

The Study of Soil Chemistry in the Guinean Coastal Zone

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Abstract

The present study focuses on the particle size and chemical characteristics of three types of soils: Kénendé, Limbita 1 and Limbita 2, with a view to their use in the manufacture of mud bricks. Particle size analyses reveal that the soil of Kénendé contains 16% gravel, 49% sand and 35% silt and clay, while Limbita 1 has a high gravel content (31.2%) and Limbita 2 a high proportion of sand (47%) and fines (51%). The latter composition is favourable to the cohesion, good drainage and mechanical resistance of the bricks. On the other hand, the high gravel content of the soil of Limbita 1 could compromise the strength of the material if no fines enrichment is envisaged. Chemically, all three soils have an acidic pH (5.5 to 5.8), below the recommended standards (6.5 to 8.5), which can affect the performance of the binders. Temperatures of 26°C to 27°C are favourable for the solidification of materials. Electrical conductivity and dissolved solids reveal a slight salinity at Kénendé and Limbita 1, and almost zero at Limbita 2. Chloride and sulphate levels are particularly high in Kénendé, posing a risk of efflorescence and deterioration of the bricks. In conclusion, the floor of Limbita 2 is the most suitable, both physically and chemically, for the manufacture of sustainable bricks. The soils of Kénendé and Limbita 1 require corrective treatments.

Keywords

Lateritic Soils, Particle Size, Mud Bricks, Mechanical Strength, Physico-Chemical Analysis

1. Introduction

The study of the chemical characteristics of soils intended for construction in the Guinean coastal zone is of paramount importance in view of the issues related to

the quality of infrastructure and the durability of constructions in an environment subject to specific climatic and ecological conditions. The chemical composition of coastal soils, influenced by factors such as salinity, humidity and contaminants, determines the strength and durability of built structures.

A fundamental aspect to consider is the capacity of soils to withstand loads and their behaviour in the face of the effects of environmental events. Zhang and Comend's research [1] on the application of finite element models in the analysis of ground movements during tunnel construction highlights the importance of the mechanical and chemical properties of soils in anticipating deformations and ensuring the stability of constructions. In addition, the development of digital tools to model these aspects can provide valuable data for infrastructure planning in coastal areas.

In addition, Hayek *et al.* [2] highlight the influence of environmental conditions, such as carbonation, on the durability of cementitious materials in the marine environment, which is relevant for Guinean coastal soils, which are often exposed to seawater. The importance of assessing the chemical quality of the soils that will serve as the foundation for the cementitious materials cannot be underestimated, as poor soil quality can lead to significant structural degradation.

In addition, more targeted studies on clay soils, such as those by Kushi [3], indicate that pre-treatments, such as chemical activation, can improve the physical and chemical properties of soils, making them more suitable for construction. This is particularly relevant in coastal areas where soils may have a variable clay composition depending on marine deposits.

A complementary study on tropical land use in construction projects, such as that of Soulat *et al.* [4], highlights the importance of understanding soil shear strength for its application in constructions such as dams, which could be extrapolated to Guinean coastal infrastructure. In addition, it raises the question of the value of tropical residual soils, which could play a crucial role in the sustainability and efficiency of coastal construction.

Finally, the impact of soil management practices and climate change on soil quality in coastal areas is highlighted by the work of Gauze *et al.* [5]. Their research highlights how changes in land use can affect soil chemistry, a reality to be taken into account when assessing the suitability of Guinean soils for sustainable construction projects.

Thus, the study of the chemical characteristics of soils intended for construction in the Guinean coastal zone requires a multidisciplinary approach, integrating geotechnics, ecology and sustainability, to provide informed recommendations on land use and best practices for construction.

The city of Dubréka, located near the Guinean coast, is an area in full urban expansion, requiring special attention to the quality of the soils used in construction projects. Soil chemistry plays a key role in the sustainability and safety of built infrastructure. The soils of Dubréka, influenced by their climatic, geological and environmental conditions, have chemical properties that deserve to be analysed in order to guarantee the viability of construction projects.

