JOURNAL AFRICAIN DES SCIENCES
VOL. 1, **2** (2024) 96-104

https://jafrisci.org

ISSN (online) : 3107-0949 ; ISSN (print) : 3107-0930

OPEN ACCESS

RESEARCH ARTICLE

Article Info.:
Received : 06th December 2024
Accepted : 14th January 2025
Published : 24th January 2025

CHEMICAL, MINERALOGICAL AND MICROBIOLOGICAL CHARACTERIZATION OF SOME GEOPHAGIC CLAYS FROM THE DEMOCRATIC REPUBLIC OF THE CONGO: CBRN RISKS

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https://doi.org/10.70237/jafrisci.2024.v1.i2.11

Resumé

Cette étude se concentre sur la caractérisation chimique, minéralogique et microbiologique des argiles géophagiques du Grand Bandundu, de Kisangani et du Kongo-Central en République Démocratique du Congo (RDC), dans le but de différencier les argiles kaolinitiques des illitiques. Traditionnellement consommées par les populations de Kinshasa, ces argiles ont été analysées pour évaluer leurs effets potentiels sur la santé. Les analyses par diffraction des rayons X (DRX) et fluorescence des rayons X (FRX) ont révélé que les argiles du Kongo-Central sont principalement kaolinitiques, contenant du quartz, tandis que celles de Bulungu et Kisangani sont majoritairement illitiques avec une faible teneur en quartz. Cette distinction met en lumière des propriétés spécifiques, telles que des apports nutritionnels possibles grâce à des minéraux comme le calcium, le magnésium et le fer. Néanmoins, la présence d'éléments toxiques tels que le plomb et l'arsenic pose un risque pour la santé. Au niveau microbiologique, bien que les analyses n'aient révélé aucune contamination par Escherichia coli ou Pseudomonas aeruginosa, les échantillons ne respectent pas les normes de l'OMS, ce qui révèle des lacunes en termes d'hygiène.

Mots clés : Argiles géophagiques, Caractérisation, minéralogique, Risques CBRN

Abstract

This study focuses on the chemical, mineralogical, and microbiological characterization of geophagic clays from Grand Bandundu, Kisangani, and Kongo-Central in the Democratic Republic of Congo (DRC), with the aim of distinguishing kaolinitic clays from illitic ones. Traditionally consumed by populations in Kinshasa, these clays were analyzed to assess their potential health effects. X-ray diffraction (XRD) and X-ray fluorescence (XRF) analyses revealed that the clays from Kongo-Central are primarily kaolinitic, containing quartz, whereas those from Bulungu and Kisangani are mostly illitic with low quartz content. This distinction highlights specific properties, such as potential nutritional benefits due to minerals like calcium, magnesium, and iron. However, the presence of toxic elements such as lead and arsenic poses significant health risks. At the microbiological level, while the analyses revealed no contamination by Escherichia coli or Pseudomonas aeruginosa, the samples do not meet WHO standards, indicating hygiene deficiencies.

Key words : Geophagic clays, Characterization, Mineralogical ,CBRN risks

1. INTRODUCTION

Clays form through the chemical weathering of rock minerals such as feldspar, amphibole, mica, and chlorite, releasing elements like aluminum, silicon, potassium, and iron **[1].**
These elements react with water and carbon compounds in the soil to form clays. Environmental conditions, such as pH, temperature, and the chemical composition of water, influence the type and quantity of clays formed, as well as the presence of other minerals and the rate of erosion. This process, which takes millions of years, results from complex reactions between rock minerals and their surroundings **[2].**

$$2(Na, K, Rb)AlSi_3O_8 + 2CO_2 + 11H_2O \rightarrow 2(Na, K, Rb)^+ + Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2HCO_3^-$$

This chemical equation describes the breakdown of primary rock into clay. Primary rocks, which may contain sodium (Na), potassium (K), or rubidium (Rb), react with carbon dioxide (CO_2) and water molecules (H_2O). This reaction produces leaching solutions, as well as kaolinite ($Al_2Si_2O_5(OH)_4$), a key component of clays alongside illites **[3]**. The presence of heavy metals in certain foods can potentially lead to acute or chronic poisoning in humans, depending on the concentration and duration of exposure, with varying impacts on different organs. This issue is exacerbated in developing countries due to increasing industrial

