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Characterization of Kaolin from Three Sites in Northern Nigeria as Alternative Raw Material for The Production of Laboratory Evaporating Dish

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ABSTRACT
This study focused on the characterization of kaolin obtained from three deposits in Nigeria—Kuba (Plateau State), Alkaleri (Bauchi State), and Itobe (Kogi State) to evaluate their suitability as locally sourced raw materials for the production of laboratory evaporating dish. The growing demand for indigenous ceramic raw materials has increased interest in kaolin because of its abundance and versatility in ceramic applications. The kaolin samples were subjected to mineralogical, chemical, thermal, and physical characterization using X-ray diffraction (XRD), X-ray fluorescence (XRF), scanning electron microscopy coupled with energy dispersive X-ray spectroscopy (SEM/EDX), thermogravimetric analysis (TGA), differential thermal analysis (DTA), Atterberg limit tests, and hydrometer analysis. The results were compared with established standards for stoneware and laboratory ceramics. The analyses revealed that the samples contained significant amounts of kaolinite with minor impurities, suitable chemical compositions, and favorable firing characteristics. XRF results showed SiO_2 contents ranging from 51.68–65.73% and Al_2O_3 contents from 24.39–39.70%. Fe_2O_3 contents ranged between 1.75–6.90%, indicating acceptable purity for ceramic applications. The beneficiated Kuba kaolin recorded the highest SiO_2 content (65.73%), while Alkaleri exhibited the lowest (51.68%). The Atterberg limit test showed plasticity indices of 42.4%, 40.7%, and 34.1% for Kuba, Alkaleri, and Itobe respectively, indicating good moulding and shaping characteristics. Hydrometer analysis confirmed the dominance of fine clay fractions, suggesting good workability and sintering behavior. TGA and DTA results revealed characteristic kaolinite dehydroxylation within 450–650°C, confirming thermal stability suitable for ceramic firing. The study demonstrates that the investigated kaolin deposits possess the mineralogical, chemical, thermal, and physical properties required for the production of durable and chemically resistant laboratory evaporating dish. The findings contribute to the characterization and utilization of indigenous raw materials and support the advancement of local ceramic technology in Nigeria.

Keywords - *Ceramic raw materials, Characterization, Kaolin, Laboratory evaporating dish*

I. INTRODUCTION

Nigeria is blessed with an estimated reserve of about two billion metric tons of kaolin (Mudi,K.Y et al, 2018) . Kaolin, a natural occurring clay material mineral that is composed of kaolinite ($Al_2Si_2O_5(OH)_4$), is widely utilized across industries due to its unique physical, chemical, and mineralogical properties (Abu, Y., *et al*, 2017) It has attracted both local and foreign investors due to its wide applications. Characterization of kaolin has been of considerable interest to investigators and investors (Mudi,K.Y *et al*, 2018). Kaolin is a phyllosilicate mineral which is usually submicron to micron in size. Application of kaolin is vast industrially due to their physical and compositional characteristic (Olisa *et al*, 2024). They are used in ceramics, paper filling and coating, refractory,

water treatment, agriculture, cracking catalyst and pharmaceutics (Murray, 2007; Gupta & Bhattacharyya, 2012; Velde, 1995) .Kaolin application in ceramic development wares in Nigeria, particularly in manufacturing and production of scientific laboratory equipment, such as laboratory evaporating dish will ultimately reduce Nigeria overdependence on import, thus create job opportunities for Nigerian teeming youths (Aderemi *et al*., 2013).

The suitability of kaolin for ceramic application is often determined through characterization techniques such as analyzing its physical and chemical properties to determine its suitability for various industrial applications. The suitability of kaolin for the production of ceramic is often determined through characterization techniques such as, X-ray diffraction (XRD), XRF, SEM, TGA/DTA (Olupol *et al*., 20015).

Differential thermal analysis (DTA) is a critical tool for assessing the thermal suitability of kaolin for evaporating dish and other form of ceramic applications. Because it identifies the characteristic endothermic and exothermic transformations associated with moisture removal, kaolinite, dehydration, metakaolin formation and subsequent mullite crystallization. The presence of a pronounced dehydration endotherm within 450-650℃ followed by a distinct high-temperature exothermic peak associated with mullite formation above 1000℃ is generally regarded as evidence of good thermal properties and suitability for refractory and heat-resistant ceramic products, owing to mullite's low thermal expansion and high mechanical integrity at elevated temperatures (Chakraborty,2003; Afolabi *et al*., 2020)

A peer-reviewed Nigerian study on sanitary ceramics successfully used kaolin, feldspar, quartz, and ball clay from southwest Nigeria, confirming that indigenous raw materials are suitable for standard ceramic ware production (Elakhame, Z. U., *et al*., 2020). According to Adejoh and Lawal, (2018), the existing evaporating dish produced locally are limited in availability and quality, thus a constant search for new and relevant sources of high-quality raw materials to enhance the quality and durability of evaporating dish and other scientific products. Kaolin a natural occurring clay mineral, plays a very important role in ceramic application, because of its mechanical strength, plasticity for shaping, high firing temperature and its white burning colour, low shrinkage (Adejoh & Lawal, 2018).

The properties of kaolin are strongly influenced by its degree of crystallinity and extent of weathering, both of which are controlled by the mineralogical composition and alteration behaviour of the parent rock material (Aparicio & Galán, 2000; Hradil et al., 2002).

This study was undertaken to characterize the properties of kaolin deposits from locations outside Niger state, in line with the recommendation of Adejoh and Lawal (2018). Consequently, three strategic locations were selected for investigations. Kuba in Bokkos local government area of Plateau state, Alkaleri in Alkaleri local government area of Bauchi state, and Itobe in Ofu local government area of Kogi state. Despite extensive studies on Nigerian kaolin, there is limited published data on specific deposits such as Itobe and Kuba thus necessitate this study.

This study contributes to the understanding of Nigerian vast kaolin deposits by providing an integrated characterization of samples from Itobe, Alkaleri, and Kuba using XRD, XRF, SEM/EDX, TGA/DTA, Atterberg limits, and particle size analysis. It establishes a direct link between their physicochemical properties and suitability for evaporating dish production. The paper is structured as follows, section II describes the material and methods, section III presents results and discussion and section III concludes with key findings and recommendations.

