



UTILIZATION OF SAHEL GRANITE DUST FROM GUDUM HAUSAWA IN BAUCHI STATE AS A GLASS FORMER IN THE FORMULATION OF STONEWARE GLAZES

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Abstract

This study investigates the suitability of Gudum Hausawa Sahel granite dust, a quarrying by-product from Bauchi, as a substitute for commercial silica in stoneware glaze formulation. The chemical and mineralogical properties of the granite dust were analysed using X-ray Fluorescence (XRF) and X-ray Diffraction (XRD) respectively. XRF results revealed high silica content (59.20% SiO₂) and substantial alumina (20.30% Al₂O₃), while XRD analysis indicated that the material is predominantly composed of quartz (~69wt.%) with significant feldspar phases (~28 wt.%), providing inherent fluxing oxides. These characteristics confirm that granite dust can function as both a glass former and a source of intrinsic fluxing agents. Glaze formulations were developed using the triaxial blend method, incorporating granite dust at varying proportions (0-40%) and compared with conventional silica-based control glazes. The glazes were applied to bisque-fired stoneware tiles and fired in an electric kiln under oxidizing conditions at temperatures between 1200 °C and 1250 °C. Post-firing evaluation showed that optimal compositions containing 20-40% granite dust exhibited good melting behaviour, producing smooth, glossy, and well-vitrified surfaces comparable in fusion, adhesion, and aesthetic quality to conventional glazes. The presence of iron oxide contributed to natural brown to dark-brown colouration without the need for additional colorants. The results demonstrate that granite dust is a technically viable and sustainable alternative to commercial silica in stoneware glaze production. Its utilization offers economic advantages through cost reduction and supports environmental sustainability by promoting waste valorization and reducing reliance on imported raw materials. This study highlights the potential of granite dust for industrial application in ceramic glaze formulation.

Keywords: Granite dust; Stoneware glaze; Silica; Sustainable production; Ceramic glaze formulation

1. Introduction

The formulation of ceramic glazes plays a critical role in ceramic production, as it determines both the aesthetic appeal and functional performance of ceramic products, including resistance to scratching, wear, and impact, as well as improved surface durability (Fabris, 2025; Sundari et al., 2024). Conventional glaze systems are typically composed of silica as the primary glass former, alumina as a stabilizer, and fluxing oxides that facilitate melting at elevated temperatures. The balance among these components is determined by key properties such as gloss, texture, durability, and resistance to thermal and chemical attack (Bhola, 2025). However, the extraction and processing of these raw materials are often associated with environmentally intensive mining activities, raising concerns about sustainability and resource depletion.

Stoneware ceramics, which are fired at high temperatures ranging from 1200 °C to 1300 °C, are characterized by their dense, vitrified structure and durability (Chidozie and Thompson, 2022; Lyons and Lyons, 2019; Martín-Márquez et al., 2008). Their production has evolved significantly over time, from early developments in China to widespread industrial applications across Europe and other regions (Yin et al., 2011; Wood, 1999; Gaimster, 1997). In modern ceramic practice, there is increasing emphasis on improving glaze formulations while adopting more sustainable material sources.

In response to environmental and economic challenges, recent research has focused on the utilization of industrial byproducts and waste materials as alternatives to conventional glaze ingredients (Caki et al., 2013). Materials such as fly ash, glass cullet, and red mud have been explored due to their suitable chemical compositions and functional properties (Hossain and Roy, 2020; Galhano et al., 2020; Toniolo et al. 2017; Andreola et al., 2005). Among these, granite dust has emerged as a promising candidate.

Granite dust is a by-product of quarrying and stone-cutting processes and is generated in large quantities worldwide (Amulya et al., 2021; Choudhary et al., 2019). Its improper disposal contributes to environmental issues such as land pollution and airborne particulate hazards (Liu et al., 2025). Chemically, granite dust is rich in silica (SiO_2) and alumina (Al_2O_3), with appreciable amounts of alkali oxides and minor iron oxide content, making it suitable for ceramic applications (Singh et al., 2020). These characteristics enable it to function as both a glass former and a source of fluxing oxides in glaze formulations.

In exploring the potential of granite waste in ceramic development, Alkali (2014) incorporated granite sawing waste into natural clay matrices for the production of decorative ceramic bodies. The results indicated that granite waste blended effectively with ball clay and kaolin, producing ceramic bodies with shrinkage values of 5–7% and water absorption ranging from 2–22%, while maintaining good structural integrity. Notably, the developed bodies exhibited excellent glaze

receptivity, achieving proper glaze fusion without observable defects. These findings align with earlier studies attributing the suitability of granite waste in ceramic systems to its aluminosilicate composition, which enables it to function both as a structural component and as a fluxing agent when finely processed (Ngayakamo et al., 2022; Amulya et al., 2021; Choudhary et al., 2019; Ogundare et al., 2016). Collectively, these results highlight the viability of granite waste as a multifunctional and sustainable raw material for ceramic bodies and potentially for glaze formulations.