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activities and the growing use of products containing these metals. Furthermore, the practice of consuming clay, known as geophagy, is widespread worldwide, particularly in Africa, often without serious health risk assessments. Studies have revealed high concentrations of toxic pollutants in these geophagic clays**[4].** According to recent studies **[5][6]**, Exposure to lead (Pb) and manganese (Mn) raises significant concern among authorities and researchers due to their detrimental health effects, particularly in children. These metals can cause neurological disorders, reduced IQ, and dysfunctions in the nervous and endocrine systems, as well as liver and kidney problems, genetic alterations, and increased risks of mutations, malformations, and cancer **[7]**. Elevated levels of certain elements in the geophagic samples studied may have health implications. For instance, calcium (Ca) is beneficial, but excessive doses can lead to kidney and cardiovascular issues. Similarly, potassium (K) and sodium (Na) are essential for electrolyte balance, but overconsumption may result in gastrointestinal disturbances. Iron (Fe), magnesium (Mg), zinc (Zn), and other elements, though necessary, can cause health problems when consumed in excess. Manganese (Mn) and silicon (Si) are essential in small quantities, but high levels can lead to neurological or gastrointestinal issues. Aluminum (Al), considered non-essential, can also pose risks at elevated concentrations. Elements such as barium (Ba), bromine (Br), chromium (Cr), nickel (Ni), and vanadium (V) may also present health risks when exceeding recommended levels**[8]**. Exploring the toxic effects of heavy metals on human health through modern analytical methods reveals variability in the toxicity of non-essential elements, including metals associated with nuclear connotations like uranium and thorium. This scale of toxicity ranges from low-toxicity elements like barium (Ba), lithium (Li), aluminum (Al), and tin (Sn), to more toxic metals such as lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg), resulting in a wide array of adverse health effects. A classification of heavy metals based on their impact on the body is illustrated from previous research **[9][10]**. Geophagy, the practice of consuming earth materials, is a custom observed in many cultures worldwide, including in the Democratic Republic of Congo (DRC). Geophagic clays are consumed for various health-related reasons, including detoxification and as a source of minerals. This study aims to provide a detailed chemical and mineralogical characterization of these clays to better understand their composition and potential health effects. Furthermore, it is crucial to evaluate the safety of consuming these clays, as they may contain both beneficial elements and potentially toxic contaminants. The study **[11]**examined the granulometric properties, mineralogical composition, and concentrations of major and trace element oxides in geophagic soils from three different countries (DRC, South Africa, and Swaziland). Chemical Index of Alteration (CIA) and Chemical Weathering Index (CIW) values ranged from 60% to 99.9%. Soils from the DRC predominantly contained kaolinite, while those from South Africa and Swaziland were dominated by quartz and feldspar.

Mubiayi *et al*.,**[12]** characterized the properties of geophagic clay samples from **DRC** to identify their potential applications. Samples collected from three different regions (Bukavu, Lubumbashi, and Kinshasa) showed variations in morphology and color, ranging from light gray/yellow to reddish and dark gray. X-ray diffraction revealed the presence of muscovite, kaolinite, illite, and quartz, while fluorescence analysis showed the presence of SiO_2, Al_2O_3, TiO_2, and Fe_2O_3 as the main chemical compounds.

2. MATERIALS AND METHODS

2.1. Sample Collection

Geophagic clay samples were collected from various regions of the Democratic Republic of the Congo (DRC) (Figure 1), where the practice of geophagy is common.

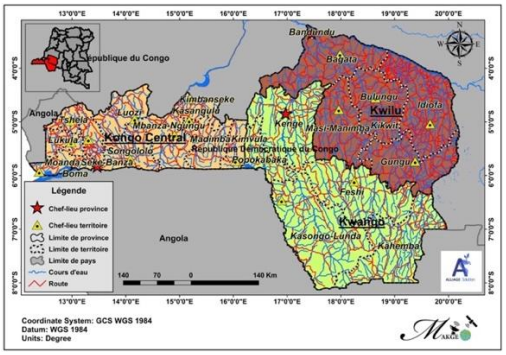


Figure 1: *Mapping of Source Areas.*

Collection sites were selected based on their popularity and accessibility for local inhabitants. The samples were carefully collected and stored in airtight containers to prevent contamination and moisture absorption, thereby ensuring the integrity of the samples for subsequent analyses. **Figure 2** highlights the various colors of geophagic clay, illustrating the range of shades that reflect the mineralogical composition in the regions of the Democratic Republic of the Congo.



Figure 2: *Clays and Various Shades*

2.2. Analytical Techniques

2.2.1. Drying & Calcination of Samples

The calcination of geophagic clays offers several advantages, including improved adsorption properties, sterilization of pathogenic microorganisms, and the elimination of organic impurities. This process enhances safety by reducing risks (CBRN). Calcination also alters the crystalline structure of clays, rendering contaminants less mobile and the clays more effective for detoxification, thus ensuring safer consumption.

Drying Procedure [13]

A **KERN** DBS 60-3 thermal balance (Kern & Sohn GmbH, Balingen, Germany) **[14]** moisture analyzer was utilized in the Heidelberg Materials/Cilu RDC laboratory to assess the moisture content of clay samples. This device is equipped with a graphic display and 10 memory slots for storing drying process data. It

features an eccentric loading system with a maximum capacity of 60 g and a sensitivity of up to 2 mg, providing precise moisture measurements with an accuracy of 0.010% and a reproducibility of 1 mg.
The analyzer was operated at a laboratory temperature of 20°C.

1. Sample Preparation: Weigh 50 grams of clay and spread it evenly on the analysis tray.
2. Analyzer Setup: Turn on the device, select the appropriate drying program set at 110°C, and activate the automatic shut-off function.
3. Initiation of Measurement: Start the process by pressing the start button to begin drying and evaporating moisture.
4. Monitoring and Conclusion of Measurement: Track the drying curve and weight loss values until the mass stabilizes, indicating that all moisture has been evaporated.

Stages of Mass Loss

1. 0 to 30 seconds: Loss of free water.
2. 30 to 90 seconds: Continued loss of capillary water.
3. 90 to 120 seconds: Loss of adsorbed water.

Calcination Experiment of Illitic, Kaolinitic, and Composite Clays

The figure 3 presents the different clay samples used in the study alongside the equipment employed for their calcination.