Dubreka is located in a coastal region, where soils are often exposed to factors such as salinization due to seawater and flooding. This situation is exacerbated by rising sea levels, which could change soil chemistry in the long term (Bocquillon *et al.*) [6]. The soil types found in this region include mainly clays and silts, which have specific properties that are essential for building. For example, clays often exhibit an ability to retain water, but can also be prone to compaction and swelling, critical properties to consider during construction (Sousa *et al.*) [7].

Chemical analysis of soils in the Dubreka region typically focuses on elements such as pH, salinity, and nutrient concentration (nitrogen, phosphorus, potassium), all of which are essential for the load and stability of building materials. Studies indicate that high levels of salinity can impair the durability of concrete structures (López and Nóvoa) [8]. Other studies highlight the importance of minerals present in clay soils, which can influence the mechanical strength of materials (Kushi) [3].

The clay soils of Dubreka could benefit from chemical treatments to improve their cohesion and resistance to erosion. For example, chemical activation of clays has shown promising results in enhancing the supporting properties of soils under various environmental conditions (Ayub *et al.*) [9].

Common construction practices in Dubreka, often based on local materials, must incorporate the results of chemical studies to ensure a sustainable approach. Pollution resulting from human activities can also affect soil quality, making regular analysis necessary (Amara, A.) [10]. In addition, educating local builders and architects about soil properties and environmental impacts could lead to more resilient constructions that respect the local ecosystem.

The study of the chemical characteristics of construction floors in Dubreka is paramount to provide a scientific basis for sustainable and safe building practices. Detailed analyses of the chemical qualities of soils will make it possible to optimize their use and prevent structurally harmful failures. It is in this context that the present study was carried out, on the samples that were taken in Kenendé, Limbita 1 and Limbita 2. The overall objective of this study is to assess the chemical characteristics of the soils used in construction projects in Dubreka, in order to provide informed recommendations for sustainable and efficient management of building materials in this coastal region. Specifically: Identify soil types; analyze their chemical composition and to assess the influence of salinity on their soil properties of the soils (**Figure 1**).

2. Material and Methods

The particle size analysis was carried out to determine the parameters of the nature of the soil, then the chemical analyses.

2.1. Sampling and Chemical Characterization Methodology

The present study on the Guinean coastal zone was conducted using a stratified approach, aimed at characterizing the chemical properties of soils representative of different geopedological contexts. Three sites were selected, including: a clay

soil in the mangrove zone (K enend e), a lateritic soil in a hilly zone (Limbita 1), and a clay soil in the continental lowlands (Limbita 2). At each site, a homogeneous plot of 10 m × 10 m was demarcated, in which five-point samples were taken (at the four corners and in the centre) at a depth of 0 to 30 cm. The sub-samples were homogenized to form a composite sample of about 6 kg, ensuring good spatial representativeness. The equipment used included a hoe, a shovel, a manual auger, strong labelled plastic bags, gloves, a GPS or smartphone for location, as well as a field notebook and a vehicle for transport. The samples were carefully labelled, air-dried if the analyses were not immediate, and then stored away from moisture and contamination.