II. MATERIALS AND METHODS

2.1 Raw Materials and Sampling Locations

Kaolin samples were collected from working surfaces and pits in Kuba in Bokkos local government area in Plateau State, Alkaleri in Alkaleri local government of Bauchi State and Itobe in Ofu local government area of Kogi State (Plate 1). The sample from kuba in bokkos local government area, was beneficiated through washing, sieving and drying to remove debris. And the solidified paste later dried in open air. All samples were air dried prior to analysis. The physicochemical and thermal characterization was carried out at the National Steel Raw Material and Exploration Agency (NSRMEA) Kaduna state.

Plate I: Kaolin Samples from the three sites.

2.2 Sample Preparation and Beneficiation

The raw kaolin samples were oven-dried, manually sorted, crushed and passed through the appropriate sieve prior to characterization. The Kuba sample was beneficiated through washing, sieving and allowed to sediment before drying prior to analysis. Three (3) representative kaolin samples from each location were pulverized, oven dried at 105+ 5℃ and sieved to obtain fine homogenous powders for analysis.

2.3 Apparatus and Equipment

Mineralogical analysis was performed using an X-ray diffractometer (Rigaku model). Chemical composition was determined using an X-ray fluorescence spectrometer (XRF, Genius IF Xenemetrix). Microstructural and elemental analysis were conducted using scanning electron microscope equipped with energy-dispersive X-ray spectroscopy (SEM/EDX, Phenom model). The thermal behaviour was evaluated using a thermogravimetric and differential thermal analyzer (TGA/DTA,Perkin Elmer 4000). Physical properties were determined using a Cassagrande liquid limit device for Atterberg limits and a standard hydrometer (Bouyoucos) setup for particle size distribution analysis.

2.4 Experimental Methods

2.4.1 Rainfall Data

2.4.1 X-ray Diffraction (XRD)

The mineralogical composition of the samples were determined using X-ray diffraction (XRD) with a Rigaku Miniflex XRD diffractometer. The powdered samples were finely ground, mounted on a sample holder to obtain a flat smooth surface and scanned within a 2Θ range of 5 - 70° at a scan speed of 2°/min for phase identification. Phase identification was carried out by comparison with standard referenc patterns from the international Centre for Diffraction Data (ICDD) database.

2.4.2 X-ray Fluorescence (XRF)

The elemental oxide composition was determined using X-ray Fluorescence (XRF) with a Genius IF Xenemetrix Spectrometer. The powdered samples were pressed into pellets and analyzed for major oxides such as SiO_2, Al_2O_3, Fe_2O_3, TiO_2, K_2O, and CaO. The obtained oxide composition was used to assess kaolin purity, refractoriness, fluxing tendency, and suitability for ceramic laboratory wares.

2.4.3 Scanning Electron Microscopy (SEM/EDX)

The surface morphology and microstructural features were examined using a Phenom Scanning Electron Microscope coupled with Energy Dispersive X-ray spectroscopy (SEM/EDX) after coating the samples to improve conductivity. Dried powdered samples were mounted on conductive stubs and imaging and elemental mapping were performed under controlled accelerating voltage.

2.4.4 Thermogravimetric/Differential Thermal analysis (TGA/DTA)

The thermal properties were evaluated using a Perking Elmer TGA 4000 thermogravimetric analyzer. Approximately 12mg of each dried sample was heated from 30℃ to 1000℃ at a heating rate of 10℃/min under nitrogen atmosphere to determine moisture loss, dihydroxylation behavior, and thermal stability.

2.4.5 Atterberg Limit Test

Liquid limit and plastic limit were determined using the Cassagrande method in accordance with ASTM D4318 standard procedures. The liquid limit, plastic limit, and plasticity index were determined to evaluate the workability and forming characteristics of the kaolin samples.

2.4.6 Particle Size Distribution analyses

The particle size distribution of the clay and silt fractions was determined using the hydrometer sedimentation method based on Stoke's law in accordance with ASTM D7928. The dispersed clay suspension was allowed to sediment, and hydrometer readings were taken at specified time intervals to calculate the percentage clay and silt fractions.

III. RESULTS AND DISCUSSION

3.1 Mineralogical Composition of Kaolin samples

3.1.1 X-ray Diffraction (XRD) and Discussion

XRD was carried out for each of the kaolin sample collected, to determine the phase transformation. The aforementioned was carried out at the National Steel Raw Material and Exploration Agency (NSRMEA), Kaduna State, and the result is presented in Table 1 and Figures 1 – 3 which shows mineralogical characterization of kaolin from the three sites.

Table 1: Phase and oxide composition of Itobe Kaolin

Mineral	Chemical Formula	Deposit (%)		
		Itobe Deposit	Alkaleri	Beneficiated Kuba
Quartz	SiO_2	62.0	25.0	36.0
Albite	$NaAlSi_3O_8$	2.2	7.6	11.6
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	3.1	1.8	1.6
Kaolinite	$Al_2Si_2O_5(OH)_4$	28.0	46.0	43.0
Illite	$KAl_2Si_3Al)O_{10}(OH)_2$	3.4	3.7	1.8
Clinochlore	$MgAl(AlSi_3)O_{10}(OH)_8$	1.1	1.9	1.8
Orthoclase	$KAlSi_3O_8$	0.2	14.7	4.1