Figure3 : *(a) Samples of White and Green Clays, (b) Calcination Oven.*

Experimental Protocol

1. Sample Preparation:
   - 50 grams of each type of clay (illite, kaolinite, and composite) were weighed and placed in crucibles.
2. Calcination Conditions:
   - The samples were subjected to increasing temperatures from 200°C to 1000°C.
   - At each temperature step (200°C, 400°C, 600°C, 800°C, 1000°C), the samples were held for one hour.
3. Measurement of Mass:
   To ensure the safety and efficacy of clays intended for geophagy, it is essential to find an optimal balance between adequate dehydroxylation to remove biological impurities and the preservation of beneficial clay properties.
   An in-depth understanding of their thermal behaviours allows for the adjustment of treatment parameters to provide a safe and effective final product for human consumption, free from CBRN risks.
   This experiment demonstrates the differences in thermal behaviour between illitic and kaolinitic clays, justifying the increased thermal stability of illite (T-O-T structure) compared to kaolinite (T-O structure).
   - After each hour at a given temperature (200°C, 400°C, 600°C, 800°C, and 1000°C), the samples were weighed to determine the remaining mass.
   - Three distinct measurements were taken at each temperature to verify the repeatability and accuracy of the results.

The diversity of microorganisms present in soils, including fungi, algae, protozoa, bacteria, and cyanobacteria, underscores the necessity of treating geophagic clays prior to consumption. Dehydration, conducted at approximately 110°C, reduces moisture levels and inhibits microbial proliferation. Sterilization at temperatures exceeding 121°C can eliminate certain pathogens. Furthermore, as illustrated in Figure 6, calcination conducted at temperatures ranging from 200°C to 1000°C indicates that for kaolinitic clays, a calcination temperature of around 600°C is sufficient to decompose organic impurities and eliminate residual microorganisms. In contrast, for illitic clays, a higher temperature, exceeding 900°C, is required to ensure complete purification. These processes collectively ensure the safety of the clays for human consumption.
According to Scrivener *et al*. (2018) **[15]**, the impact of secondary phases on the determination of kaolinite content was examined to assess whether they significantly influence this measurement. Goethite and gibbsite dehydroxylate at lower temperatures (250–350°C) compared to kaolinite, while calcite undergoes decarbonation at much higher temperatures (700–800°C). Furthermore, 2:1 clay, like illite, partially dehydroxylate within the same temperature range as kaolinite. **Figure 4** presents the TGA (Thermogravimetric Analysis) data for clays predominantly composed of kaolinite, illite, muscovite, and montmorillonite.

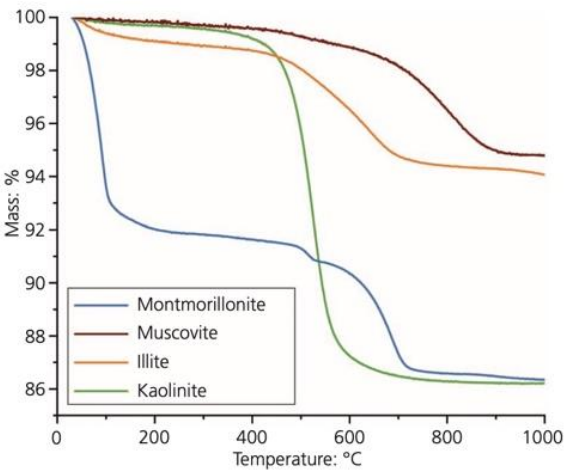


Figure 4: *the TGA (Thermogravimetric Analysis) curves for clays [15].*

2.2.2. X-ray Diffraction (XRD)

X-ray Diffraction (XRD) analysis was performed to investigate the phase composition of both uncalcined and calcined clays in this study, conducted at the Heidelberg/Cilu RDC laboratory. The

XRD measurements were carried out using a Bruker D2-Phaser diffractometer. Data were collected within the 2° to 75° 2θ range using Cu Kα radiation (30 kV, 10 mA, λ = 1.540 Å), with a step size of 0.02° 2θ and a counting time of 0.4 seconds per step.

2.2.3. X-ray Fluorescence (XRF)

X-ray fluorescence (XRF) was utilized to analyze the elemental composition of the clay samples. This technique facilitates the detection and quantification of chemical elements present within the samples. The samples were prepared as compressed pellets, and analyses were conducted using an XRF spectrometer. The results allowed for the determination of concentrations of both major and trace elements, providing critical insights into the chemical composition of the clays.

2.2.4. Clay Alteration Indices [16]

Chemical alteration indices, such as the Chemical Index of Alteration (CIA) and the Chemical Index of Weathering (CIW), assess the transformation of primary minerals into secondary minerals in soils and sediments, as analyzed via X-ray fluorescence (XRF).

- **Chemical Index of Alteration (CIA):** The CIA indicates the transformation of feldspars into clays.
- **Chemical Index of Weathering (CIW):** The CIW specifically measures the alteration of plagioclase (potassium-free feldspar).

Physical Interpretation:

- **Low (30-50%):** Indicates low alteration, with primary minerals still present.
- **Moderate (50-70%):** Suggests moderate alteration, with the initial transformation into clays.
- **High (70-100%):** Reflects high alteration, with feldspars largely transformed into secondary minerals such as kaolinite.