Notwithstanding the potential, the abundance of silica and other ceramic raw materials in Nigeria has not translated into widespread industrial utilization. The ceramic industry continues to rely heavily on imported inputs due to limitations in local processing, beneficiation, and quality consistency (Iyasara et al., 2014; Abiola 2023; Ajadi et al., 2023). This dependence not only increases production costs but also constrains the effective use of locally available resources. Furthermore, locally sourced materials often require extensive treatment before they can be employed in glaze formulation, thereby reinforcing reliance on high-purity imported silica and related inputs. Accordingly, despite its demonstrated potential in ceramics and glass-ceramic applications as evident in Odewole et al. (2022) and Ngayakamo et al. (2022), the use of granite dust as a substitute for conventional silica in stoneware glaze formulation remains relatively underexplored, particularly within the Nigerian context.

Therefore, this study aims to investigate the suitability of granite dust as a glass-forming material in stoneware glazes. Specifically, the study seeks to determine its chemical properties, formulate glazes with varying proportions of Gudum Hausawa Sahel granite dust, evaluate their aesthetic and functional performance, and compare them with conventional silica-based glazes. The findings are expected to contribute to sustainable ceramic production by promoting the use of locally sourced industrial waste materials (Fig. 1).

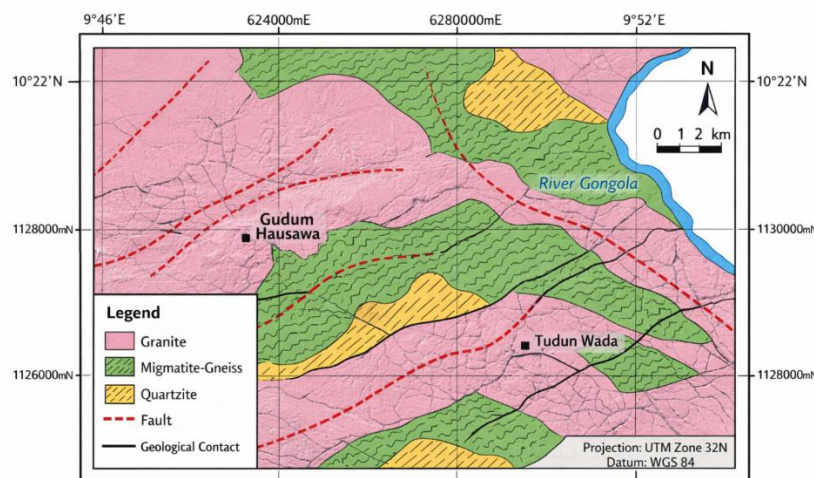


Fig. 1: Geological map of Gudum Hausawa, Bauchi State (modified after NGSA geological sheets and regional geological studies).

2. Literature Review

Stoneware ceramics have a long and well-documented history, originating in China and later spreading to other parts of Asia and Europe. These ceramics were produced by firing clay at elevated temperatures, typically between 1200 °C and 1300 °C, resulting in dense, vitrified, and non-porous bodies with enhanced durability and aesthetic appeal. Early Chinese stoneware, such as Yue and Ding wares, were highly valued for their strength and refined glaze finishes (Henderson et al., 2020; Wood, 1999). The technology later spread to Korea, Japan, and the Islamic world, where it was adapted to local materials and artistic traditions. In Europe, significant advancements occurred during the 13th and 14th centuries, particularly in the German Rhineland, where salt-glazed stoneware became prominent due to its durability and distinctive surface texture (Gaimster, 1997). The Industrial Revolution further transformed stoneware production through mechanization and improved kiln technologies, enabling large-scale manufacturing and standardization of glaze compositions (Rhodes, 1973). Today, stoneware remains an important material in both industrial and studio ceramics, with ongoing research focused on improving glaze formulations and exploring sustainable raw material alternatives.

Stoneware glazes are vitreous coatings applied to ceramic bodies to enhance both aesthetic and functional properties. These glazes are designed to mature at high temperatures and typically consist of three essential components: silica, alumina, and fluxes. Silica serves as the primary glass former, providing the structural framework of the glaze, while alumina acts as a stabilizer that controls melt viscosity and improves mechanical strength, chemical durability, and resistance to thermal shock. Fluxes, such as feldspar, calcium carbonate, and dolomite, lower the melting temperature of silica and promote vitrification during firing. The interaction and balance among these components determine the final characteristics of the glaze, including surface texture, gloss, colour response, and durability (Bhola 2025; Hamer & Hamer, 2004).