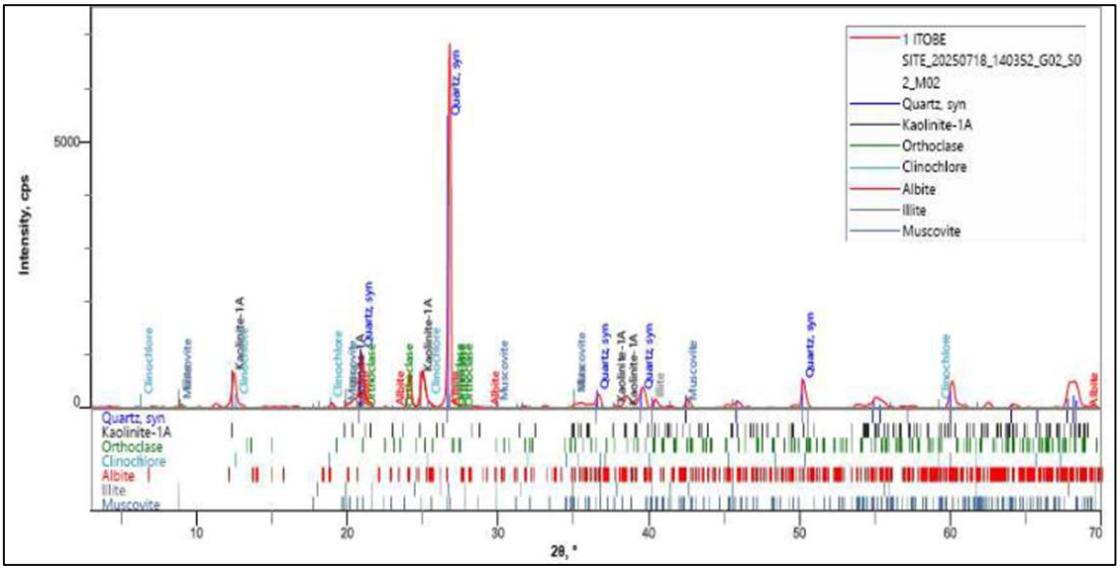

Figure 1: Itobe Spectrograph

The results of the analysis are shown above in Table 1 and Figures 1 - 3 show the presence of Quart, Albite, Muscovite, Kaolinite, Illite, Clinochore, Orthoclase and SiO_2, $NaAlSi_3O_8$, $KAl_2(AlSi_3O_{10})(OH)_2$, $Al_2Si_2O_5(OH)_4$, $MgAl(AlSi_3)O_{10}(OH)_8$ and $KAISi_3O_8$.

The XRD analysis identified the dominant mineral phases and quantifying their relative abundance. Kaolinite, the principal clay mineral of interest, was most abundant in Alkaleri (46%) and Beneficiated Kuba (43%), followed by Itobe (28%). However, Alkaleri's sample also contained a relatively high concentration of orthoclase and quartz (25%), which may dilute the active ceramic phase and influence sintering behavior. Notably, Beneficiated Kuba kaolin presented a balanced composition with high kaolinite, moderate quartz (36%), and minor accessory minerals such as illite (1.8%), albite (11.6%), and muscovite (1.6%), making it suitable for precise thermal control during ceramic processing. According to Emilio Galán and Robert E. Ferrell (2013), kaolin intended for refractory applications should contain a high proportion of kaolinite and minimal fluxing and non-clay mineral impurities such as mica, feldspar, and alkali-bearing phases, since these constituents reduce refractoriness by promoting premature liquid-phase formation during firing. This align with findings from other studies that impurities such as illite, smectite, and feldspar decrease the suitability of kaolinite-rich raw materials for high-grade ceramic and refractory wares such as laboratory evaporating dish due to their role in enhancing early sintering and liquid-phase formation.

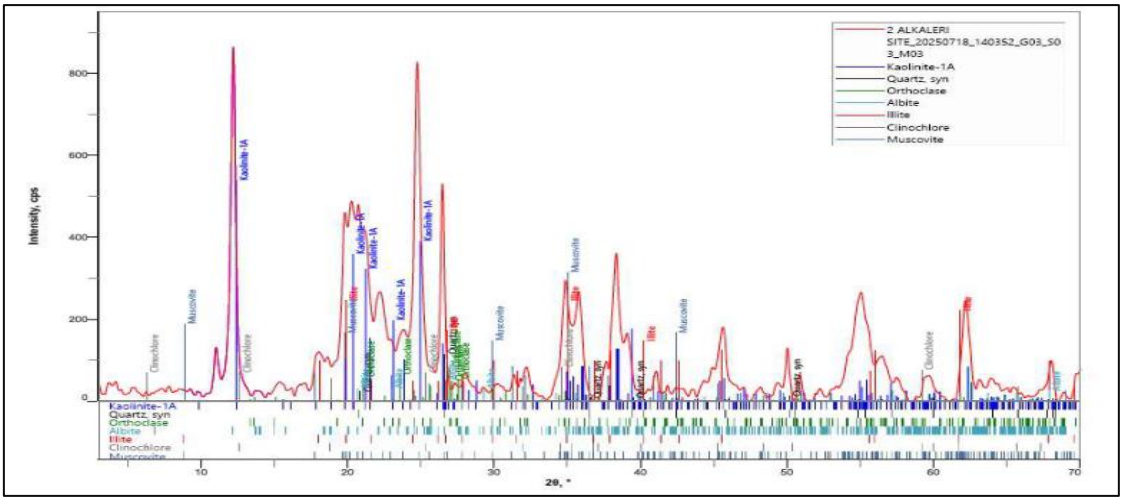

Figure 2: Alkaleri Spectrograph

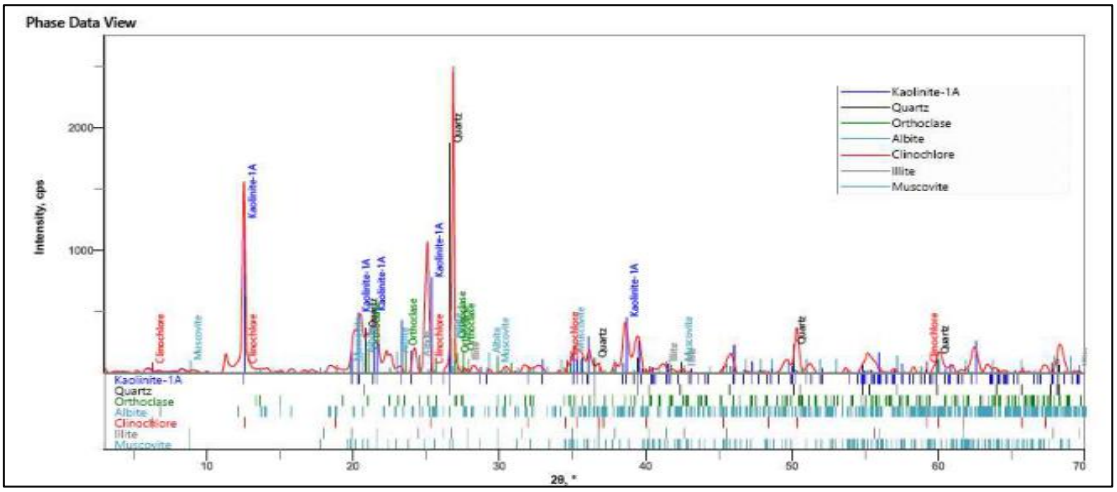

Figure 3: Beneficiated Kuba Spectrograph

3.1.2 Geochemical Analyses of the Kaolin Samples

X-ray Fluorescence (XRF) analysis provided critical insights into their structural purity, crystallinity, and chemical suitability for high-temperature ceramic applications. These parameters are foundational in assessing the potential of clay materials for producing laboratory-grade evaporating dish, which require refractory behavior, high alumina content, minimal fluxing oxides, and a predominant kaolinite phase.

