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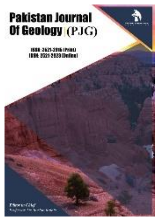

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RESEARCH ARTICLE

GEOTECHNICAL AND MINERALOGICAL ASSESSMENT OF GERINYA CLAYS WITHIN THE PATTI FORMATION, SOUTHERN BIDA BASIN, NIGERIA

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ABSTRACT

Clay is predominant in most subgrade soils of Nigeria and it has found wide application in engineering construction due to its relative abundance coupled with the ease of acquisition. Therefore, there is the need to ascertain the geotechnical behaviour of these clays especially the Gerinya clays within the Patti Formation, Southern Bida Basin, Nigeria for their construction and industrial suitability. The Gerinya clays samples were examined for their geotechnical properties such as; specific gravity, Atterberg's limit, grain size analysis, shear strength and mineralogical analysis (X-ray diffraction (XRD)). The Gerinya clays liquid limit ranges from 46% to 56%, the plastic limit ranges from 16.95% to 29.10% and the plasticity index ranges from 20.20% to 35.40%. The specific gravity ranges from 2.55 to 2.70, while the angle of internal friction and cohesion ranges from 13^0 to 20^0 and 31 KPa to 48 KPa respectively. Kaolinite was identified as the clay mineral in the Gerinya clays ranging from 22.34 to 67.61 wt% and quartz is the dominant non-clay mineral in the Gerinya clays. The other non-clay minerals are muscovite, anatase and rutile. The Gerinya clays samples exhibit intermediate to high compressibility and medium to high plasticity. The shear strength reveals that the Gerinya clays has a low bearing capacity. The Gerinya clays are not suitable for construction since they will cause problems when employed as sub-base or sub-grade materials. However, the clays can be employed as raw materials for bricks manufacturing and landfill liners in a waste disposal facility.

KEYWORDS

Clays, geotechnical behaviour, inorganic soils, landfill liners, X-ray diffraction (XRD)

1. INTRODUCTION

Clays are fine-grained soils with small particles sizes (< 0.002 mm) and they can be formed from weathering/disintegration of primary rock-forming minerals (Ehibor et al., 2019). Furthermore, fine-grained soils (clays) are made up of either single or mixed layered clay minerals (kaolinite, montmorillonite, illite) with other minerals (quartz, muscovite, carbonate, and metal oxides) that are of clay-sized crystals (Oyetade et al., 2021). The mineral composition of clays plays a key role in their mechanical behaviour and suitability. In addition, the stability and firmness of civil engineering structures/buildings are contingent on the soil characteristics for example shear strength, hydraulic conductivity, and compressibility of the soil (Thian and Lee, 2014). When an expansive soil (clay) becomes wet and expands, it can produce uplift against rigid concrete slabs and foundation footings, resulting in a range of engineering structure damages (Murali et al., 2018). Failure in soils occurs when the shear stress exceeds the shears' strength. Therefore, the strength of soils provides safety for structures emplaced on them. The interactions between clay particles and water greatly determine the behaviour of the soils, such that clays that attract more water molecules to their surfaces will exhibit high plasticity, swelling/shrinkage and volume changes depending on the load placed on them (Ural, 2018). Ultimately the change in clay plasticity directly affects the mechanical behaviour of the soils. Volume change experienced by clays can cause damage to the concrete foundation, floor slabs and the entire structure (Murali et al., 2018).

In Nigeria, clay is predominantly subgrade soil, and it has found widespread use in engineering construction/structure projects due to its relative abundance coupled with the ease/cheapness of acquisition (Oyediran and Durojaiye, 2011). Therefore, clay-rich soils and rocks serve as the foundation for transportation routes and structures. These clays materials could pose a considerable risk to engineering buildings because of their capacity to shrink and swell with changes in water content (Ural, 2018). Construction and road failures have been reported in Lokoja, Kogi State, Nigeria and the Lokoja highway pavement failure has been described as a result of low resistivity weather layer (clay) and some other parameters, which has led to the loss of lives, revenue and investments (Ibitomi et al., 2014; Vanguard Nigeria, 2021). Therefore, there is a need for detailed geotechnical and mineralogical evaluations of all the soils in this environment (Lokoja) before any construction activities are being embark on. The studied clay is located in Gerinya, Lokoja, Kogi State, Nigeria. This study was done to carry out a careful pre-use assessment of the geotechnical properties of Gerinya clays to determine their suitability for use as construction materials and their mineralogical composition to identify the mineral-type present in the clays as well as their proportion to understand their mechanical behaviour.