2.2.5. Microbiological Analysis

2.2.5.1. Sample Origins and Collection

Geophagy poses significant biological risks, including the ingestion of parasites such as *Ascaris lumbricoides*, pathogenic bacteria like *Clostridium perfringens* and *Clostridium tetani*, and toxic cyanobacteria resulting from nitrate runoff. These hazards can lead to various health issues. Thus, it is essential to conduct microbiological analyses on geophagic clays to evaluate and better understand these risks **[17]**. For hygienic food control, six equivalent samples of the geophagic clays were collected from retail points and vendors near the University of Kinshasa. These samples were transported in a box to the Applied Microbiology Laboratory for Biological and Natural Resources (LaMARBN) at the University of Kinshasa.

2.2.5.2. Microbiological Analyses [18]

The food samples were analyzed following the official Moroccan procedures for microbiological analysis of food (Moroccan standard on general food hygiene principles, 1995). The microorganisms enumerated or sought included:

- **Total Germs (TG):** Cultured on Miller Hinton agar and incubated at 37°C for 72 hours.
- **Fecal Coliforms, particularly *Escherichia coli*:** Cultured on MacConkey agar and incubated at 44°C for 72 hours.
- ***Staphylococcus aureus* (S. aureus):** Cultured on Chapman agar and incubated at 37°C for 72 hours.
- **Yeasts and Molds (Lev/Moisi):** Cultured on Sabouraud agar and incubated at 37°C for 72 hours.
- ***Pseudomonas aeruginosa* (PA):** Cultured on CA medium and incubated at 37°C for 72 hours.

3. RESULTS

3.1. Dehumidification Kinetics

The isothermal dehumidification kinetics and drying processes of white kaolinitic and green illitic clays at 110°C are depicted in two figures. **Figure 5** illustrates the temporal variation in moisture loss for the white kaolinitic clay, whereas **Figure 6** presents the corresponding drying curve for the green illitic clay under identical thermal conditions. These figures facilitate a comparative analysis of the dehumidification dynamics and drying efficiency between the two clay types at 110°C.

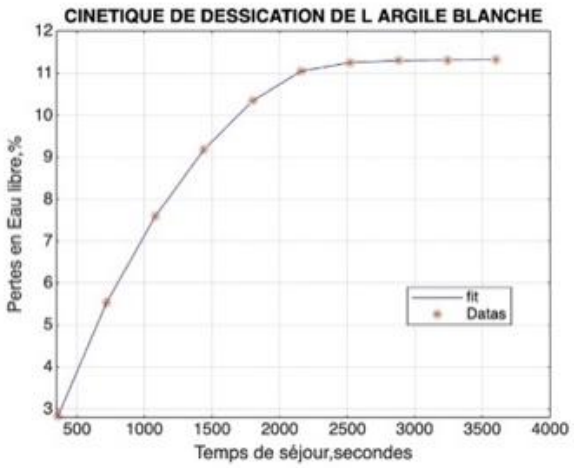


Figure 5: *Isothermal Dehumidification Kinetics (110°C)*

Figure 6 illustrates the moisture loss over time, while Figure 5 specifically shows the gradual dehumidification of the clays in a KERN desiccator. As the drying process progresses, both clay types lose moisture due to the applied heat. The kaolinitic clays, in particular, were found to contain approximately 11.3% free water at the start of the process.

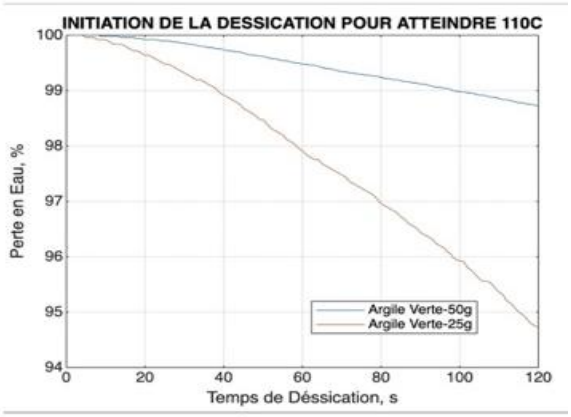


***Figure 6** :Water Loss During Heating < 110°C*

Figure 7 presents the thermogravimetric curves for white kaolinitic clay, green illitic clay, and a 50% mixture of both, with calcination carried out up to 1000°C.

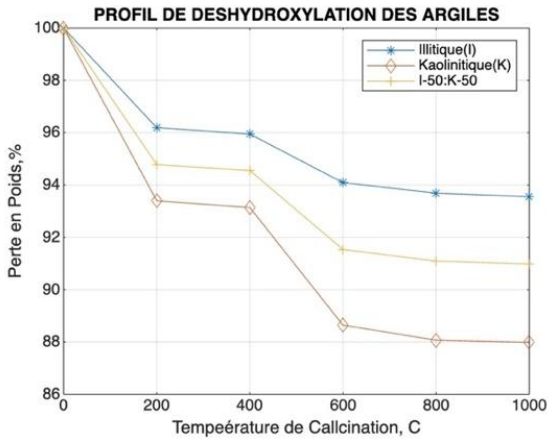


***Figure 7:** Dehydroxylation profile of clays*

3.2. Mineralogical Composition

X-ray diffraction (XRD) analysis reveals in **figure 8 and figure 9** that the geophagic clays are primarily composed of kaolinite, quartz, and illite. Kaolinite, a hydrated aluminum phyllosilicate, exhibits diffraction peaks at 12.3° and 24.8° (2θ). Quartz, composed of silicon dioxide, is identifiable by peaks at 20.9°, 26.6°, and 50.1° (2θ), while illite shows peaks at 8.8°, 17.8°, and 26.5° (2θ). These minerals possess excellent adsorption properties, which justify their application in detoxification processes. Furthermore, calcination of kaolinitic clays at 650°C transforms kaolinite into metakaolin, evidenced by the disappearance of the peak at 12.3° (2θ).