The XRF results revealed that the Beneficiated Kuba kaolin exhibited the highest silica (SiO_2) content at 65.73% and alumina (Al_2O_3) content at 24.39%, compared to Alkaleri (SiO_2: 51.68%, Al_2O_3: 39.70%) and Itobe (SiO_2: 57.37%, Al_2O_3: 31.08%). This SiO_2:Al_2O_3 ratio is characteristic of high-purity kaolinite (ideal ratio ~1.18) as corroborated by Zhou Cao et al., (2021), and suggests a well-formed kaolin structure with minimal silica dilution from quartz or feldspar. The Kuba sample's has lower iron oxide (Fe_2O_3:)3.92%) and titanium dioxide (TiO_2:) 3.36%) contents further attest to its superior whiteness and thermal resistance, aligning with ISO 1248:2006 and ASTM C373 requirements for refractory ceramics. In contrast, the Itobe sample contains higher Fe_2O_3 (6.90%) and quartz content, indicating lower purity and potentially greater thermal expansion during firing—undesirable for laboratory ceramics.

The presence of alkali fluxing oxides such as K_2O and Na_2O was generally low across all samples but comparatively higher in the Alkaleri sample, likely due to the presence of feldspar minerals, specifically orthoclase (14.7%) and albite (7.6%) identified through XRD analysis. These feldspathic constituents can introduce alkali oxides that lower the vitrification temperature and reduce refractoriness by promoting earlier liquid-phase formation during firing (Emilio Galán & Robert E. Ferrell, 2013). The XRF results for the three study locations are presented in Tables 2a and 2b.

The XRF results in Tables 2a and 2b revealed that the beneficiated Kuba kaolin exhibited the highest silica (SiO_2) content at 65.73% and alumina (Al_2O_3) content at 24.39%, compared to Alkaleri (SiO_2: 51.68%, Al_2O_3: 39.70%) and Itobe (SiO_2: 57.37%, Al_2O_3: 31.08%). This SiO_2:Al_2O_3 ratio is characteristic of high-purity kaolinite (ideal ratio ~1.18) and suggests a well-formed kaolin structure with minimal silica dilution from quartz or feldspar. The Kuba sample's lower iron oxide (Fe_2O_3: 3.92%) and titanium dioxide (TiO_2: 3.36%) contents further attest to its superior whiteness and thermal resistance, aligning with ISO 1248:2006 and ASTM C373 requirements for refractory ceramics. In contrast, the Itobe sample contains higher Fe_2O_3 (6.90%) and quartz content, indicating lower purity and potentially greater thermal expansion during firing—undesirable for laboratory ceramics. The presence of alkali fluxing oxides such as K_2O and Na_2O (through feldspar minerals) was minimal across all samples but highest in the Alkaleri sample, due to orthoclase (14.7%) and albite (7.6%) detected in XRD, which may lower the vitrification point and risk deformation at elevated temperatures.

3.1.3 Scanning Electron Microscope/Energy Dispersive X-ray (SEM/EDX) Analyses

The SEM micrograph of the Itobe kaolin sample as seen in Figure 4, revealed a generally heterogeneous and poorly defined microstructure.

FOV: 682 µm, Mode: 15kV - Map, Detector: BSD Full, Time: JUL 18 2025 13:24

Figure 4: Itobe Kaolin Micrograph

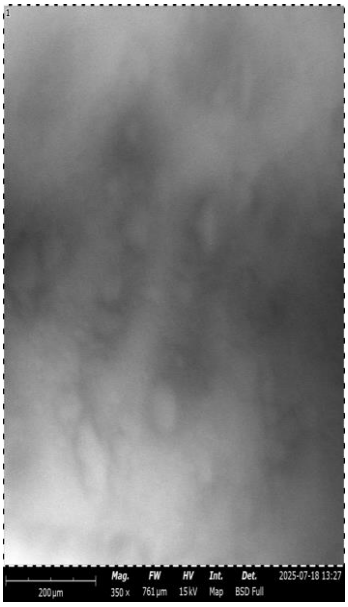

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Figure 5: Alkaleri Kaolin Micrograph

FOV: 769 µm, Mode: 15kV - Map, Detector: BSD Full, Time: JUL 18 2025 13:29

Figure 6: Beneficiated kuba Kaolin Micrograph

At a magnification of 350x, the image displays irregularly shaped aggregates with minimal visible porosity and indistinct platy morphology. The surface texture appeared relatively coarse and compact, indicating less refinement and a possible presence of impurities or non-kaolinitic inclusions. The SEM micrograph revealed platy to flaky particles typical of kaolinite morphology. This observation agrees with the XRD results, which identified Kaolinite as the dominant mineral phase.

Table 2a: Geochemical Analyses of Kaolin Samples (Wt %)

Sample	SiO_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	CoO	NiO	CuO	Nb_2O_5	WO_3	P_2O_5	SO_3	CaO	MgO
Itobe	57.37	0.05	0.04	0.08	6.9	0.01	0.01	0.08	0.1	-	-	0.49	0.63	-
Alkaleri	51.68	0.19	0.02	0.06	1.75	0.01	0.01	0.05	0.03	-	0.08	0.09	0.11	-
Beneficiated Kuba	65.73	0.16	0.08	0.04	3.92	0.02	0.002	0.06	0.02	-	-	0.27	0.19	-

Table 2b: Geochemical Analyses of Kaolin Samples (Wt %) Continued

Sample	K_2O	BaO	Al_2O_3	TiO_2	ZnO	Ag_2O	Cl	ZrO_2	SnO_2	PbO	Rb_2O	Cs_2O	SrO	Ta_2O_5
Itobe	0.7	0.2	31.08	0.16	0.06	0.02	1.52	0.09	-	0.03	0.08	0.08	0.01	
Alkaleri	0.45	0.23	39.7	4.02	0.03	0.03	0.74	0.46	-	0.02	0.01	0.18	0.03	
Beneficiated Kuba	-	0.28	24.39	3.36	0.02	0.04	0.84	0.42	-	0.02	0.003	0.11	0.01	0.05

The EDS spectrum further compliments this finding by showing strong Al, Si, and O peaks. The EDS elemental distribution as seen in Table 3, is consistent with the mineral phases identified by XRD thereby confirming that the detected Si – Al rich matrix corresponds predominantly to kaolinite, while excess Si indicates associated quartz impurities. The accompanying EDS spectrum revealed Si, Al, and O as the dominant elements, with minor traces of Fe, Ti, and K. The relatively higher Fe content, as confirmed by both EDS and XRF analyses, suggests the presence of iron-bearing minerals such as iron oxides or mica. These impurities are considered to adversely affect the whiteness and firing characteristics of kaolin, particularly by reducing its brightness after firing and influencing its suitability for high-quality ceramic applications (Emilio Galán & Robert E. Ferrell, 2013). These observations imply that although the Itobe kaolin contains kaolinite, the microstructure and chemical purity may not meet the optimal standard for high-performance ceramic ware without beneficiation.