2. DESCRIPTION OF THE STUDY AREA

The study area is Gerinya, part of Kogi State located within the Southern Bida Basin at latitude N 08^0 14' 44.2'' and longitude E006^0 45' 54.9'' (Figure 1). The area lies within the Tropical Hinterland Climatic zone (about 150-240 km northwards from the coast) with an annual rainfall of 1000 to 1500mm. Also, it lies within the rainforest belt of Nigeria, characterized by two distinct seasons; the rainy season and the dry season. The wet season within the study area runs from March through October,

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while the dry season extends from November to February. The study area has a mean temperature range of 27-28^{0}C and the relative humidity ranges between 50-80%. The vegetation of the study area consists mainly of tropical forest/rainforest tree species such as oil palm and food crops.

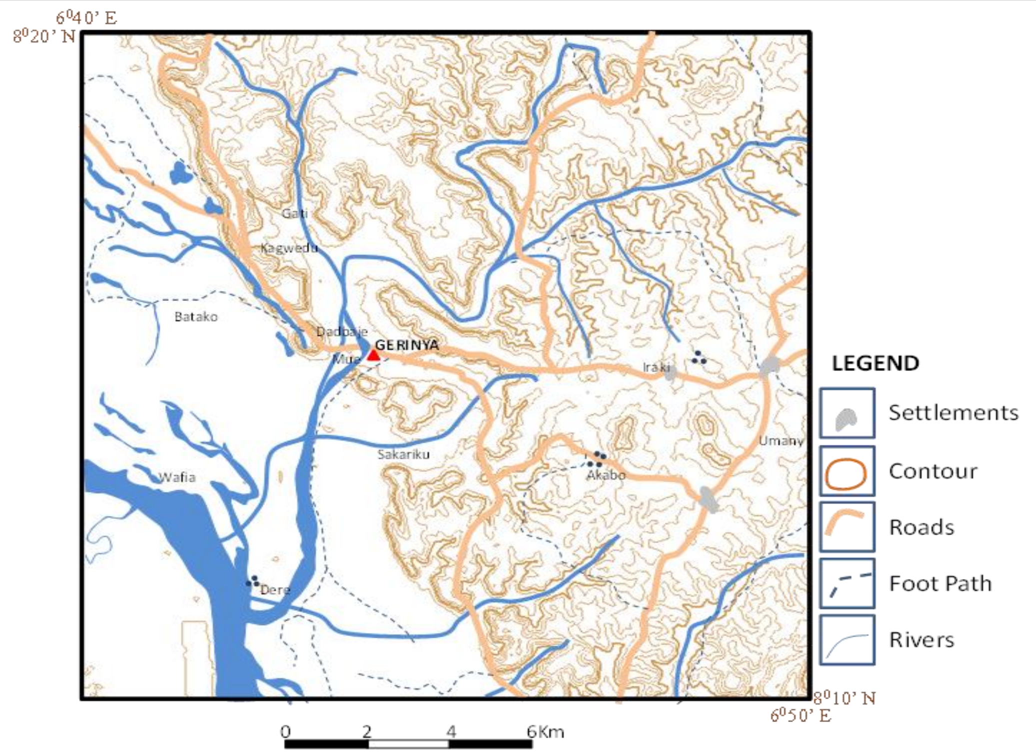

Figure 1: Map of the study area and locations of the investigated exposure (Oyetade et al., 2021)