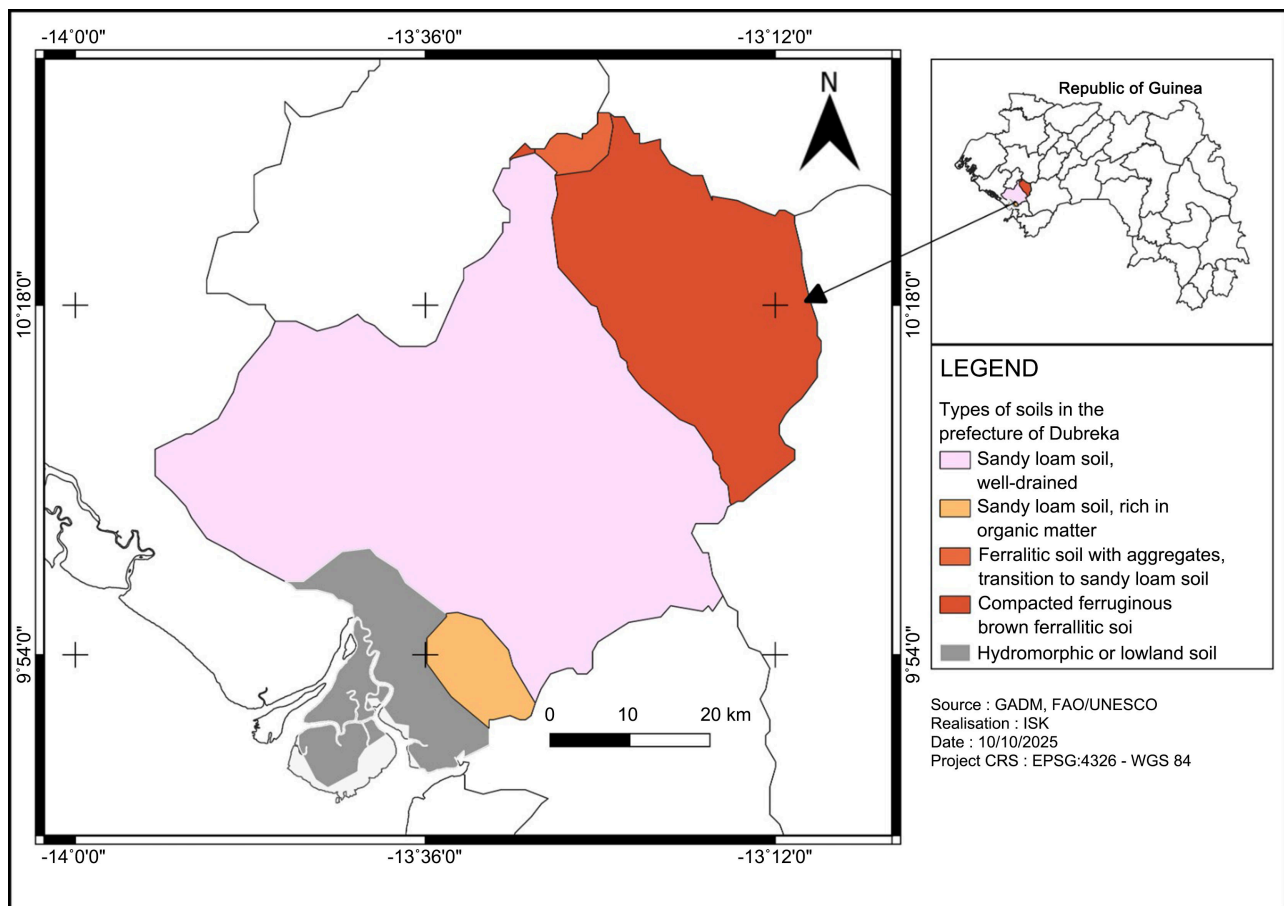


Figure 1. Types of soils in the Prefecture of Dubreka.

The analyses focused on chemical characterization, two procedures were applied: acid digestion and leaching extraction. Acid digestion, used to determine the total or pseudo-total content of metallic elements, consisted of digesting 0.5 g of sieved soil ($\leq 250 \mu\text{m}$) with a mixture of 7.5 mL of hydrochloric acid (HCl) and 2.5 mL of nitric acid (HNO₃), heated to 95°C for two hours. After cooling, the solution was filtered (0.45 μm), supplemented to 50 mL with distilled water, and then stored in a polyethylene vial for spectrophotometric analysis. Strict precautions were observed, including the use of clean glassware, gloves, and extractor

hoods.

In addition, leaching extraction was performed to estimate the mobile or bioavailable fraction of the chemical elements. This method simulates the natural leaching of soils by low-acid aqueous solutions. It involved the contact of 10 g of sieved soil with 100 mL of dilute nitric acid (HNO_3 0.01 M), stirred for 4 hours at 200 rpm at room temperature. After resting (4000 rpm for 15 minutes), the solution was filtered ($0.45 \mu\text{m}$) and stored at 4°C until analysis. The leaching rate was calculated by comparing the extracted concentration to the total content obtained by digestion, according to the formula: (extracted concentration/total concentration) \times 100.

$$\text{Leaching (\%)} = \left(\frac{C_{\text{extract}}}{C_{\text{total}}} \right) \times 100$$

C_{extract} = Concentration of the element in the leached solution (mg/kg soil or mg/L depending on the protocol).