Table 3: EDX Elemental Table for Kaolin from the three Sites

Element			Atomic Conc.			Weight Conc.		
Number	**Symbol**	**Name**	**Itobe**	**Alkaleri**	**Kuba**	**Itobe**	**Alkaleri**	**Kuba**
14	Si	Silicon	64.79	52.69	58.34	61.22	51.16	56.52
13	Al	Aluminium	28.47	40.95	36.18	25.85	38.2	33.68
26	Fe	Iron	3.22	1.88	3.04	6.05	3.62	5.86
22	Ti	Titanium	2.45	1.37	0.16	3.94	2.26	0.26
47	Ag	Silver	0.43	0.22	0.26	1.55	0.81	0.96
50	Sn	Tin	0.2	0	0	0.81	0	0
19	K	Potassium	0.44	0.48	0.4	0.58	0.65	0.54
56	Ba	Barium	0	0	0	0	0	0
11	Na	Sodium	0	0.65	0.38	0	0.52	0.3
12	Mg	Magnesium	0	0.73	0.18	0	0.62	0.15
20	Ca	Calcium	0	0	0	0	0	0
40	Zr	Zirconium	0	0.28	0.17	0	0.88	0.53
30	Zn	Zinc	0	0	0	0	0	0
15	P	Phosphorus	0	0	0	0	0	0
16	S	Sulfur	0	0	0.57	0	0	0.63
17	Cl	Chlorine	0	0.23	0	0	0.28	0
23	V	Vanadium	0	0	-	0	0	-
24	Cr	Chromium	0	0	0.32	0	0	0.57
25	Mn	Manganese	0	0.53	0	0	1	0

The SEM micrograph of the Alkaleri sample as seen in Figure 5, obtained at 350x magnification, revealed partially aligned platy to lamellar particles with discernible sheet-like staking and relatively uniform particle orientation. These plate-like aggregates are consistent with the typical morphology of kaolinite, which commonly occurs as pseudo-hexagonal or flaky platelets in SEM images. The moderate degree of particle ordering, compared with the more heterogeneous Itobe sample as seen in Figure 6, formed the basis for describing the microstructure as moderately organised. The surface showed better definition and clearer lamellar morphology than the Itobe sample, with moderate porosity and interparticle spaces. These structural features are consistent with kaolins known to perform well in thermal environments due to their more defined layer silicate arrangements. The EDS analysis supported these microstructural findings by confirming a strong presence of Si, Al, and O, which are typical of kaolinite ($Al_2Si_2O_5(OH)_4$). Trace amounts of Ti and Fe were present but relatively lower than those observed in the Itobe sample, suggesting a higher purity index. The elemental homogeneity and structured micrograph indicate that the Alkaleri kaolin also has the potential suitable for producing laboratory evaporating dish as it aligns with ASTM C373 and ASTM C67 standards that recommend low impurity content and fine microstructure for ceramic raw materials (ASTM, 2014).

The SEM image of the beneficiated Kuba sample demonstrated the most refined microstructure among the three sites. Captured at 350x magnification, the micrograph showed uniformly distributed and well-aligned platy particles with fine grain size and evident laminar orientation. The structure was highly porous and smooth, suggesting effective beneficiation which likely removed impurities and enhanced the particle dispersion. This level of microstructural order is typical of high-quality kaolin clays and aligns with those used in high-temperature

ceramic processes. The EDS analysis corroborated this, showing high peaks of Si, Al, and O, with only trace levels of Fe and Ti, which confirms the effectiveness of the beneficiation process in enhancing compositional purity. According to Chritidis, (2011), Such a well-ordered and chemically consistent microstructure makes the Kuba kaolin highly suitable for laboratory ceramic ware, consistent with standards set by the European Ceramic Society (ECerS), which emphasize high purity and crystallinity for ceramic-grade kaolin.

3.1.4 Thermogravimetric/Differential Thermal Analysis (TGA/DTA)

The thermogravimetric analyses (TGA and DTA) for the three-kaolin sample are presented in Figure 7-12 (Itobe site, Beneficiated Kuba site, Alkaleri site)

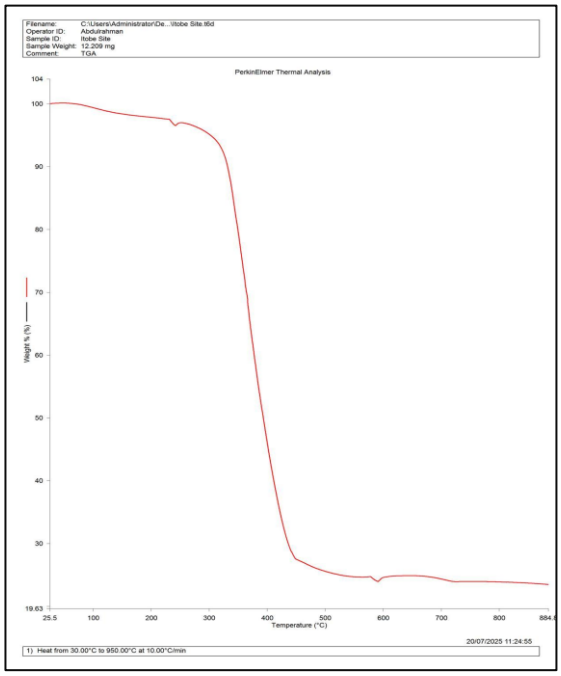


Figure 7 Thermogravimetric Analyses (Itobe site)