2.1 Geology Settings

The Bida Basin is a northwest-southeast trending intracratonic sedimentary basin in Nigeria that stretches from Kontagora to locations just beyond Lokoja (Obaje, 2009). The Bida Basin is separated into two stratigraphic sub-basins: Northern and Southern Bida Sub-Basins (Figure 2). Infills into the basin comprise of Upper Cretaceous sediments that were deposited as a product/result of block faulting, basement fragmentation, subsidence, rifting and drifting trending north-west, consequent to the Cretaceous opening of the South Atlantic Ocean (Obaje 2009). There are four distinct and mappable stratigraphic units within the Bida Basin namely, Bida Sandstone, Sakpe Ironstone, Enagi Siltstone, and Batati Formation (argillaceous, oolitic and geothitic ironstone with ferruginous claystone, and siltstone intercalations, as well as shaley beds (Figure 2). In the southern Bida Sub-Basin exposure of sandstones and conglomerates of the Lokoja Formation directly overlies the Pre-Cambrian to Lower Paleozoic basement gneisses and schists. The Lokoja Formation is overlain by the alternating shales, siltstones, claystones and sandstones of the Patti/Ahoko Formation within the Koton-Karfi and Abaji axis. The formation was later succeeded by the claystones, concretionary siltstones and ironstones of the Agbaja Formation (Obaje, 2009).

3. Materials and Methods

3.1 Sample Collection and Preparation

Bulk disturbed samples were taken from clay exposures within the study area (Figure 3). These disturbed samples were obtained using a hand trowel and placed into a well-labelled sample bag. The samples were crushed, air-dried and subjected to laboratory tests that include; particle size distribution analysis, consistency limits, specific gravity, and shear strength. The samples were air-dried to attain reliable results because some clay materials experience irreversible changes when oven-dried at a temperature of 100 °C to 110 °C.

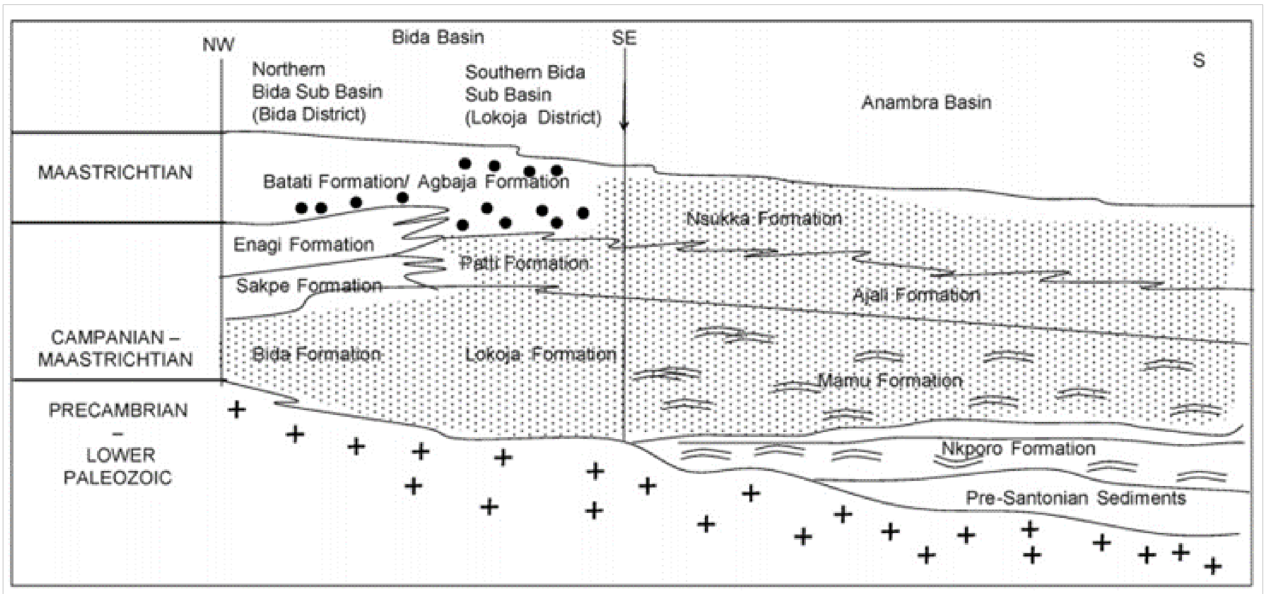

Figure 2: Stratigraphic succession in the Bida Basin and correlation with adjacent Upper Cretaceous successions Anambra Basin (Ojo and Akande, 2009)