C_{total} = Total concentration of the element in soil, determined after complete acid digestion (e.g. aqua regia).

2.2. Particle Size Test

Particle size analysis by sieving is carried out using square mesh sieves with dimensions between 100 mm and 0.080 mm (NFP 94-056) [11]. For particles smaller than 0.080 mm, it was done by sedimentation (NF P94-057) [12].

At the end of these analyses, the soils sampled are:

- Powdery soils (stony, gravelly and sandy soils, gravel and sandy soils)
- Fine soils (silty and clayey). The below **Figure 2** shows the different categories of soil grains.

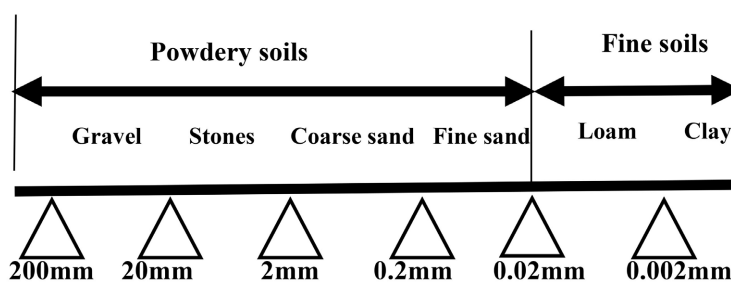


Figure 2. Grain grade.

Equipment:

- A washing device with sprinkler;
- A nesting sieve column with lid and bottom;
- A precision electronic scale 0.01 g;
- Bowls;
- The drying oven with adjustable temperature;
- The mortar with pestle;
- Brushes, brushes.

Procedure:

- Sampling of a test portion after quartage;
- 0.080 mm sieve washing with a 2.5 mm support sieve;
- Drying in the oven;
- Sieving;
- Weighing of refusals.

2.3. Methodology for Chemical Analysis of Soil

The chemical analysis concerned three soil samples taken respectively in Kénendé, Limbita 1 and Limbita 2. The dates of collection, transport to the laboratory and analysis are presented in **Table 1**.

Table 1. Dates of collection, transport and analysis of soil samples.

Sample Type	Location of collection	Sample code	Dates		
			Levy	Reception at the Laboratory	Analysis
<i>Granular soil</i>	Kende	20230158 03	7/06/2023	24/10/2023	From 25 to 29/2023
<i>Granular soil</i>	Limbita 1	20230158 01	7/06/2023	24/10/2023	From 25 to 29/2023
<i>Granular soil</i>	Limbita 2	20230158 02	7/06/2023	24/10/2023	From 25 to 29/2023

The analysis was carried out in accordance with established standards at the CERE laboratory (Centre for Environmental Studies and Research/University of Conakry). It focused on the parameters: pH, Temperature, Conductivity, Total Dissolved Solids (TSS), Nitrates, Nitrites, Sulphates, Total Iron, Phosphate and Chloride. The analytical methods used for each of these parameters above are given in the following **Table 2**.

Table 2. Analytical parameters and methods used (EISC-2023).

Parameters	Method of analysis
Ph	NF T 90-008
Temperature °C	NF T 90-008
Conductivity (µs/cm)	Conductimetry/Conductivity Meter 70 + WATERPOOF
TDS (mg/l)	Conductimetry/Conductivity Meter 70 + WATERPOOF
Nitrates (NO ₃ ⁻) (mg/Kg MS)	NF EN 196-2
Nitrite (NO ₂ ⁻) (mg/Kg MS)	ISO 11048:2021
Sulfate (mg/Kg MS)	ISO 11048:2021
Total Iron (Fe ²⁺) (mg/Kg DM)	ISO 11048:2021
Phosphate (mg/Kg MS)	ISO 11048:2021
Calcium (Ca ²⁺) (mg/Kg MS)	ISO 11048:2021
Chloride (Cl ⁻) mg/Kg DM	NF EN 196-2
REDOX Potential (Eh) mV	Electrometry/Multiparameter (Eh, CE, T°, pH)

Temperature °C (NF T 90-008) [13]

The temperature was measured with a thermometer calibrated according to the NF T 90-008 standard. The method consists of completely immersing the thermometer probe in the sample and reading the temperature, after stabilization of the display.

pH

The pH was measured by the electrometric method, using a pH meter (pH meter reference). The method consists, after calibrating the pH, of immersing the pH meter probe in the sample and waiting for the display to stabilize before reading the results.