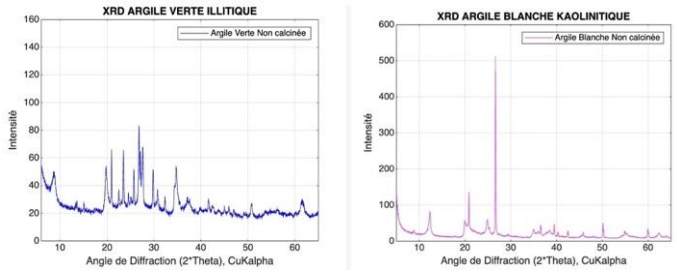


***Figure 8**: X-ray Diffractogram. Green & White Clay.*

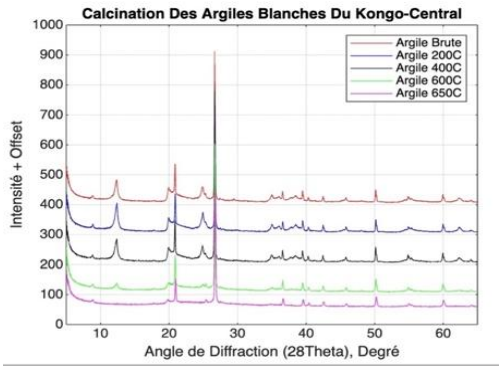


Figure 9: X-ray Diffractogram of Calcined White Clays.

In geophagy, the three clays on **figure10** are distinguished by their content of illite, kaolinite, and quartz. Illite (54-58.78%) is predominant and plays a key role in detoxification by adsorbing toxins. Kaolinite (12.97-20.41%) is beneficial for soothing gastric irritations due to its adsorptive and anti-inflammatory properties. Quartz (0.7-2.01%) is an inert and potentially abrasive mineral, offering no significant health benefits. Clays with higher kaolinite content, such as Arg1 and Arg3, may be better suited for digestive benefits.

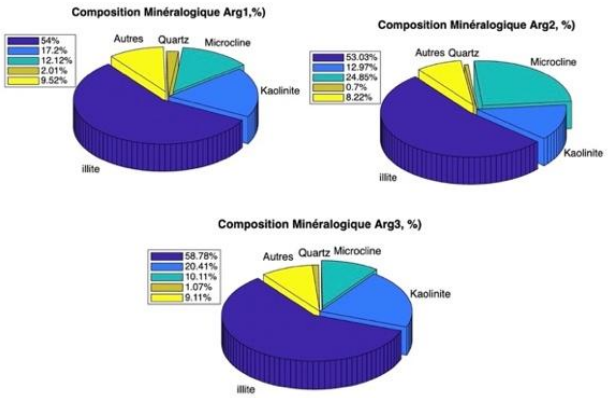


***Figure10:** Mineralogical Composition of Selected Green Clay Samples.*

For the figure 11, in this comparison of clays: Illite (11.66-12.66%) is present in smaller amounts, contributing less to detoxification.

Kaolinite (50.71-51.43%) is dominant, making these clays beneficial for digestive health due to its soothing properties.

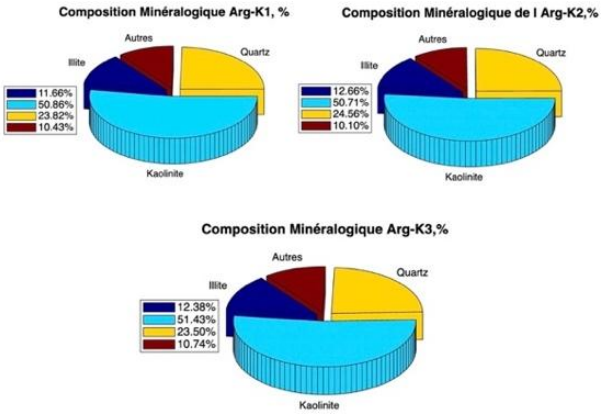


Figure 11: *Mineralogical Composition of Selected White Clay* Samples.

Quartz (23.5-24.56%) is higher, which may introduce some abrasiveness. These clays, rich in kaolinite, are good for digestion, though the higher quartz content could be a slight drawback.

In the figure12 clays from Kisangani, Kazamba, and Bulungu contain 35% to 50% microcline, 30% to 60% illite, and less than 5% kaolinite, making them predominantly illitic.

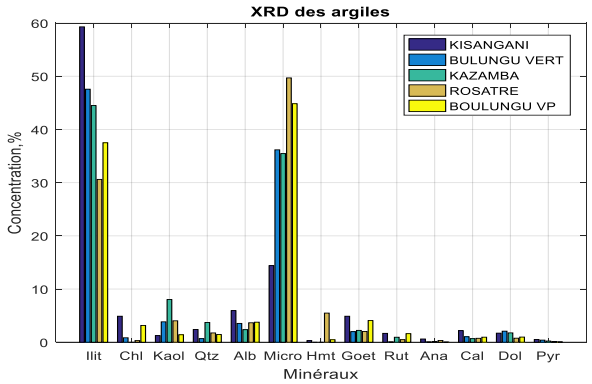


Figure 12*: X-ray Diffraction of Kisangani, Kazamba, and Bulungu Clays.*

They have lower quartz content and higher microcline levels compared to typical clays used in geophagy and cosmetics. This higher illite content may enhance their texture, absorption properties, and mineral content, potentially making them more suitable for cosmetic applications rather than for geophagy, where kaolinite and more absorbent minerals are favored.