In recent years, there has been increasing interest in the use of alternative materials to replace conventional glaze ingredients due to environmental concerns, economic pressures, and the need to conserve natural resources. Industrial by-products and waste materials such as fly ash, glass cullet, and red mud have been widely investigated for their potential use in ceramic applications. Fly ash, a by-product of coal combustion, contains silica, alumina, and iron oxides, making it suitable for partial substitution in glaze formulations (Galhano et al., 2020). Similarly, glass cullet, when finely ground, acts as both a flux and glass former, reducing firing temperatures and energy consumption (Silva et al., 2017; Andreola et al., 2005). Red mud, a by-product of alumina refining, has also been explored for its fluxing and colouring properties, although its application requires careful management due to the presence of potentially hazardous elements (Vuković et al., 2024; Liu et al., 2024; Singh et al., 2016). The successful incorporation of these materials depends on thorough characterization and compatibility with ceramic systems.

Granite dust, a by-product of quarrying and stone-cutting operations, has gained attention as a potential alternative material in ceramic glaze formulation. It is generated in large quantities and

often disposed of improperly, contributing to environmental pollution (Chen et al., 2025; Liu et al., 2025). Chemically, granite dust is rich in silica and alumina, with appreciable amounts of alkali oxides such as potassium oxide and sodium oxide, as well as minor quantities of iron oxide (Singh et al., 2020). Mineralogically, it consists primarily of quartz and feldspar phases, which are essential components in glaze systems. These characteristics enable granite dust to function as both a glass former and a source of intrinsic fluxing oxides, making it a promising substitute for conventional glaze materials.

The concept of sustainable ceramic production has gained significant attention in response to environmental challenges associated with traditional manufacturing processes. Sustainable practices in ceramics involve minimizing environmental impact through resource efficiency, waste recycling, and energy conservation. The incorporation of industrial waste materials into ceramic bodies and glazes reduces dependence on virgin raw materials and diverts waste from landfills, thereby supporting circular economy principles. Energy efficiency is another critical aspect, as ceramic production requires high firing temperatures that contribute to energy consumption and greenhouse gas emissions. Strategies such as optimizing kiln performance, reducing firing temperatures through flux-enhanced formulations, and utilizing alternative energy sources have been explored to improve sustainability (Mingione et al., 2025; Alves et al., 2024; Hussnain et al., 2021). Granite dust represents a viable material for sustainable ceramic production due to its abundance, chemical suitability, and potential to reduce both environmental impact and production costs.

The chemical properties of granite dust further support its suitability for ceramic applications. Typically, granite dust contains high proportions of silica (60–75%) and alumina (10–20%), along with alkali oxides (5–10%) and minor amounts of iron oxide, calcium oxide, and magnesium oxide (Chajec, 2023; Singh et al., 2016). These components contribute to the formation of a stable glass network during firing, while the alkali oxides act as fluxes that lower the melting temperature and enhance glaze fluidity. The presence of iron oxide also influences the colour and aesthetic properties of the glaze. Consequently, granite dust offers a combination of functional and aesthetic advantages, making it a strong candidate for use in stoneware glaze formulations.

3. Materials and Methods

3.1. Materials

Granite dust sourced from Sahel Granite Company, Bauchi State Nigeria was used as the primary raw material for the study. It is produced as a by-product of granite rock cutting and polishing processes (Figures 2 and 3). Other materials included commercial silica, feldspar, and red iron oxide (Fe_2O_3). Stoneware test tiles were prepared using standard stoneware clay, molded and bisque-fired at 900°C prior to glaze application.



Fig. 2: Granite fragments



Fig. 3: Processed granite dust sample material

3.2. Methods

3.2.1. Sample Preparation

The granite dust was collected from the quarry site and dry-sieved through a 120-mesh (125 μm) sieve in accordance to ASTM E11-17 standard to ensure uniformity then subjected to chemical and mineralogical analysis before formulation into glazes.

3.2.2. Chemical Analysis (XRF)

The granite dust was collected from the quarry site and sieved through a 120-mesh screen. X-ray analysis was conducted to determine the chemical composition using a MiniPal 4 (PW 4030) Energy-Dispersive X-ray Fluorescence (EDXRF) spectrometer.

3.2.3. Mineralogical Analysis (XRD)

The crystalline phases were identified by X-ray Diffraction using a Rigaku diffractometer with Cu-K α radiation ($\lambda = 1.5406 \text{ \AA}$). Data was collected from 3° to 70° 2θ with a 0.03° step size. Quantitative phase analysis was performed using Rietveld refinement with the ICDD PDF-4+ Minerals 2025 database.

3.2.4. Glaze Formulation

Glaze formulation was carried out using the triaxial blend method, a systematic approach for evaluating compositional variations among three primary glaze constituents. The formulation was

guided by the principles of the Seger formula, which ensures appropriate balance among silica (glass former), alumina (stabilizer) and fluxes for optimal glaze performance. Two glaze systems were developed:

- **Glaze A (Experimental):** Granite dust (GD), feldspar (F), and iron oxide (IO), where granite dust served as a partial replacement for commercial silica as the glass former.
- **Glaze B (Control):** Commercial silica (CS), feldspar (F), and iron oxide (IO).