Figure 3: A typically claystone exposure at Gerinya

3.2 Laboratory Analysis

All the procedures adopted for the tests were in accordance/conformity with the British Standard 1377. The specific gravity of the samples was measured/determined using the pycnometer method, while the sieve analysis and hydrometer methods were used to study the particle size distribution of the samples. Consistency limits, which include a liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) were all determined using the Atterberg tests. The consistency/reliability limits were performed on air-dried soil samples passing through the British standard sieve no. 40 (slot size of 0.425 mm). The Casagrande method was used for LL tests, and shear strength parameters/values (cohesion (Cu) and angle of shearing resistance ($Ø^0$) were obtained using the direct shear test. The direct shear test begins with compacted samples positioned inside the shear box under loading blocks weighing 5kg, 10kg, 15kg and 20 kg respectively. Readings were measured/determined using the deformation dial gauges. The mineralogy of the samples was determined at the University of Pretoria using the X-Ray diffraction (XRD) method. Powdered samples were illuminated with X-rays of a fixed wavelength and the intensity of the reflected radiation was recorded using a goniometer.

3.3 Data Interpretation

The inter-atomic spacing (D value in angstrom's units- 10-8cm) is then calculated by analyzing the data for the reflection angle. The intensity (I) is determined to differentiate the various D-spacing and the outcome/results were used to find possible matches. The plasticity index is plotted against the liquid limit on a Casangrande classification chart using Grapher-10 software.

4. Result and Discussion

4.1 Geotechnical Evaluation

4.1.1 Specific Gravity

The specific gravity of soil gives an idea about the suitability of the soil as a construction material. The value of the specific gravity of the samples ranges from 2.55 to 2.70 with a mean value of 2.65 (Figure 4). The higher the specific gravity, the better it is for construction usage/purposes. Previous studies have indicated that soils with low specific gravity (< 2.65) are usually weak and potentially non-durable (Reidenoeur, 1970). Based on the specific gravity result, the samples are expected to be strong and durable and therefore can be used as subgrade material for low load construction. Specific gravity is closely linked with the mineralogical, chemical composition and degree of weathering (Oyediran and Fadamoro, 2015).

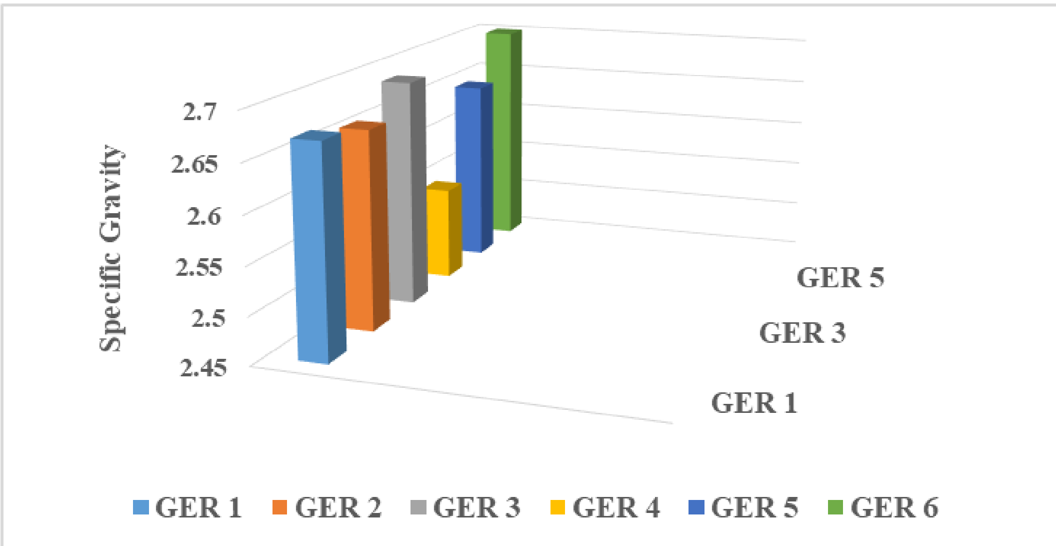

Figure 4: Specific gravity values of Gerinya clays

4.1.2 Atterberg Limits

The water content of fine-grained soil has a significant impact on its consistency. Results from the study show that the liquid limit ranges from 46.00% to 56.00%, while the plastic limit and plasticity index range from 16.95% to 29.10% and 20.20% to 35.40% respectively. According to the Casangrande classification system for fine-grained soils, the samples will exhibit intermediate to high compressibility (Tables 1 and 2). The

Casagrande chart classification (Figure 5) also shows that the clays are of medium to high plasticity and hence compressibility. The soils can be said to be inorganic plastic clays since they all fall above the A-line. The samples within the study area were deemed suitable as a lining material based on the relationship developed between the plasticity of clays to suitability as shown in Figure 5 (NRA, 1989).

