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Research Article

Comparative Analysis of Chemical Properties of Locally-Made Ware

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Abstract

The chemical composition of ceramic raw materials significantly influences the properties and quality of the final products. This study investigates the chemical properties of key raw materials—galena, kaolin, and silica—sourced from various Nigerian locales to assess their suitability for high-quality ceramic production. Using X-ray Fluorescence (XRF) spectroscopy, the primary oxides analyzed include SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, Pb, and Cu. The results indicate that silica possesses a high SiO_2 content (92.50%), making it ideal for glass formation in ceramics, while kaolin contains significant amounts of alumina (32.54%) and silica (46.12%), enhancing mechanical strength and thermal stability. Galena, composed mainly of lead (79.47%) and copper (9.74%), is unsuitable for traditional ceramics due to toxicity concerns but may have specialized applications in glaze formulations. The findings provided essential baseline data, which was applied in the production of locally-made pottery and ceramic ware.

Keywords	*Chemical Properties; Locally-Made Ware; Glass Formation in Ceramics; Ceramic Production; X-ray Fluorescence (XRF)*
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Introduction

The chemical composition of ceramic raw materials significantly influences the properties and quality of the final products. Understanding these compositions is essential for optimizing production processes and achieving desired characteristics in ceramic wares. This study focuses on the chemical analysis of key raw materials—galena, kaolin, and silica—sourced from various Nigerian locales, aiming to assess their suitability for high-quality ceramic production. Several authors have highlighted the chemical properties of locally available raw materials used in ceramic production.

Olatunji et. al. (2023) studied the geochemical and mineralogical properties of kaolin from Isan Ekiti using X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD). It indicates that the kaolin's composition is suitable for applications in coated paper and, with proper beneficiation, in ceramic production. Shaaibu et. al., 2020 evaluated the physio-chemical and thermal properties of alkaleri kaolin, Bauchi State, Nigeria for ceramics applications. The research revealed that the kaolin possesses characteristics favorable for ceramic applications, including appropriate plasticity and thermal behavior. Chemical and mineralogical characterization of Duguri Galena (Bauchi State, Nigeria) was done by Munyao et. al., 2024. This work presents a detailed study of the chemical and mineralogical properties of galena samples collected from Duguri. The analysis confirms the presence of lead oxide and silica, indicating the ore's potential for industrial applications. Azubuike et. al., 2024 evaluated the mineralogical, geochemical, and physical properties of clay deposits in Umuoke Obowo, indicating their suitability for refractory bricks, ceramic tableware, and other ceramic products. Olaoye et. al., 2016 characterized various Nigerian clays and explored their potential industrial applications, particularly in ceramics and refractories. Borode et. al., 2012 compared the chemical compositions of clay deposits from different locations in South-Western Nigeria, assessing their suitability for ceramic production. Adeola et. al., 2013 evaluated the geotechnical and geochemical properties of clay deposits in Ekiti State, discussing their potential for use in ceramics and other industries. Nwajagu et. al., 2014 investigated the physicochemical properties of Ukpor clay, highlighting its potential applications in the ceramic industry. Adekeye et. al., 2010 assessed the industrial potential of various Nigerian kaolinitic clay deposits, focusing on their suitability for ceramic applications. Sanni et. al., 2015 characterized selected Nigerian clays, evaluating their properties for potential use in ceramic production. Olatunji et. al., 2011 examined the chemical and physical properties of Nigerian kaolinitic clays, analyzing their suitability for industrial applications, including ceramic production. The reviewed studies demonstrate that Nigerian clay and mineral deposits exhibit properties suitable for ceramic production. The findings provide essential baseline data for further research and industrial applications, particularly in improving the quality of locally-made pottery and ceramic ware. This study therefore explores the **c**omparative analysis of chemical properties of locally-made ceramic and pottery ware using three indigenous raw materials, namely, Orhionmwon river sand (silica), Abakiliki galena (lead sulphide) and Nsu clay (kaolin).

Methods

Sample Collection

The primary raw materials (samples) utilized were**;** Silica, sourced from Orhionmwon River sand in Edo State; Lead Sulphide (Galena), obtained from Abakaliki in Ebonyi Stat, and Kaolin gotten from Nsu in Imo State. Other additives includes bentonite to enhance plasticity and sodium silicate to improve fluidity.

Processing

These raw materials were processed individually, following the steps below:

Crushing: In this process, big pieces of raw materials are broken up into smaller, more manageable pieces. Since a hammer mill uses mechanical force to break hard raw materials, it is usually utilized for this purpose. Because it impacts the homogeneity of the final glaze composition and dictates how easy further milling will be, the crushing process' efficiency is vital. In the later phases of glaze preparation, improved homogeneity is made possible by properly crushed components.