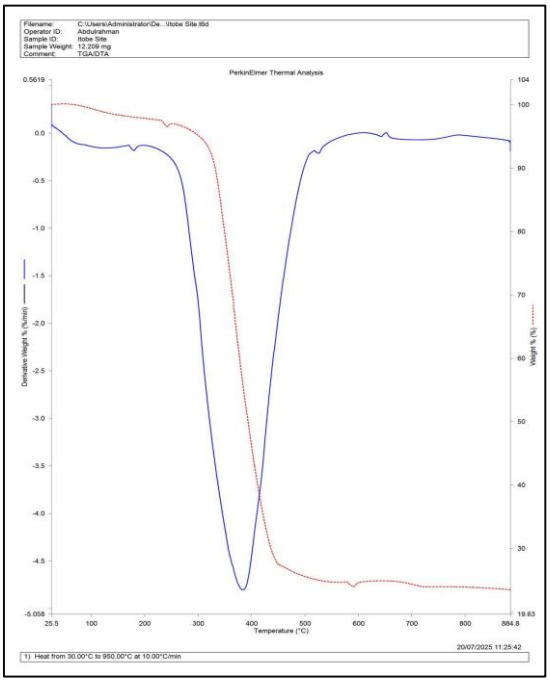
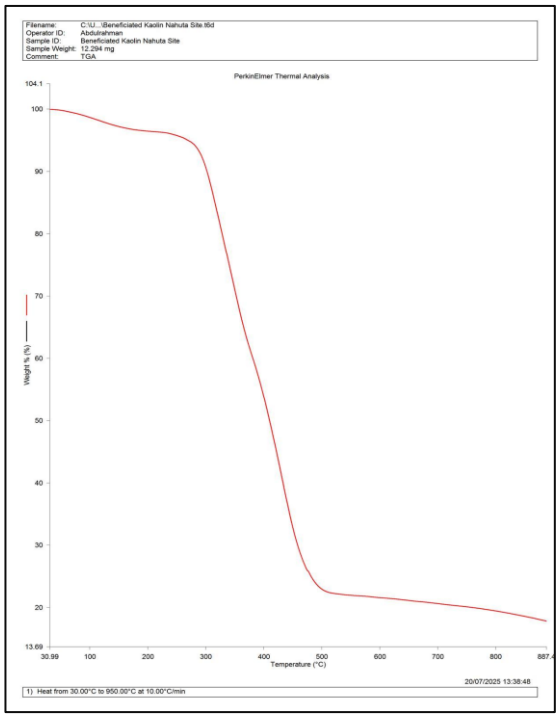


Figure 8 Differential Thermal Analyses (Itobe site)



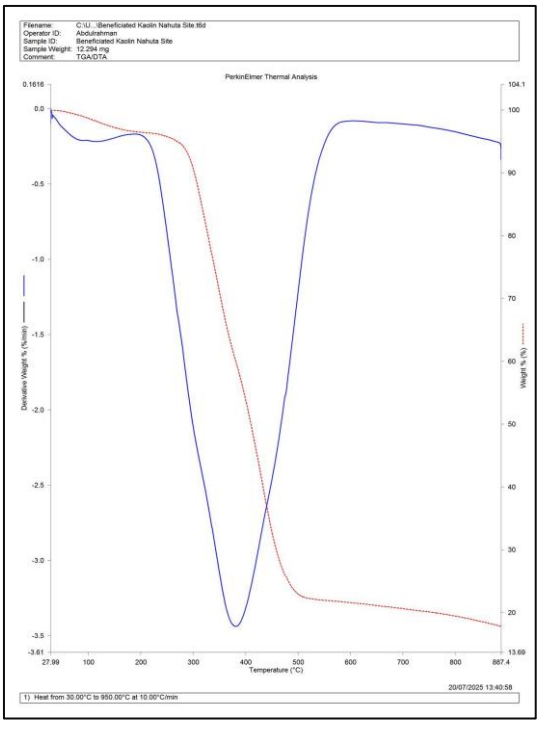


Figure 9 Thermogravimetric Analyses (Beneficiated Kuba site)

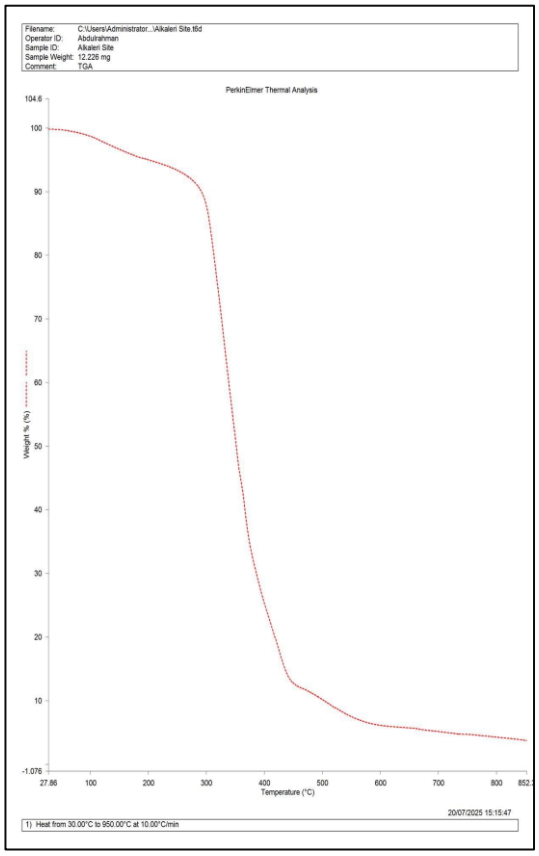


Figure 10 Differential Thermal Analyses (Beneficiated Kuba site)

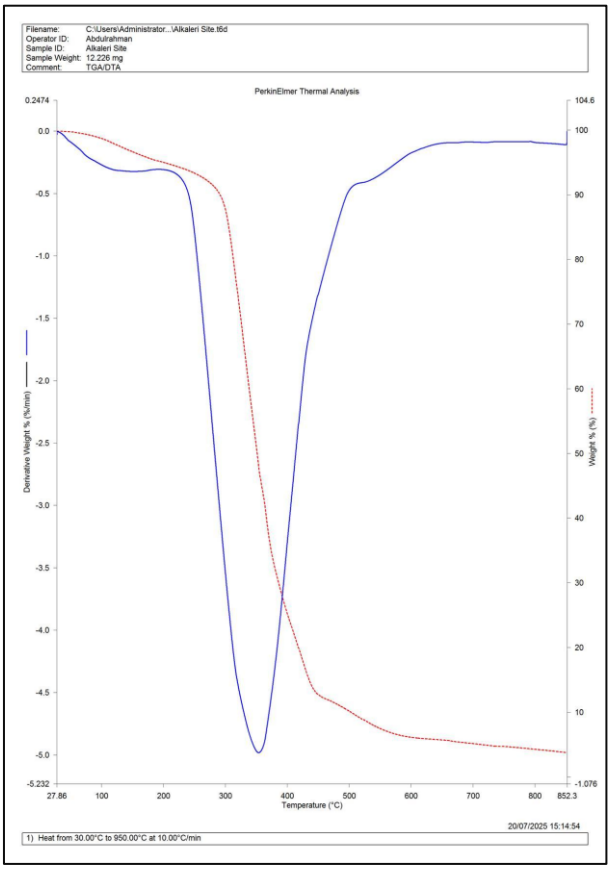


Figure 11 Thermogravimetric Analyses (Alkaleri site)