For each glaze system, twenty-one (21) compositions were generated using a triaxial blending scheme as shown in Figures 4 and 5. The compositional variations included 20%, 30% and 40% granite dust in Glaze A, with corresponding silica substitutions in Glaze B. All raw materials were weighed in dry form and subsequently wet-milled using a ball mill with deionized water for 30 minutes, achieving a slurry with a specific gravity of approximately 1.45, following established procedures (Umar, 2000; Braganza, 2001; Datiri, 2012).

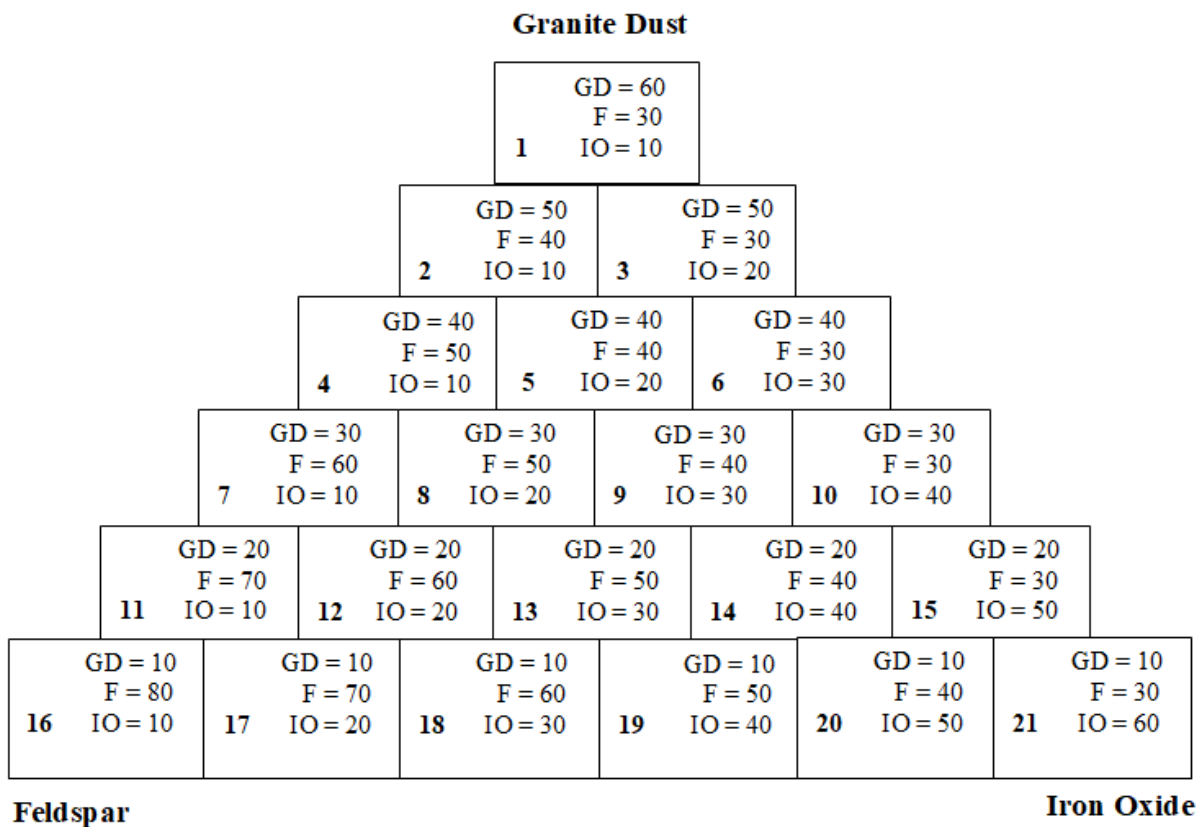


Fig. 4: Glaze A: Granite Dust (GD), Feldspar (F), and Iron Oxide (IO)