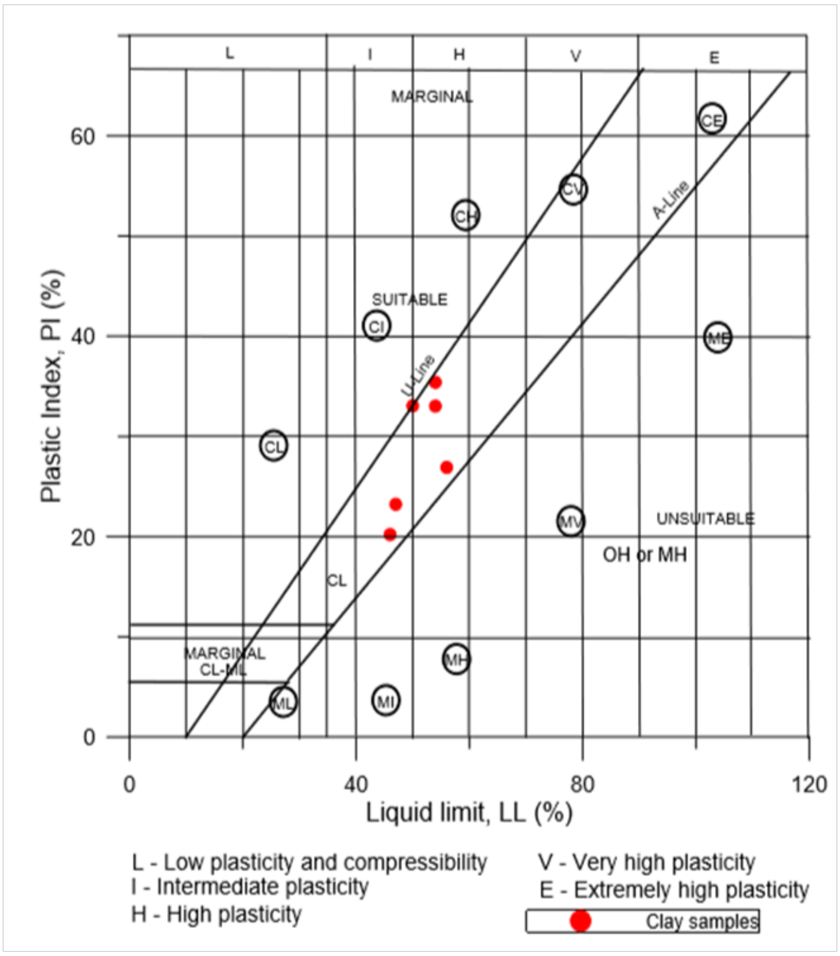

Figure 5: Casangrande chart classification of Gerinya clays

Table 1: Classifications for Fine Grained Soils

Casangrande Classification		Holtz and Gibbs (1956) Volume Changes			Holland (1981) Potential Volume Changes		
		Plasticity Index	Shrinkage Limit	Volume Changes	Plasticity Index	Shrinkage Limit	Potential Volume Changes
LL < 35%	Low Compressibility	0-30	>12	Little	0-30	0-12	Little
35 < LL ≤ 50%	Medium Compressibility	30-50	10-12	Moderate	30-50	12-18	Moderate
LL > 50%	High Compressibility	>50	<10	High	>50	>18	High

LL: Liquid limit

Table 2: Consistency Limit for Gerinya Clay Samples

Location	Code	Consistency Limit				Casangrande Classification	Holtz and Gibbs (1956)	Potential Changes
		Liquid limit	**Plastic Limit**	**Plasticity Index**	**Shrinkage Limit**			
Gerinya	GER 1	50.00	16.95	33.05	12.90	Intermediate compressibility	Moderate	Moderate
	GER 2	56.00	29.10	26.90	13.50	High compressibility	Little	Low
	GER 3	47.00	23.78	23.22	14.30	Intermediate compressibility	Little	Low
	GER 4	46.00	25.80	20.20	15.10	Intermediate compressibility	Little	Low
	GER 5	54.00	18.60	35.40	12.60	High compressibility	Moderate	Moderate
	GER 6	54.00	20.98	33.02	12.60	High compressibility	Moderate	Moderate

Further, the samples within the study area will likely undergo little to moderate volume changes based on classification as a result of the approximate relationship between the volume change, shrinkage limit and plasticity index (Holtz and Gibbs, 1956). However, other classification has revealed that the sample will exhibit low to medium potential volume changes (Holland, 1981). It is observed that the findings using these classifications were similar and the only difference lies in the terminology employed.