Milling: To produce a finer particle size, the raw materials were ground after the crushing stage. To guarantee the glaze's uniformity and smooth texture, this step is crucial. The crushed materials and grinding medium, like ceramic balls, are placed into a revolving cylindrical drum in a ball mill. The particles are reduced to micron-sized powders by the constant impact and friction. The surface smoothness, adhesion characteristics, and melting behavior of the glaze during firing are all strongly impacted by the level of fineness attained during this procedure. Longer milling times frequently produce finer particles, which enhance the stability and visual appeal of the glaze.

Batch Formulation: To produce various glaze compositions, the raw components are weighed and mixed in precise amounts after being finely ground. As shown in Table 1, four batches (A, B, C, and D) were prepared for this investigation using different proportions of silica, kaolin, and lead sulfide. The final glaze's chemical and physical characteristics are determined by the formulation process, which makes it crucial. Lead sulphide is used as a flux to reduce the melting point and improve the glossy finish of the glaze, silica helps to create a glassy phase, and kaolin functions as a suspending agent. Every composition satisfies the intended aesthetic and functional criteria.

Mixing: To produce a consistent glazing suspension, the next step is to combine the prepared batches with water. The components are thoroughly blended using a roller mill. In addition to minimizing settling and improving the glaze's adherence to ceramic surfaces, this wet mixing method helps achieve a uniform particle dispersion. To guarantee that the glaze has a uniformly smooth consistency, the mixture is further sieved to get rid of any coarse particles or contaminants. In order to avoid flaws like pinholes or uneven coats in the finished product, proper mixing is essential.

Application: The process starts once the glaze suspension is thoroughly combined. For around ten seconds, bisque-fired ceramic items (figure 1) are submerged in the glaze suspension. This time frame enables the glaze to be applied evenly on the ceramic surface. After that, the dipped items are taken out and let to air dry before being fired. Because variations in glaze thickness can result in flaws like crawling, cracking, or uneven color development after fire, the application procedure is crucial. The success of this phase depends on variables like drying conditions, dipping time, and glaze viscosity.

Firing: A kiln was used to heat the glazed ceramic wares (figure 1) to about 1108°C. The glaze changes during firing in a number of ways, including the silica forming a glassy network that binds with the ceramic body, the fluxing agents lowering the melting point, and the volatile components evaporating. Carefully regulating the firing temperature and duration is necessary to avoid flaws like blistering, crazing, or insufficient vitrification. When the glaze is at the right temperature, it creates a smooth, translucent, and long-lasting surface that improves the ceramic's appearance and usefulness.

Figure 1: Sample of glazed ceramic wares with a glossy and colorful finish

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Chemical Analysis

The chemical compositions of the samples were determined using X-ray Fluorescence (XRF) spectroscopy. The primary oxides analyzed included SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, and trace elements.

Results and Discussion

Table 1: Chemical Composition of Raw Materials

Oxide	*Galena (%)*	*Kaolin (%)*	*Silica (%)*
SiO_2	-	46.12	92.50
Al_2O_3	-	32.54	0.46
Fe_2O_3	5.10	1.90	0.25
CaO	-	4.15	4.35
MgO	-	1.45	0.45
Na_2O	-	0.08	0.03
K_2O	-	1.60	0.62
TiO_2	0.01	0.50	0.15
Pb	79.47	-	-
Cu	9.74	-	-