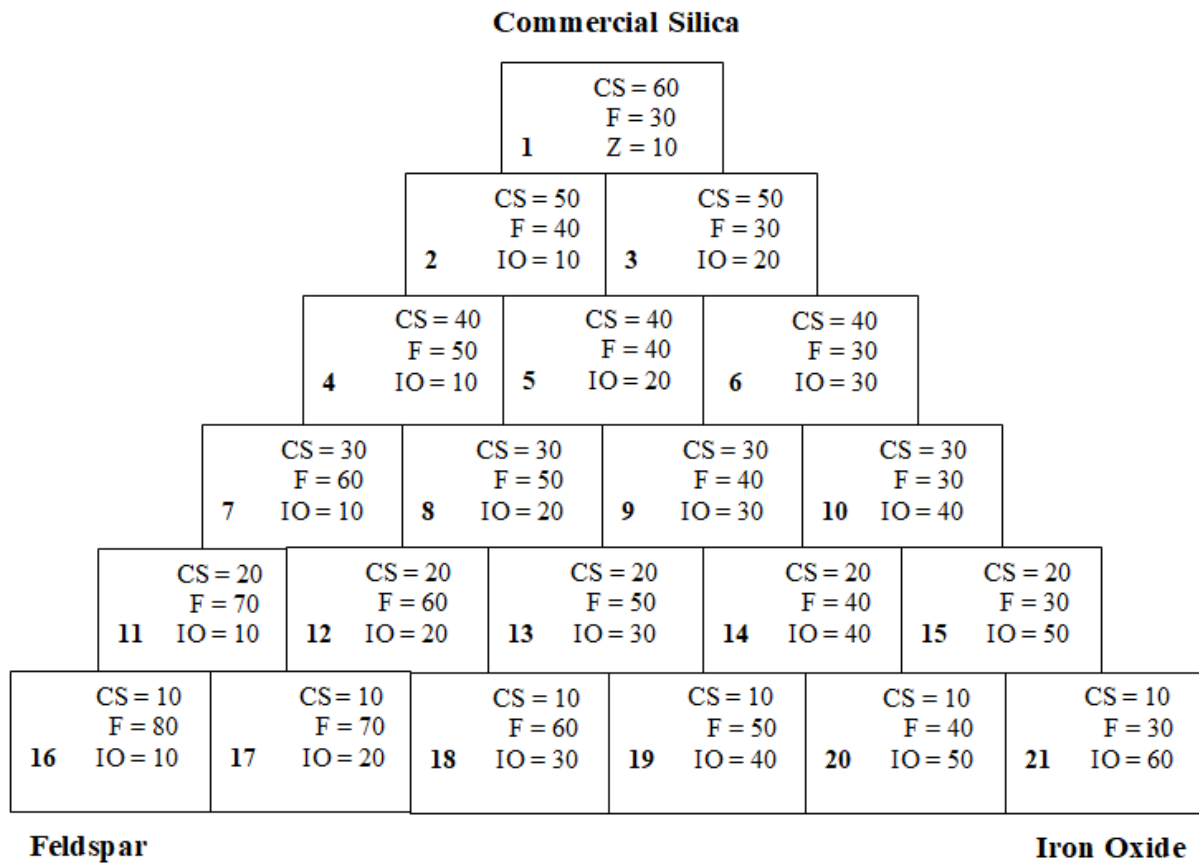


Fig. 5: Glaze B: Commercial Silica (CS), Feldspar (F) and Iron Oxide (IO)

3.2.5. Glaze Application and Firing Procedure

The prepared glaze slurries were applied to bisque-fired stoneware test tiles using a uniform dipping method to achieve consistent coating thickness. The coated specimens were air-dried under ambient laboratory conditions prior to firing. Firing was carried out in an electric kiln under an oxidizing atmosphere achieved by the natural presence of atmospheric oxygen in the kiln chamber due to the absence of fuel combustion and maintained through controlled ventilation at temperatures between 1200 °C and 1250 °C, with a soaking period of 1 hour at peak temperature to ensure proper glaze maturation (Figures 6 and 7).



Fig. 6: Triaxial blend of Glaze A: Granite Dust (GD), Feldspar (F), and Iron Oxide (IO)



Fig. 7: Triaxial blend of Glaze B: Commercial Silica (CS), Feldspar (F), and Iron Oxide (IO)

3.2.6. Evaluation of Glaze Performance

Post-firing evaluation of the glaze samples was conducted to assess melting behaviour, surface quality, and overall visual characteristics through systematic visual inspection of all fired specimens under consistent lighting conditions. The parameters evaluated included surface texture (smoothness or roughness), gloss level (ranging from matte to high gloss), colour development, and the presence of surface defects such as cracking, pinholes, or evidence of incomplete melting. Selected samples from the experimental glaze system (Glaze A) were directly compared with corresponding control samples (Glaze B) to determine the effects of substituting commercial silica with granite dust. These evaluation criteria were used to determine the degree of vitrification and glaze maturity, as well as to assess the influence of compositional variations on both functional and aesthetic properties, thereby providing a basis for evaluating the suitability of granite dust as a potential glass-forming material in stoneware glaze formulations.