4.2 Grain Size Analysis

A summary of the particle size distribution/spread and the corresponding curve reveals that the samples contain low amounts of sand-sized particles with a mean value ranging from 0.8% to 5.8%, while the mean values of fines range from 94.2% to 99.2% (Table 4). When utilized as a sub-base or subgrade material, soils with less than 50% fines are believed to have better engineering qualities, whereas those with more than 50% fines are predicted to cause field compaction difficulties (Oyediran and Williams, 2010). It can be stated that clay samples from the research area will provide field challenges when used as sub-base or sub-grade materials in the construction of roads due to the number of fines present. Furthermore, based on the recommendation by the federal ministry of works and housing specifications for highway construction, the material does not qualify as general filling and embankment materials (FMWH, 1974). Soils with clayey or silty-clay content have been recommended as an important requirement for a waste repository (Elsbury et al., 1990). Clays analysed from the study area have thus met this requirement and are expected to exhibit low permeability. This type of soil also satisfies the requirement proposed by that soil liners should have at least 30 % fines and less than 30 % gravel (Daniel, 1993; Benson et al., 1994; Oyetade et al., 2021). The clay samples underlying Gerinya and its environs have high amounts of fines greater than 30 % indicating that they will have a high specific surface and allow less migration of contaminants (Oyediran and Fadamoro, 2015).

4.3 Shear Strength

Shear strength is an essential mechanical parameter in soil characterization. Values of the angles of friction ($Ø^0$) for the clay samples vary from 13^0 to 20^0 while the cohesion ranges from 31 KPa to 48 KPa (Table 4). These values are attributed to the low bearing capacity of the soil.

4.4 Mineralogy

Clay minerals strongly reflect the character of their parent materials and the climatic conditions that existed during their formation (Friedman and Sanders, 1997). The X-ray diffractogram revealed that minerals present in the Gerinya clay are; anatase, muscovite, rutile, quartz and kaolinite (Figure 6a-e). Mesida mentioned that the amount and the type of clay minerals present in soils affect their geotechnical properties (Mesida, 1985). The clay mineral present in the samples analysed was found to be kaolinite (22.34 – 67.61%) and it is the most abundant in composition (Table 5). This mineral makes the soil less reactive unlike soils composed of the montmorillonite group. The presence of Kaolinite may be attributable to the weathering of feldspars present in the parent material.

Table 3: Particle Size Distribution of Gerinya Clay Samples

Location	Code	Particle Size Distribution			
		% Sand	**% Silt**	**% Clay**	**% Fines**
Gerinya	Ger 1	0.8	15.2	84.0	99.2
	Ger 2	1.8	18.2	80.0	98.2
	Ger 3	4.8	15.2	80.0	95.2
	Ger 4	5.8	25.2	69.0	94.2
	Ger 5	2.8	24.2	73.0	97.2

Table 4: Shear Strength for the Studied Gerinya Clay Samples

Location	Code	Shear Strength	
		Cohesion (KPa)	**Angle of Internal Friction ($Ø^0$)**
Gerinya	Ger 1	48	16
	Ger 2	38	14
	Ger 3	48	18
	Ger 4	34	13
	Ger 5	31	20
	Ger 6	47	15