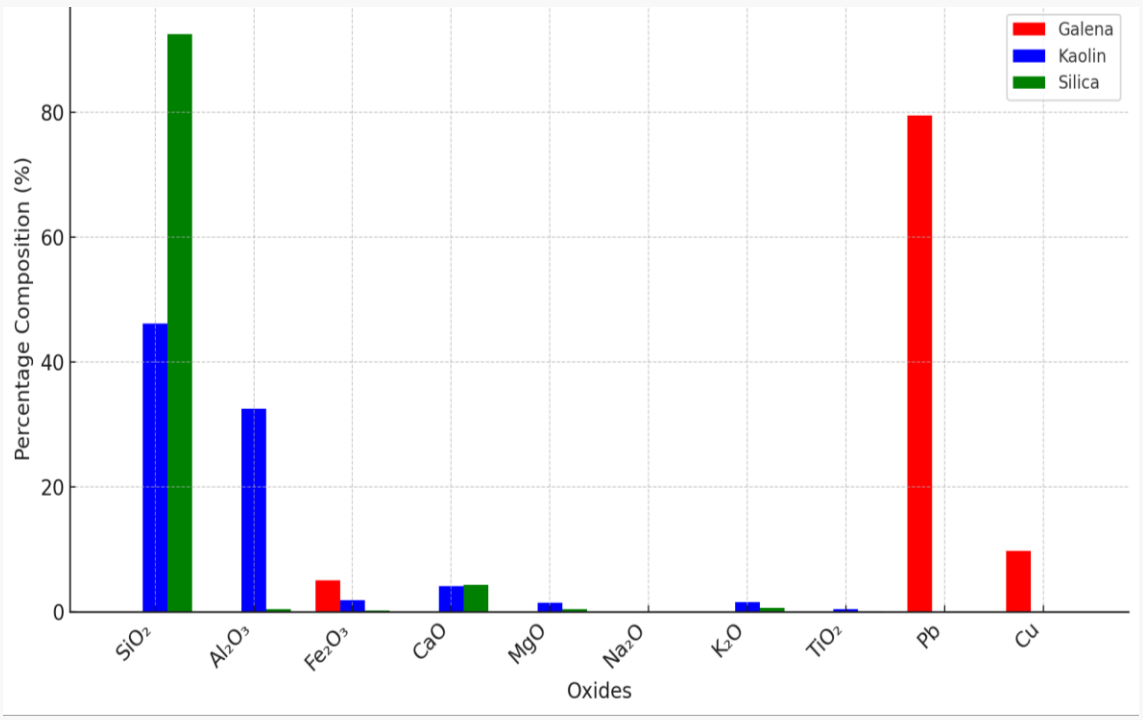

Figure 1: Chemical Compositions of Raw Materials

From Figure 1 and Table 1 above, the Galena predominantly composed of lead (79.47%), which made it a potent flux in glaze formulations. The presence of iron (5.10%) and copper (9.74%) suggests potential color variations in glazes, as these elements can act as colorants. Kaolin was observed to possess high alumina with 32.54% and silica (46.12%), indicating its suitability for enhancing the mechanical strength and thermal stability of ceramic bodies. The low iron content (1.90%) is advantageous, as excessive iron can cause undesirable coloration. Silica possesses high silica content of 92.50% and minimal impurities, this material is ideal for forming the glass.

Furthermore, in analyzing the oxide contents; Silica (SiO_2) was found to be high in silica (92.50%) and kaolin (46.12%) proportions, thereby showed silica as an essential component in ceramic materials, contributing to strength and thermal stability. However, its absence in galena suggests that this mineral may not contribute significantly to ceramic durability. Alumina (Al_2O_3) is present in kaolin (32.54%) and in a very low concentration in silica (0.46%), alumina enhanced the refractory nature of ceramic wares, providing resistance to high temperatures and mechanical stress. Iron Oxide (Fe_2O_3) detected in galena (5.10%), kaolin (1.90%), and silica (0.25%), iron oxide impacts the coloration of ceramic products and may have influenced their thermal properties. Calcium Oxide (CaO) was present in both kaolin (4.15%) and silica (4.35%), and contributes to ceramic vitrification and affects shrinkage during firing. Magnesium Oxide (MgO) was found in kaolin (1.45%) and silica (0.45%), MgO helps regulate the thermal expansion properties of ceramics, improving crack resistance. Sodium Oxide (Na_2O) and Potassium Oxide (K_2O), which are alkali oxides, were present in minor amounts in kaolin and silica, act as fluxing agents, lowering the melting point of ceramic compositions and enhancing glass formation. Titanium Dioxide (TiO_2) were present in small amounts in galena (0.01%), kaolin (0.50%), and silica (0.15%), TiO_2 influences the opacity and color of ceramic materials. In Lead (Pb) and Copper (Cu), Galena contains a significant amount - 79.47%) and - 9.74% respectively, making it unsuitable for traditional ceramic applications due to toxicity concerns, but it may have specialized applications in glaze formulations.

Conclusion

This study successfully described the comparative analysis of chemical properties of locally-made ceramic ware, which was made using locally sourced raw materials—silica, kaolin, and galena—supported by additives like bentonite and sodium silicate. The methodical processing of the materials through crushing, milling, mixing, and firing was pivotal in achieving a uniform glaze with a smooth and glossy finish. Chemical analysis using XRF revealed a high silica content in river sand (92.50%), making it a primary glass-forming agent. Kaolin, rich in alumina (32.54%), significantly enhanced thermal resistance and mechanical strength. Galena, containing 79.47% lead, served as a powerful flux, promoting melting at lower temperatures, while its copper (9.74%) and iron (5.10%) contents suggested potential color enhancements. The interplay of oxides like CaO, MgO, Na_2O, and K_2O contributed to vitrification, fluxing, and thermal expansion control. The results validated the suitability of these raw materials for glaze formulation, providing a cost-effective and sustainable option for ceramic production. However, the presence of heavy metals like lead and copper necessitates caution and restricts their use to non-domestic applications. Overall, the research affirms that local raw materials can be effectively harnessed to produce high-quality ceramic glazes with desirable structural and aesthetic properties.

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