2.1	2.9	3.0	6.7
CIA	72.0	77.4	64.9	72.2

5. Conclusion

From fieldwork and laboratory analysis, it can be concluded that: On the physical account, the studied soils have a massive structure, and their textural properties are designated as sandy silty and sandy clayey. These soils are well-graded. According to the Casagrande diagram, the studied samples are respectively low plasticity silts (MAM and DJO) and medium plasticity clays (GOU and FRO). On the mineralogical and geochemical plan, these soils are made up of the clay minerals: kaolinite, illite, and smectite and non-clay: such as k-feldspar, quartz, and goethite. The geochemical composition shows a relatively high content of SiO_2, followed by Al_2O_3 and Fe_2O_3. According to the different parameters obtained, the studied materials from this area are suitable for use as raw materials in compressed earth bricks.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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