Conductivity ($\mu\text{S}/\text{cm}$) and TDS (mg/l)

Conductivity and TDS were determined using a Model 70 + WATERPOOF conductivity meter. The procedure includes calibration of the conductivity meter with standard solutions of known conductivity. The method consists of immersing the Conductivity Meter probe in the sample and reading the result after stabilizing the display. For some conductivity meter models, the TDS is simply read by pressing the MODE button on the device.

According to the NF EN 206/CN [14] standard, a soil is said to be: non-saline ($\text{CE} < 2000$), slightly saline ($2000 < \text{CE} < 4000$), saline ($4000 < \text{CE} < 8000$) and very salty ($\text{CE} > 8000$). **Table 3** presents the assessment of soil pH and salinity.

Table 3. Assessment of soil pH and salinity (Bocoum, 2004) [15].

pH Range	Ph	Electrical Conductivity (CE)	
	Ground	Conductivity ($\mu\text{S}/\text{cm}$)	Ground
<4.5	Extremely acidic soil	<250	Non-salt
4.6 - 5.2	Very acidic	250 - 500	Slightly saline
5.3 - 5.5	Acid	500 - 1000	Saline
5.6 - 6.0	Moderately acidic	1000 - 2000	Very saline
6.1 - 6.6	Slightly acidic	>2000	Extremely saline
6.7 - 7.2	Neutral		
7.3 - 7.9	Slightly alkaline		
8.0 - 8.5	Alkaline		
>8.6	Very alkaline		

Nitrate (NO_3^-) (NF EN 196-2) [16]

The NF EN 196-2 method [16] was used to measure the nitrate concentration. It includes the preparation of the sample in accordance with the standard, the use of a colorimetric or other specified method, and the recording of the results.

Nitrite (NO_2^-)

ISO 11048:2021 [17] has guided the nitrite analysis process, including the steps for sample preparation and application of the specified analytical method.

Sulfate, Fer Total, Phosphate, Calcium (ISO 11048:2021) [17]

These components have been analyzed in accordance with ISO 11048:2021 [17], with sample preparation steps and application of the analytical methods specified in this standard.

Chloride (Cl⁻)

The NF EN 196-2 method [15] is used to measure the chloride concentration, which involves preparing the sample according to the standard, using a colorimetric or other specified method, and recording the results.

REDOX Potential (Eh) mV (Multi-parameter)

The REDOX potential was measured by the electrometric method using a multi-parameter equipped with a REDOX probe. The process includes immersing the probe in the sample, waiting for the reading to stabilize, and recording the REDOX potential value.

3. Presentation of the Results

3.1. Soil Identification

The particle size analyses focused on three types of soils, namely: the Kénendé soil, the Limbita 1 soil and the Limbita 2 soil. The particle size analysis of the Kénendé soil sample gave a proportion of 0% pebbles, 16% gravel, 49% sand and 35% silt and clay. For the soil sample of Limbita 1, the results of the particle size analysis yielded 31.2% gravel, 19.8% sand and 49% silt (silt) and clay. As for the soil of Limbita 2, the proportions of the different types of particles are 2% gravel, 47% sand and 51% silt (silt) and clay.