Figure 12 Differential thermal Analyses (Alkaleri site)

Based on the Differential Thermal Analysis (DTA) results obtained for the kaolin samples from Alkaleri, Kuba, and Itobe sites, as seen in Figure 5, 10 and 12, a comparative evaluation was conducted to assess their thermal behaviour and viability for producing evaporating dish. The DTA curves for the three samples provided insights into their endothermic and exothermic reactions as a function of temperature, which are critical in evaluating their suitability for ceramic applications, particularly under high thermal conditions. The endothermic peaks observed in the thermal curve indicate heat absorption associated mainly with dehydration and dehydroxylation of kaolinite. In contrast, the exothermic peak signifies heat evolution due to structural reorganization and crystallization of high-temperature phases, particularly mullite. Overall, the predominant thermal reaction in the studied kaolin is endothermic, owing to the dominance of dehydroxylation process. A more recent study by Iriate *et al*. (2025) further confirms that the dominant thermal transformation in kaolinite is the endothermic dehydroxylation step where kaolinite converts to metakaolin and loses structural hydroxyl groups. A good corroboration comes from Chakraborty (2003) who studied kaolinite thermal decomposition using DTA in the mullite formation region. He reported that kaolinite shows two endothermic peaks at 120℃ (Removal of physical absorbed moisture), 550-650℃ (Dehydroxylation of kaolinite) and exothermic peaks at 980℃ (Crystallization of Al-Si spinel phase, and at 1250℃ (Mullite formation).

The DTA curve for each kaolin sample revealed characteristic thermal transitions associated with dehydration, dehydroxylation, and possible phase transformations. All samples displayed prominent endothermic peaks between approximately 100 °C and 650 °C, typically corresponding to the loss of physically adsorbed water and structural hydroxyl groups from kaolinite, leading to the formation of metakaolinite. According to Iriarte *et al*. (2025), the removal of structurally bound hydroxy (-OH) groups from the kaolinite lattice during heating, usually within 450 - 650℃ (dehydroxylation) was a trend observed consistently across the three datasets. The

presence of a sharp and well-defined endothermic peak withing 450 - 650°C indicates a relatively well- ordered kaolinite structure with medium-to-high crystallinity, as the dehydroxilation reaction occurs over a narrow temperature interval. This structural order enhance uniform thermal decomposition, minimizes differential shrinkage during firing, and supports homogenous mullite precursor formation, thereby enhancing the thermal reliability and resistance to thermal shock required for ceramic wares such as evaporating dish. Overall, the combined TGA/DTA analysis confirms that all samples exhibit characteristic kaolinite thermal behaviour, with the beneficiated Kuba sample demonstrating superior thermal properties for high ceramic application such as evaporating dish.

3.1.5 Atterberg Limit and Hydrometer Analyses

From the results of the hydrometer analysis and Atterberg limits test of the three kaolin sites (Itobe, Alkaleri, Beneficiated Kuba), the particle size distribution and plasticity characteristics of the clay samples have been critically analysed in relation to standard benchmarks for ceramic-grade kaolin and their suitability for evaporating dish production. A benchmark for ceramic-grade kaolin with a plasticity index within 15-25% is considered most suitable for evaporating dish production because it provides sufficient workability for shaping while minimizing excessive drying, shrinkage and crack formation Andrade *et al*. (2011).

The Casagrande plasticity chart presented in Figure 13 shows that the kaolin samples from Itobe, Alkaleri, and Kuba plot predominantly above the A-line within the clay domain, confirming the dominance of fine clay-sized particles and the absence of significant organic matter. This classification is characteristic of kaolinite clays with sufficient cohesive behaviour required for ceramic forming operation. The liquid limit, defined as the minimum moisture content at which a soil or clay changes from plastic to a liquid state and begins to flow under its weight, plasticity limit is defined as the lowest moisture content at which a clay or soil can be rolled into threads (usually 3mm diameter) without crumbling, and plasticity index is defined as PI = LL – PL where LL = Liquid limit, PL = Plastic limit, PI = Plasticity Index. These were determined across the three kaolin sites as shown in Tables 4 – 6.

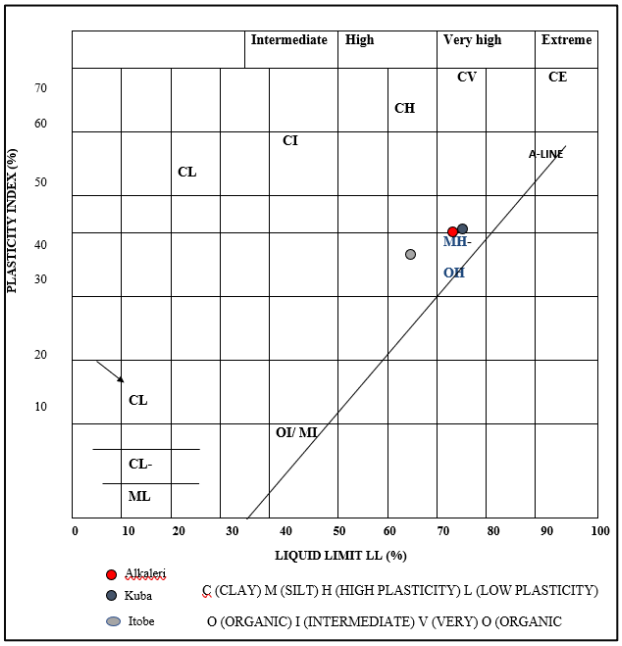


Figure 13: Casagrande A- Line plasticity chart showing soil classification of Kaolin samples from, Akaleri, Kuba and Itobe sites.

Table 7 shows Atterberg limits of kaolin classification, while Table 8 shows its suitability for laboratory dish production.