3.3. Elemental Composition

The X-ray fluorescence (XRF) analysis revealed a variety of elements in the clay samples, including essential minerals such as calcium, magnesium, and iron. These elements are beneficial for human health, as they play critical roles in various biological functions. However, trace amounts of potentially toxic elements, such as lead and arsenic, were also identified. The presence of these contaminants poses health risks, highlighting the importance of assessing the safety of consuming these clays. **Figure 13** shows the results of the X-ray fluorescence analysis, highlighting the concentrations of elements present in each sample. **Figure 14** focuses on the Kisonga clay, emphasizing the specific levels of certain elements. Finally, **Figure 15** provides a comparison of the X-ray fluorescence analyses of the clays from the three sites.

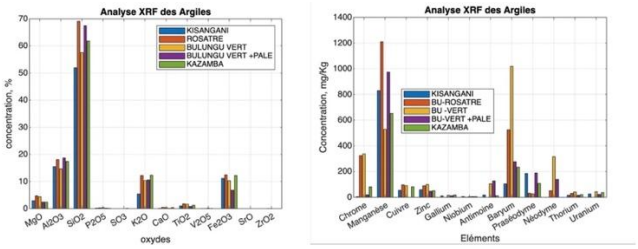


Figure 13: X-ray Fluorescence of Kisangani, Kazamba, and Bulungu Clays.

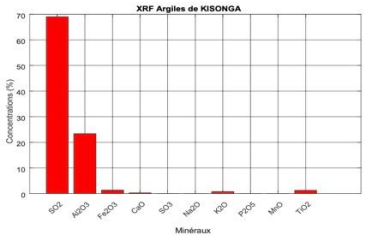


Figure 14: X-ray Fluorescence of Kisonga Clay.

Analysis of Selected Elements (in ppm)

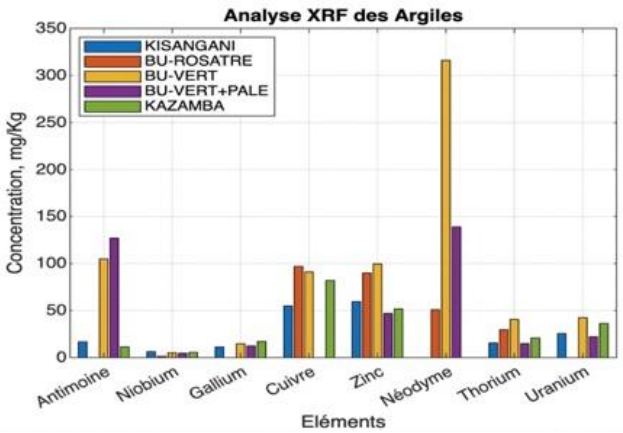


Figure 15: *X-ray Fluorescence of Kisangani, Kazamba, Bulungu Clays*

The analysis revealed the following concentrations of selected elements in parts per million (ppm): Chromium (Cr): Mbanza-Ngungu: 223 ppm; Kisantu: 176 ppm. Manganese (Mn): Mbanza-Ngungu: 158 ppm; Kisantu: 71 ppm. Copper (Cu): Mbanza-Ngungu: 16 ppm; Kisantu: 0 ppm. Zinc (Zn): Mbanza-Ngungu: 157 ppm; Kisantu: 92 ppm. Gallium (Ga): Mbanza-Ngungu: 14 ppm; Kisantu: 10 ppm. Arsenic (As): Mbanza-Ngungu: 0 ppm; Kisantu: 0 ppm. Rubidium (Rb): Mbanza-Ngungu: 16 ppm; Kisantu: 29 ppm. Niobium (Nb): Mbanza-Ngungu: 83 ppm; Kisantu: 35 ppm. Palladium (Pd): Absent in all samples. Cadmium (Cd): Mbanza-Ngungu: 2.3 ppm; Kisantu: 2.2 ppm. Tin (Sn): Mbanza-Ngungu: 19.7 ppm; Kisantu: 13.8 ppm. Iodine (I): Mbanza-Ngungu: 20.2 ppm; Kisantu: 27.6 ppm. **Cesium** (Cs): Mbanza-Ngungu: 16.3 ppm; Kisantu: 8.2 ppm. Barium (Ba): Mbanza-Ngungu: 139 ppm; Kisantu: 141 ppm. Lanthanum (La): Mbanza-Ngungu: 212 ppm; Kisantu: 452 ppm. Cerium (Ce): Mbanza-Ngungu: 195 ppm; Kisantu: 188 ppm. Praseodymium

(Pr): Mbanza-Ngungu: 42.3 ppm; Kisantu: 74.3 ppm. Neodymium (Nd): Mbanza-Ngungu: 249 ppm; Kisantu: 135 ppm. Tantalum (Ta): Absent in all samples.
The concentrations of trace elements exhibited significant variability between the samples from Mbanza-Ngungu and Kisantu. Elements such as chromium and manganese showed notable differences between the two sources, while others, including copper and arsenic, were absent in all samples. This analysis underscores the geochemical variations between the sampling sites, which may have significant implications for the characterization of soils and geological materials in these regions.