4. Results and Discussion

4.1. Chemical Composition (XRF Analysis)

XRF analysis as presented in Table 1 revealed that granite dust sourced from Sahel Granite Company, Bauchi, contains a high proportion of silica (SiO_2 , 59.20%) and alumina (Al_2O_3 , 20.30%), with fluxing oxides such as K_2O , Na_2O , CaO , and MgO present in smaller amounts. Iron oxide (Fe_2O_3 , 5.20%) contributes both to fluxing action and potential colouration. The high LOI (10.60%) indicates moisture and volatile components. The dominance of silica as shown in Fig. 8 confirms its role as a primary glass former in glaze structure, alumina acts as a stabilizer controlling melt viscosity, while alkali and alkaline-earth oxides lower the melting point. The presence of Fe_2O_3 suggests the potential for natural brown to dark brown glaze colouration without additional colourants.

Table 1: Chemical composition of Gudum Hausawa Sahel granite dust (wt.%)

Compound %	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI*
	59.20	20.30	5.20	0.20	2.35	0.50	0.06	0.17	10.60

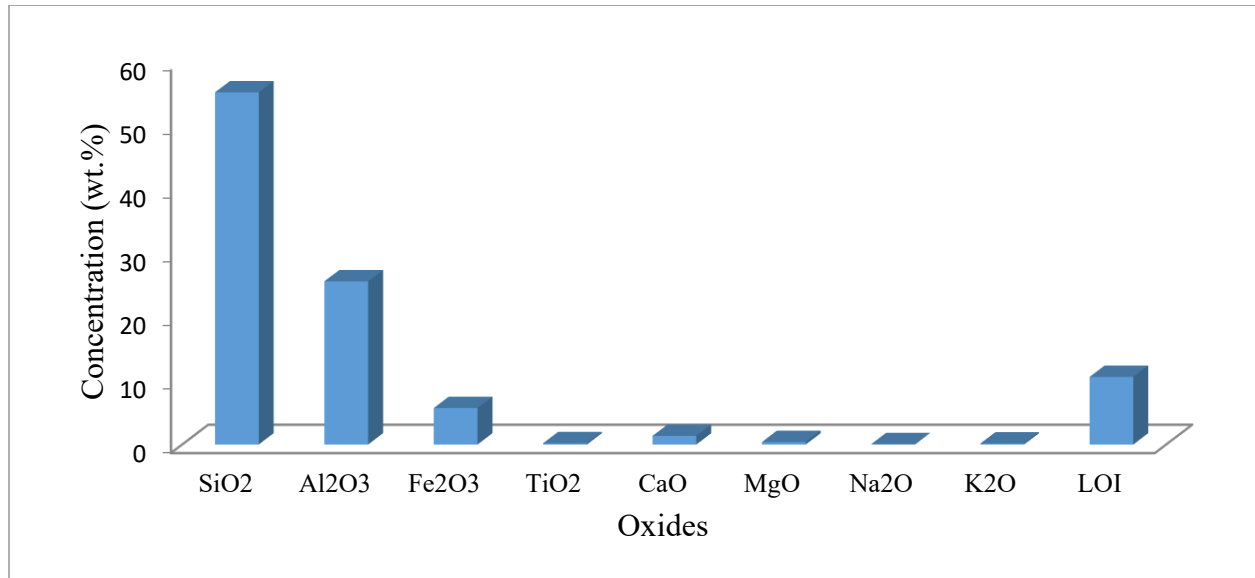


Fig. 8: Chemical constituents of the Gudum Hausawa Sahel granite dust, Bauchi

4.2. Mineralogical Composition (XRD Analysis)

XRD analysis provided detailed mineralogical information complementing the chemical data derived from XRF. Quantitative phase analysis as shown in Table 2 revealed that the granite dust is a multiphase material dominated by quartz (~69%) and feldspathic minerals (~28%), including albite, orthoclase, and anorthite, with minor muscovite content.

Table 2: Quantitative mineralogical composition of Gudum Hausawa Sahel granite dust

Mineral	Chemical Formula	Weight %	Primary Role in Glaze
Quartz, syn	SiO ₂	69 ± 4	Primary glass former
Albite	NaAlSi ₃ O ₈	12.7 ± 1.4	Flux (Na ₂ O), provides Al ₂ O ₃
Orthoclase	KAlSi ₃ O ₈	8 ± 3	Flux (K ₂ O), provides Al ₂ O ₃
Anorthite	CaAl ₂ Si ₂ O ₈	7 ± 2	Flux/Stabilizer (CaO, Al ₂ O ₃)
Muscovite	KAl ₂ (AlSi ₃ O ₁₀)(OH) ₂	3.4 ± 0.6	Source of K ₂ O; contributes to LOI