If we compare these data with those of the study conducted by Cissé [18] as part of his doctoral thesis on the optimization of the rheological and mechanical characteristics of soil stabilized with hydraulic lime for its use in construction in the Guinean coastal zone, found a good lateric earth in Kendoumaya, Prefecture of Coyah, Republic of Guinea, soil composed of 0.65% gravel against 31.2% for the soil of Limbita 1, 16% for the soil of Kénendé and 2% gravel for the soil of Limbita 2, then 69.5% of sand against 19.8% for the soil of Limbita 1, 49% sand for the soil of Kénendé and 47% for the soil of Limbita 2 and 29.4% silt and 0.6% clay against 49% of silt and clay for the land of Limbita 1, 35% for the land of Kénendé and 51% for the soil of Limbita 2. In addition, according to the recommendations made by Houben *et al.* [13] for the construction of compressed earth blocks, the values should be between 0% to 40% gravel, 25% to 80% sand, 10% to 25% silt and 8% to 30% clay. Taking into account the recommendations of Houben *et al.* [13], the lands of Kénendé, Limbita 1 and Limbita 2 are suitable for making these blocks. And based on the NF P94-093 (1999) [19] standard, the samples of Kénendé and Limbita 1 meet the particle size criteria for the production of quality bricks, because they have clay proportions between 5% and 30%. The Limbita 2 samples, on the other hand, have a clay proportion greater than 30%, which may require corrections to its particle size for the manufacture of quality bricks. In addition, despite the satisfactory performance of Kénendé earth, in the practice of brick making, the sampling site is located near the mangrove, which is a nationally and in-

ternationally protected wetland.

Variations in soil composition underline the importance of carrying out site-specific particle size studies before undertaking construction projects, as the proportions of the different particle fractions determine the mechanical properties of the building materials. These differences should be taken into account when planning construction projects, as they affect the quality of building materials.

3.2. Determination of Chemical Parameters of K enend , Limbita 1 and Limbita 2 Soil Samples

The analysis of the mangrove soil samples from Kenend , the Limbita 1 and Limbita 2 clays yielded the results recorded in **Table 4** below.

Table 4. Results of the chemical analysis of the mangrove soil of K enend , the clays of Limbita 1 and Limbita 2.

Parameters	Unit	Values obtained		
		Sulphur	Limbita 1	Tongue 2
ph	-	5.5	5.8	5.7
Temperature	�C	26	27	27
Conductivity	�s/cm	392	434	150
Total dissolved solids (TDS)	mg/L	196	217	75
Sulfate (SO_4^{2-})	mg/Kg MS	160	8	16
Chloride (Cl^-)	mg/Kg MS	265	116	132
Redox potential	Mv	88	72	79
Nitrates (NO_3^-)	mg/Kg MS	309.8	16.5	54.9
Nitrite (NO_2^-)	mg/Kg MS	7.2	0.06	1.2
Phosphate (PO_4^{3-})	mg/Kg MS	11.1	11.1	11.1
Fer total	mg/Kg MS	9.9	0.8	0.9

In the context of brick manufacturing, certain physicochemical parameters such as pH, temperature, electrical conductivity, total dissolved solids (TDS), chlorides and sulphates play a decisive role. Analysis of soil samples from Kenende, Limbita 1 and Limbita 2 reveals that the pH of these soils varies between 5.5 and 5.8, indicating an acidic character for all the samples. However, according to the NF EN 206/CN (2015) [13] standard, a pH between 6.5 and 8.5 is required for floors intended for construction. Failure to do so could compromise the responsiveness of the hydraulic binders used in the bricks, reducing their strength and compressive strength (Bhattarai *et al.*) [15].

On the other hand, the temperatures recorded in the three samples—26 C for K enend , 27 C for Limbita 1 and 27 C for Limbita 2—are within the range recommended by the same standard, *i.e.* between 25 C and 30 C. This range promotes the chemical reactions necessary for the solidification of materials, an essential condition for guaranteeing the mechanical performance and durability of

bricks (Bhattarai *et al.*) [20].