3.4. Indices of Clay Alteration

The two indices commonly employed for assessing clay alteration are the Chemical Alteration Index (CIA) and the Chemical Weathering Index (CIW).
The Table1 and figure16 display the Chemical Alteration Index (CIA) and the Chemical Weathering Index (CIW) for various clay samples sourced from different locations. The values of CIA and CIW provide insights into the degree of transformation of feldspars into secondary minerals, primarily clays **[19]**.

Table 1: Elementary Composition of Clays and Alteration Indices.

Échant.	Al_2O_3	CaO	Na_2O	K_2O	CIA	CIW
Kis 1	20,76	0	0	0,711	96,7	100
Kis 2	17,43	0,2705	0	0,773	94,4	98,5
Kis 3	20,17	0,735	0	1,203	91,2	96,5
Kis 4	23,36	0,29	0	0,75	95,7	98,8
B1	14,67	0,375	0	10,36	57,7	97,5
B2	18,69	0,0914	0	10,57	63,7	99,5
B3	17,41	0,378	0	12,34	57,8	97,9

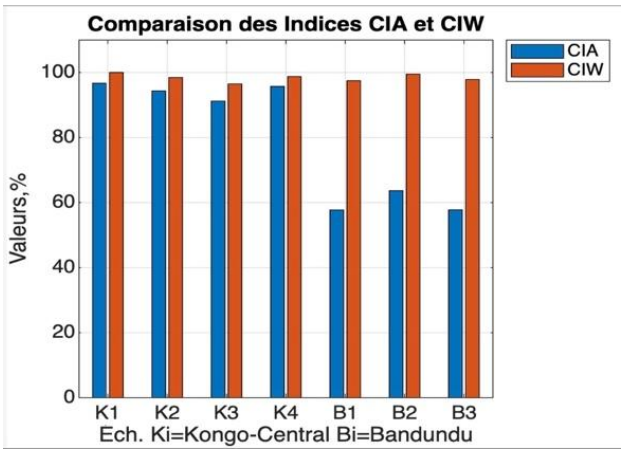


***Figure 16**: Histogram Representation of Alteration Indices*

- **Mbanza-Ngungu (Iskis, Synty, Andy)**: The high CIA and CIW values indicate a significant alteration of feldspars into clays. This suggests that these samples have undergone intense geochemical processes, nearly completely transforming feldspars into kaolinite with minimal illite content.
- **Kisantu (Kis 1, Kis 2, Kis 3)**: Similar to Mbanza-Ngungu, the elevated CIA and CIW values indicate advanced alteration. The CIW value of 100 for Kis 1 suggests complete alteration of plagioclases, with no residual potassium.
- **Kisonga**: The high values, akin to other samples, indicate significant alteration.
- **Kisangani (Rosâtre)**: The relatively lower CIA values (especially for the rosé sample) suggest moderate to advanced alteration. The high CIW reflects advanced transformation of plagioclases, but the presence of residual potassium in the CIA indicates that total alteration has not yet been achieved.
- **Bulungu (Pale Green)**: The CIA suggests moderate to advanced alteration, while the high CIW indicates advanced alteration of plagioclases. These samples are less altered compared to others, indicating a presence of feldspars that have not been completely transformed.
- **Kazamba**: The values indicate moderate to advanced alteration, similar to the Bulungu samples, suggesting significant but incomplete transformation of feldspars into clays.

Overall, these indices show a general trend towards advanced alteration, particularly for the Mbanza-Ngungu and Kisantu samples. The high values indicate an almost complete transformation of feldspars into secondary minerals, primarily clays. In contrast, the Kisangani and Bulungu samples exhibit less advanced alteration, which may indicate less intense geochemical or climatic conditions or a shorter duration of alteration.

3.5. Microbiological Quality

The results of the microbiological analyses were interpreted based on WHO standards. Non-compliance was adopted as an indicator of clay quality. Samples not meeting the recommended WHO standards are considered non-compliant and, therefore, of poor hygienic quality **[20]**.
The analyses reveal a complete absence of contamination by **Escherichia coli** and **Pseudomonas aeruginosa**. However, the results indicate that, in no case, was the microbiological quality of the various samples satisfactory.

Identification of Various Microbial Pathogens
Microbial Enumeration
The total count of mesophilic aerobic bacteria is a metric that represents all bacteria, yeasts, and molds present in the product at the time of analysis. A high count indicates that unsanitary conditions have occurred or that microbial growth has taken place. The primary causes include poor hygienic quality of raw materials, deficiencies during manufacturing, or inadequate storage conditions. Such products are prone to rapid spoilage, leading to a decrease in intrinsic value and an increase in health risks. Staphylococcus aureus can reside in the mucous membranes of the nose and throat, as well as in purulent wounds and on the skin. During coughing, sneezing, or contact with infected skin, the bacteria can contaminate food items. Staphylococcus aureus produces a potent toxin that is not destroyed by cooking, which can lead to severe food poisoning. Yeasts and molds are commonly found in the environment surrounding food products. Unless intentionally added, their presence indicates spoilage. Many molds can produce hazardous toxins known as mycotoxins. Moldy products should not be consumed. **Figure17 (a) and (b)** illustrate the cultivation of total

germs in Miller's agar culture medium. **Figure18 (a) and (b)** showcase the cultivation of *Staphylococcus aureus* on Chapman agar medium. Finally, **figure19 (a) and (b)** depict the cultivation of yeasts and molds on Sabouraud Dextrose agar medium.