Table 4: Liquid and plastic Limits of Itobe Kaolin

Test/No.	1	2	3	4	5	6
Type of test	LL	LL	LL	LL	PL	PL
No. of blows (liquid limit test)	11	18	32	45	-	-
Container No.	019	020	021	022	023	024
Mass of wet soil +container (g)	88.70	82.09	88.38	88.47	41.77	44.63
Mass of dry soil +container (g)	53.62	52.58	56.26	57.50	33.47	35.72
Mass of container (g)	7.80	7.82	8.00	8.00	7.81	7.80
Mass of moisture (g)	35.08	29.51	32.12	30.97	8.30	8.91
Mass of dry soil (g)	45.82	44.76	48.26	49.50	25.66	27.92
Moisture content (%)	76.56	65.93	66.56	62.57	32.35	31.90

Liquid Limit (%):66 .2 **Linear Shrinkage** (%):14
Plastic Limit (%): 32.1 **Soil Classification: Inorganic Clay of High Plasticity**.
Plasticity index (%):34.1

Table 5: Liquid and plastic Limits of Alkaleri Kaolin

Test/No.	1	2	3	4	5	6
Type of test	LL	LL	LL	LL	PL	PL
No. of blows (liquid limit test)	12	17	22	35	-	-
Container No.	037	038	039	040	041	042
Mass of wet soil +container (g)	90.56	93.67	93.46	85.61	46.42	47.43
Mass of dry soil +container (g)	52.45	55.74	56.93	53.67	36.79	37.63
Mass of container (g)	8.00	8.10	8.00	7.90	7.81	7.81
Mass of moisture (g)	38.11	37.93	36.53	31.94	9.63	9.80
Mass of dry soil (g)	44.45	47.64	48.93	45.77	28.98	29.82
Moisture content (%)	85.74	79.61	74.66	69.78	33.23	32.86

Liquid Limit (%):73.8 **Linear Shrinkage** (%):14 **Plasticity index (%)**: 40.7
Plastic Limit (%): 33.1 **Soil Classification: Inorganic Clay of High Plasticity.**

Table 6: Liquid and plastic Limits of Beneficiated Kuba Kaolin

Test/No.	1	2	3	4	5	6
Type of test	LL	LL	LL	LL	PL	PL
No. of blows (liquid limit test)	12	21	34	41	-	-
Container No.	007	008	009	010	011	012
Mass of wet soil +container (g)	86.62	81.66	78.62	92.51	47.43	48.41
Mass of dry soil +container (g)	50.65	49.33	48.76	58.36	37.95	38.66
Mass of container (g)	8.00	8.00	8.00	8.00	8.00	8.00
Mass of moisture (g)	35.97	32.33	29.86	34.15	9.48	9.75
Mass of dry soil (g)	42.65	41.33	40.76	50.36	29.95	30.66
Moisture content (%)	84.33	78.22	73.26	67.82	31.65	31.80

Liquid Limit (%): 74.0 **Linear Shrinkage** (%):15
Plastic Limit (%): 31.6 **Soil Classification**: **Inorganic Clay of High Plasticity.**
Plasticity index (%): 42.4

Table 7: Atterberg Limits of Kaolin Samples Classification

Sample	LL (%)	PL (%)	PI (%)	LS (%)	Plasticity Classification
Alkaleri	73.8	33.1	40.7	14	CH (High Plasticity Clay)
Beneficiated Kuba	74.0	31.6	42.4	15	CH (High Plasticity Clay)
Itobe	66.2	32.1	34.1	14	CH (High Plasticity Clay)

Table 8: Suitability for Laboratory Evaporation Dish Production

Sample Site	Clay Suitability	Plasticity Suitability	Shrinkage Risk	Overall Suitability for Evaporating Dish
Alkaleri	Good	High	Low	High (post-beneficiation)
Beneficiated Kuba	Excellent	Very High	Moderate	Very High
Itobe	Moderate	Adequate	Low	Moderate

IV.CONCLUSION

This study comparatively characterized Kaolin deposits obtained from Itobe (Kogi State), Alkaleri (Bauchi State), and Kuba (Plateau State), Nigeria, with the aim of evaluating their suitability for ceramic laboratory ware applications, particularly laboratory evaporating dish production. The integrated results from mineralogical, chemical, thermal and microstructural analyses confirm that all three samples possess the fundamental characteristics of Kaolinite clay, although with notable site-dependant variations in purity, crystallinity, particle morphology. Among the investigated samples, the beneficiated Kuba kaolin exhibited the highest level of refinement and compositional uniformity, attributable to impurity reduction during beneficiation.

The Alkaleri sample demonstrated a relatively well-ordered plate-like morphology and favourable thermal behaviour, indicating good structural integrity during firing, while the Itobe kaolin showed satisfactory plasticity and acceptable ceramic-forming characteristics, making it suitable for shaping operations. The comparative assessment revealed that the three kaolin samples fall withing the performance range required for ceramic-grade raw materials, particularly in terms of plasticity, thermal reliability, and microstructural stability after firing. However, the beneficiated Kuba sample showed superior overall suitability, followed by Alkaleri and Itobe, due to its enhanced purity, reduced accessory minerals, and improved expected fired performance. Overall, the findings establish that kaolin deposits from these Nigerian sites represent valuable indigenous raw materials for local production of laboratory evaporating dish and related ceramic wares, thereby supporting import substitution, value addition to local mineral resources, and sustainable development of Nigeria's ceramic materials sector.

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AUTHOR(S) CONTRIBUTIONS

Kamtu M. Peter undertook Supervision, methodology, validation, writing review and editing, manuscript review, Silas Gabriel Onuche undertook conceptualization, methodology, investigation, data collection, formal analysis, validation, visualization, project administration, resources, writing original draft and writing and editing while Hamisu Mohammed undertook supervision, validation, writing review and editing, manuscript review and project oversight.

AI DISCLOSURE

Artificial Intelligence tools were used solely to assist in language refinement, grammar checking, formatting, and manuscript editing during the preparation of this study. Specifically, Google AI tools were utilized to improve the clarity and presentation of the manuscript. The authors reviewed, verified and approved all content generated or modified with AI assistance and take full responsibility for the accuracy, integrity and originality of

the work. AI tools were not involved in the conceptualization, data analysis, interpretation of results or the final scientific conclusions of the study.

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DECLARATION OF CONFLICT OF INTEREST

Authors have no conflict of interest to declare

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