Concerning the electrical conductivity, the measured values are 392 $\mu\text{s}/\text{cm}$ in K enend e, 434 $\mu\text{s}/\text{cm}$ in Limbita 1 and 150 $\mu\text{s}/\text{cm}$ in Limbita 2. According to the NF EN 206/CN (2015) [13] standard, these values below 2000 $\mu\text{s}/\text{cm}$ classify these soils as non-saline, which is favourable to the manufacture of bricks. However, according to the Bocoum classification [15], the soils of K enend e and Limbita 1 are considered to be slightly saline ($\text{EC} > 250 \mu\text{s}/\text{cm}$), unlike Limbita 2, which is classified as non-saline ($\text{EC} < 250 \mu\text{s}/\text{cm}$). This analysis is corroborated by the total dissolved solids levels: 196 mg/L for Kenende, 217 mg/L for Limbita 1 and only 75 mg/L for Limbita 2, confirming a lower salt content for the latter.

The salinity of the soil, in particular the presence of chlorides and sulphates, is a major concern in the manufacture of bricks. Indeed, these salts can disrupt the chemical reactions essential to the cohesion of materials, reducing the strength and durability of bricks. They can also cause efflorescence phenomena—deposits of salts on the surface—altering the aesthetics and potentially weakening the structural integrity of the bricks. In addition, the migration of salts through the material can lead to early deterioration of joints and surfaces, leading to accelerated erosion (Steenhoudt, O. and Vanderleyden, J. [21]; Yue *et al.* [22]).

The measured chloride concentrations reached 265 mg for Kenend e soil, 116 mg for Limbita 1 and 132 mg for Limbita 2. Similarly, the sulphate content in Kenend e’s soil is 160 mg/kg DM, a value that is likely to have a negative impact on the chemical stability of the bricks. These high levels of dissolved salts are a risk factor for the durability of materials, in particular because of their corrosive potential on structural components (Yue *et al.*) [22].

In addition, recent research confirms that certain salts such as sodium chloride or magnesium sulfate can exert internal pressure in the pores of bricks, causing gradual degradation. Conversely, others, such as calcium chloride, have a less pronounced effect on the physical integrity of materials (Yue *et al.*) [22]. Thus, rigorous monitoring of the chemical composition of the soils used in the manufacture of bricks would prevent structural failures and guarantee better long-term performance (Fustamante, J.) [23].

Finally, the durability of bricks also depends on mechanical properties such as compressive strength and swelling behaviour, which are strongly influenced by the physicochemical conditions of the soil. Too acidic a pH can affect the porosity of bricks and lead to insufficient consolidation, increasing the chances of cracking and stress failure (Bhattarai *et al.*) [20].

In short, the chemical analysis of the soils of K enend e, Limbita 1 and Limbita 2 highlights several challenges for their use in the manufacture of bricks, in particular due to the acidic pH and the presence of dissolved salts. Of the three samples, the soil of Limbita 2 has the most favourable characteristics, with low salinity, optimal temperature and lower chloride content. This in-depth understanding of physico-chemical parameters is essential to guide the choice of raw materials and improve the quality of bricks from a sustainable construction perspective (Fusta-

mante [21]; Yue *et al.*, 2022 [20]; Bhattarai *et al.* [20]).

4. Conclusions

The comparative study of the particle size and chemical characteristics of the soils of Kénendé, Limbita 1 and Limbita 2 has made it possible to draw essential lessons for their recovery in the manufacture of mud bricks. The results highlight the floor of Limbita 2, which has a good balance between sand and fines, guaranteeing cohesion, compactness and mechanical resistance. This composition makes it particularly suitable for the production of durable bricks without the need for major modifications.

On the other hand, the soil of Limbita 1, with its high gravel content, requires enrichment of fine elements to improve its plasticity and cohesion, which are essential for the holding of the bricks. As for the Kénendé soil, although relatively balanced in particle size, it has high concentrations of chlorides and sulphates, as well as an acidic pH, which could affect the durability of the materials manufactured, by promoting efflorescence or corrosion phenomena.

Chemically, all three soils are outside the recommended pH ranges, which underlines the need for corrective treatment, including the addition of binders or alkaline amendments. These adjustments are essential to optimize the adhesion of the materials and ensure the longevity of the structures.

In short, this study demonstrates the interest of finely characterizing local soils before their use in construction, and highlights the potential of Limbita 2 soil as a material of choice for the manufacture of ecological and economical bricks, with a view to sustainable development and the enhancement of local resources.

Conflicts of Interest

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

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