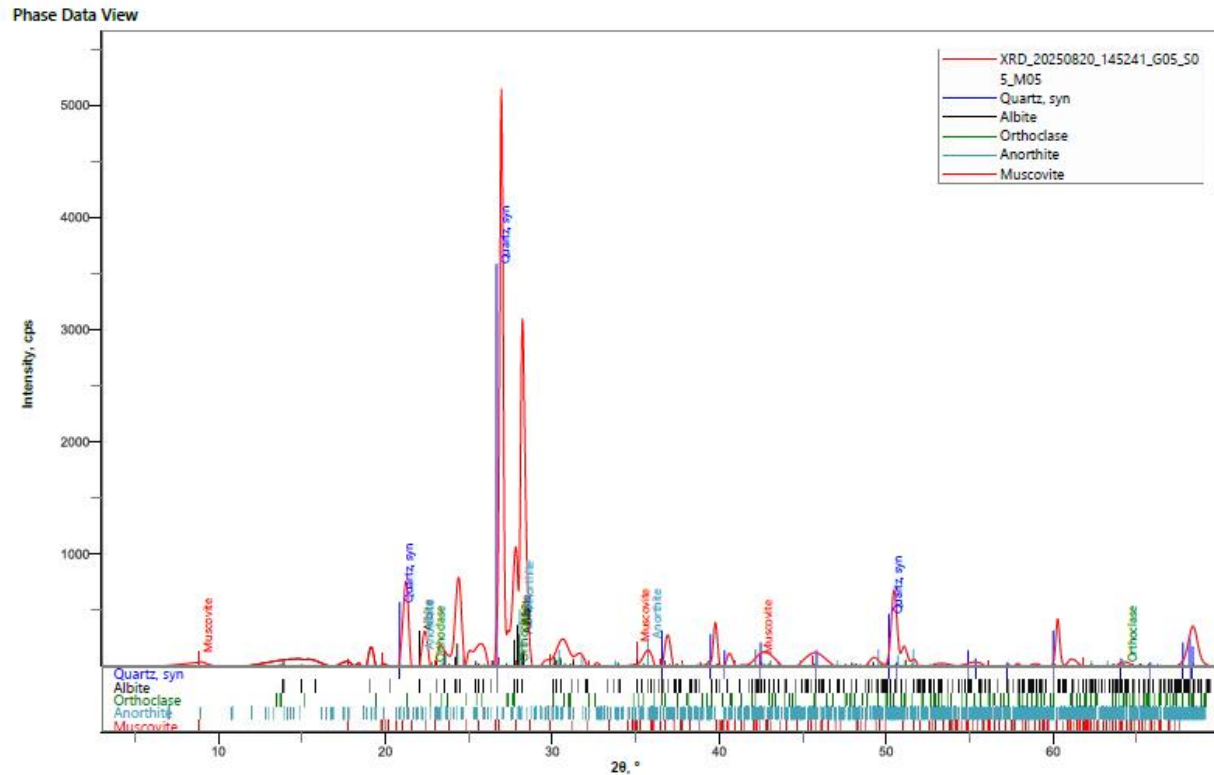


Fig. 9: XRD pattern of Sahel granite dust with phase identification (Q=Quartz, Ab=Albite, Or=Orthoclase, An=Anorthite, Ms=Muscovite)

The dominance of quartz confirms its role as the principal glass former, while the feldspar phases provide intrinsic fluxing oxides (K_2O , Na_2O , CaO) and stabilizing alumina (Fig. 9). Muscovite contributes additional potassium and is partially responsible for the high LOI observed. This mineralogical composition confirms that granite dust inherently functions as a blended glaze material, providing both the glass network and the fluxing components necessary for effective melting and vitrification during firing.

4.3 Glaze Performance and Melting Behaviour

The firing behaviour of both experimental (Glaze A) and control (Glaze B) compositions revealed clear variations across the triaxial blends. Samples with low granite dust or silica content (Tiles 1–3) as shown in Figure 10 exhibited incomplete melting, poor adhesion, and surface cracking, indicating insufficient fluxing and inadequate liquid phase formation during firing. This observation aligns with established glaze theory, where insufficient flux limits vitrification (Mathias, 2013).



Fig. 10: Glaze A: The incomplete melting glazes (1, 2 and 3)

In contrast, mid-range compositions (Tiles 4, 7, 11, and 17) as presented in Figure 11 demonstrated optimal melting behaviour, producing smooth, well-fused, and glossy surfaces. These compositions reflect a balanced ratio of silica, alumina, and fluxing oxides consistent with the principles of the Seger formula. The improved performance in these samples can be attributed to the dual contribution of granite dust, which not only supplies silica but also introduces fluxing oxides through its feldspathic components, thereby enhancing melt formation. This is further backed by the mineralogy where substituting silica with granite dust simultaneously adds reactive quartz and feldspathic fluxes, effectively creating a more melt-ready batch.



Fig. 11: Glaze A: The smooth glossy glaze samples

Samples with inadequate proportions of either glass formers or fluxes (Tiles 10, 13, 14, 15, and 19) as shown in Figure 12 exhibited rough and underdeveloped surfaces, further confirming the importance of compositional balance in glaze formulation.