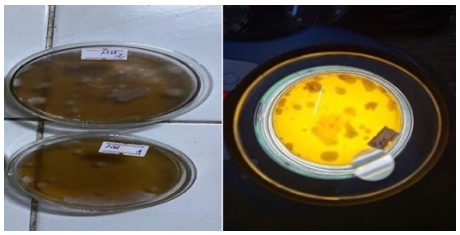


***Figure 17** : (a),(b)The cultivation of total germs in Miller's agar culture medium.*

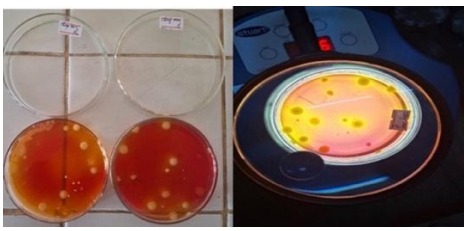


***Figure 18:** (a),(b) Cultivation of Staphylococcus aureus on Chapman agar medium*



***Figure 19**: (a),(b) Cultivation of yeasts and molds on Sabouraud Dextrose agar medium*

Figure 20 displays the quantitative assessment of target microorganisms, highlighting their abundance in different samples and offering insights into microbial diversity with implications for ecological and health-related studies.

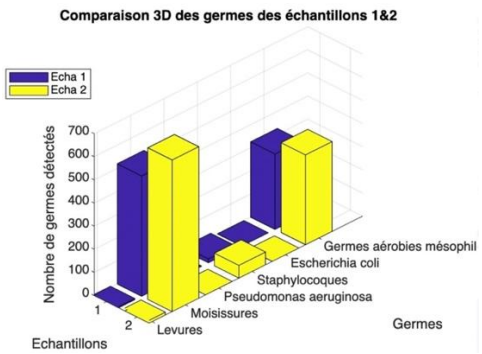


***Figure 20:** Enumeration of Target Microorganisms*

4. DISCUSSION

Provenance of Geophagic Clays (Kisonga and Bulungu Samples). In accordance with the article by Nesbitt *et al.* (1996) **[21]**, the impact of chemical weathering and sorting on the formation of siliciclastic sediments is examined, with a focus on the implications for provenance studies. The analysis of Kisonga samples reveals a high degree of silicate alteration, with CIA values ranging from 91.2 to 96.7, indicating significant weathering typical of humid environments. The high CIW values (between 96.5 and 100) show a kaolinite-dominated composition, suggesting strongly weathered felsic source rocks. In contrast, the Bulungu samples have lower CIA values (between 57.7 and 63.7), indicating more moderate alteration and possibly a more varied source, including intermediate or mafic rocks. Ingesting soils rich in kaolinite can disrupt the body's mineral balance, impair nutrient absorption, and affect digestion due to their low content of essential base cations. In contrast, soils dominated by illite, which are less altered, retain more resistant minerals and higher levels of exchangeable cations, resulting in a less disruptive impact on the digestive system **[22].** Thus, kaolinitic soils generally have a more negative effect on digestion compared to illitic soils, which are less affected by leaching. The illitic clay from Bulungu, usually consumed raw, is seen as a natural, accessible resource for geophagy, fulfilling cultural and psychological needs by providing satisfaction or relief. Its reputation as a safer product than other types of soil partly explain its growing popularity in Kinshasa **[11][22].** The illitic clay from Bulungu (Grand Bandundu), containing quartz (0.7-2.01%), an inert and abrasive mineral with no significant health effects, nonetheless offers protection against dental damage and preserves the tissues of the digestive tract **[23]**. In contrast, the kaolinitic clay from Kisonga (Kongo-Central), with a quartz content of up to 23.5%-24.56%, poses a higher health risk due to its more pronounced abrasive properties.

The results obtained indicate that geophagic clays from the DRC contain a mixture of beneficial elements and potentially toxic contaminants. The presence of essential minerals such as calcium, magnesium, and iron highlights the possible nutritional benefits of these clays. However, the detection of toxic elements such as lead and arsenic necessitates a thorough risk assessment regarding their consumption.

Chemical, biological, radiological, and nuclear (CBRN) risks must be considered when evaluating the safety of geophagic clays. Chemical risks involve the ingestion of toxic elements like lead and arsenic, which may have long-term adverse health effects. Biological risks may arise if the clays are contaminated with pathogens. Although radiological risks are less common, they cannot be entirely ruled out without specific analysis of radioactivity levels. Finally, while nuclear risks are generally unlikely, routine checks can ensure the absence of radioactive contamination.

5. CONCLUSION

Geophagic clays from the DRC exhibit a complex composition, containing both beneficial elements and potentially harmful contaminants. While they may provide essential minerals for human health, their consumption requires caution, particularly due to the presence of toxic elements. In addition to recommendations concerning CBRN risks, it is most important to pay attention to the storage and packaging conditions of clays intended for consumption. Proper management of these factors, including storage in hygienic conditions and the use of appropriate packaging materials, could reduce the risk of contamination and preserve the nutritional benefits of the clays.

Further studies are needed to more thoroughly assess the associated health risks and to establish guidelines for their safe use.

Acknowledgement

We extend our sincere thanks to the local communities in the DRC for their valuable collaboration in the collection of samples, as well as to the Quality Control Laboratory of Heidelberg Materials/Cilu DRC for the X-ray diffraction, X-ray fluorescence, and desiccation analyses.

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