Fig. 12: Glaze A: The rough glazed samples (10, 13, 14, 15, and 19)

4.4. Surface Quality and Aesthetic Characteristics

Visual evaluation of the fired glazes as evident in Figures 13 and 15 indicated that compositions containing 20-40% granite dust produced surfaces comparable to, and in some cases superior to, the control glazes. These samples exhibited smooth, glossy to highly glassy finishes with good surface uniformity. The observed colour ranged from brown to dark brown, primarily influenced by the presence and concentration of iron oxide within the formulations (Table 3).

Lower iron oxide contents (<10%) resulted in transparent, high-gloss finishes, while higher concentrations (>30%) produced darker, more opaque surfaces with reduced gloss. The inherent iron oxide present in the granite dust contributed significantly to colour development, reducing the need for additional colourants. These results demonstrate that granite dust-based glazes can achieve high aesthetic quality suitable for stoneware applications.



Fig. 13: Glaze A: Granite dust glazed ware



Fig. 14: Glaze B: Commercial silica glazed wares



Fig. 15: Post-fired samples of Glaze A and Glaze B wares in the electric kiln

Table 3: Performance of optimal granite dust-based glazes

Formulation	GD (%)	F (%)	IO (%)	Surface Texture	Colour	Gloss
G-20	20	70	10	Smooth	Brown	High
GD-30	30	50	20	Smooth, glossy	Dark brown	High
GD-40	40	30	30	Smooth, glassy	Dark brown	Very high

4.5. Functional Performance and Material Behaviour

Glazes that achieved complete fusion exhibited good adhesion to the ceramic body, absence of major surface defects, and resistance to scratching, indicating adequate vitrification and surface hardness. The ability of granite dust to perform effectively in these formulations is directly linked to its mineralogical composition, where the combination of quartz and feldspar phases enhanced both glass formation and melt fluidity. The substitution of commercial silica with granite dust effectively transforms the glaze system from a single-component glass former to a multi-component reactive mixture, improving melting efficiency and reducing the need for additional fluxing agents.

4.6 Sustainability and Industrial Implications

The successful incorporation of granite dust (20-40%) as a replacement for commercial silica demonstrates significant potential for sustainable ceramic production. By utilizing an industrial waste material, the study supports waste valorisation and reduces dependence on conventional raw materials. Furthermore, the dual role of granite dust as both a glass former and fluxing agent simplifies glaze formulations, potentially lowering production costs and raw material requirements. The comparable performance of granite dust-based glazes to conventional silica-based systems suggests that this substitution can be implemented in existing ceramic production processes without major modifications. This aligns with sustainable manufacturing principles and promotes a circular economy approach within the ceramics industry.

5. Conclusion

This study has demonstrated the technical viability of utilizing granite dust as a substitute for commercial silica in stoneware glaze formulation. Chemical and mineralogical analyses confirmed that the granite dust, sourced from Bauchi, is rich in silica and alumina, with XRD results indicating a natural quartz–feldspar composition (approximately 69% quartz and ~28% feldspars).

This composition enables the material to function effectively as both a glass former and a source of inherent fluxing oxides. The performance of the triaxial glaze blends revealed that compositions containing 20-40% granite dust achieved optimal melting behaviour, producing smooth, glossy, and well-vitrified surfaces at firing temperatures up to 1250 °C. These glazes performed comparably to conventional silica-based formulations, with good adhesion, surface integrity, and resistance to scratching. The improved glaze maturity is attributed to the synergistic interaction between quartz and feldspathic phases, which enhances melt formation and reduces the need for additional fluxing agents.

Furthermore, the presence of iron oxide contributed to desirable brown to dark-brown colouration, minimizing the need for external colourants. Beyond its technical merits, the use of granite dust presents significant environmental and economic benefits. Its successful incorporation into glaze formulations supports sustainable ceramic manufacturing by reducing reliance on imported raw materials, lowering production costs, and promoting the utilization of industrial waste in line with circular economy principles. Overall, granite dust is established as a promising alternative raw material for stoneware glaze production. Future research should focus on optimizing firing parameters, expanding compositional ranges, and evaluating long-term durability to further enhance its industrial applicability.

6. Recommendations

1. Granite dust should be adopted as a viable alternative raw material for stoneware glaze production, particularly at substitution levels of 20-40%, where optimal melting behaviour and surface quality were achieved.
2. Ceramic industries are encouraged to incorporate granite dust as a partial replacement for commercial silica in glaze formulations, as it offers both technical and economic advantages without requiring significant modifications to existing production processes.
3. Further research should focus on optimizing processing conditions, including firing parameters (heating rates and soaking times), to enhance glaze performance across a wider range of compositions.
4. Additional studies are recommended to evaluate the long-term durability, chemical resistance, thermal expansion, and surface hardness of granite dust-based glazes to ensure their suitability for diverse functional applications.

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