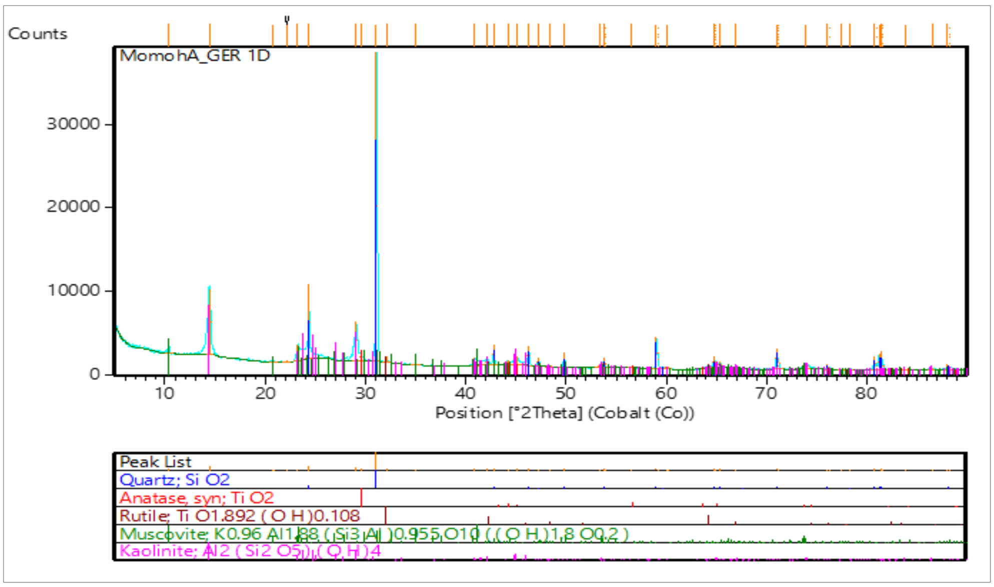

Figure 6a: X-ray diffractogram for GER 2

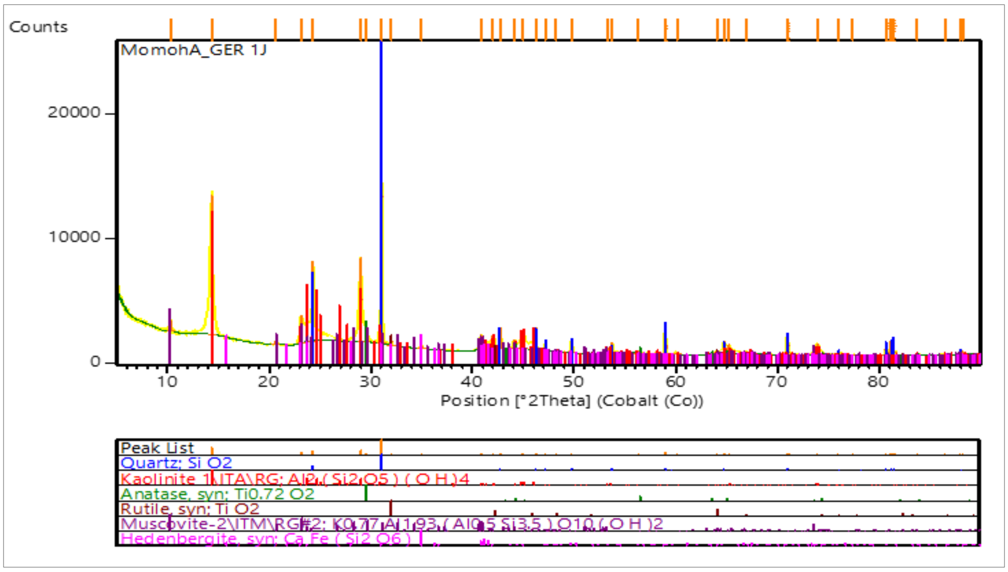

Figure 6b: X-ray diffractogram for GER 3

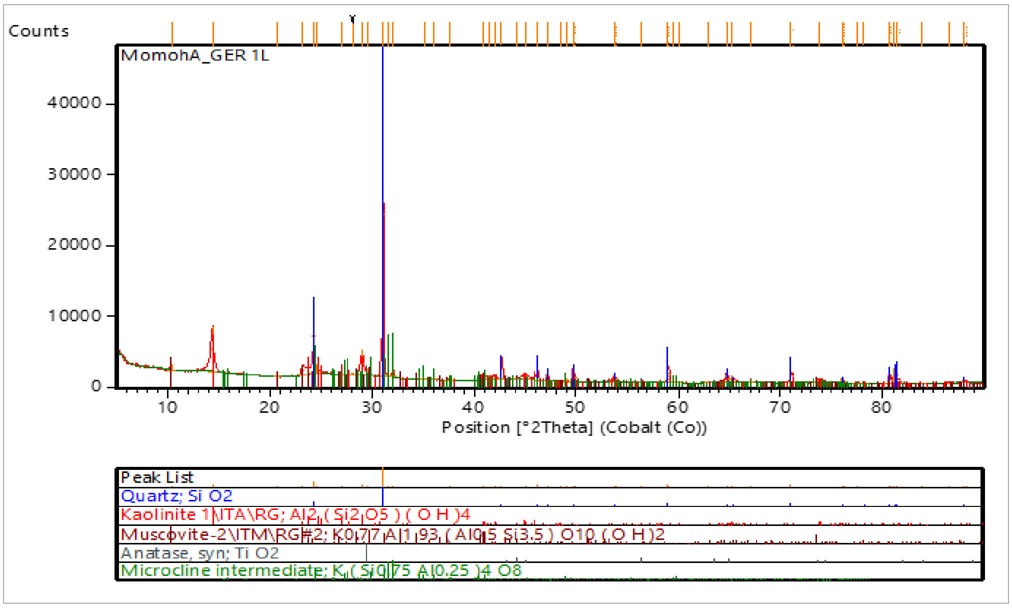

Figure 6c: X-ray diffractogram for GER 4

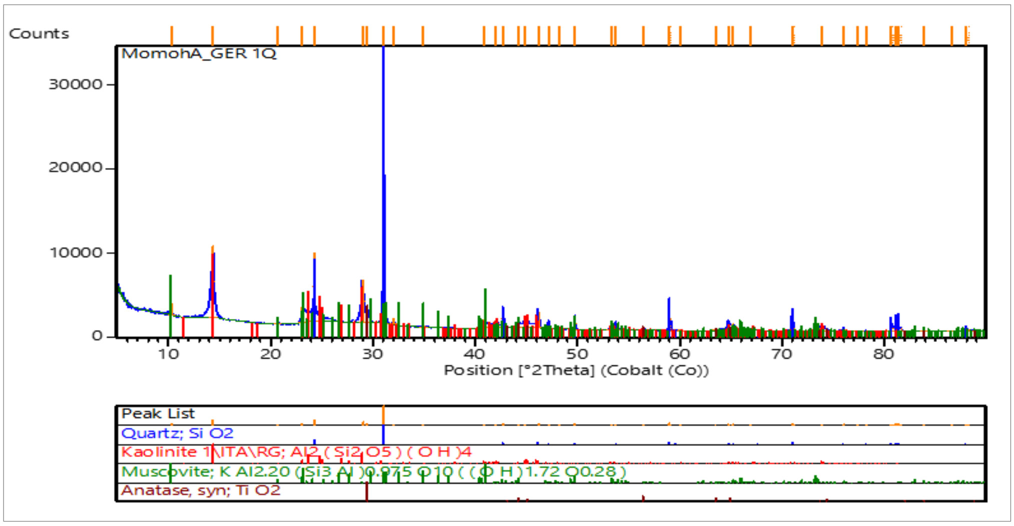

Figure 6d: X-ray diffractogram for GER 5

The abundance of kaolinite indicates that the Gerinya clays will possess a low affinity for water with greater stability and confining ability. It also implies that the clay will exhibit low to moderate shrinkage on drying and low to moderate expansion on wetting (Oyediran and Olalusi, 2017). According to the presence of kaolinite as the predominant clay mineral suggests that the Gerinya clays are sediments from the fluvial environment, which also supported the research of that the Gerinya clays are of low energy floodplain/interchannel depositional environment (Weaver, 1960; Oyetade et al., 2021). Also, the presence of quartz in significant amounts gives strength and durability hence making the soil a suitable raw material for bricks. The occurrence of hematite is an indication of the environment of deposition of the soil.

Table 5: Mineralogical Composition of the Studied Gerinya Clay Samples (wt%)

Location	Code	Mineral Content				
		Kaolinite	**Muscovite**	**Quartz**	**Anatase**	**Rutile**
Gerinya	Ger 2	57.20	2.69	35.50	3.78	0.83
	Ger 3	67.61	2.69	21.15	4.87	0.90
	Ger 4	48.56	2.02	39.33	4.43	-
	Ger 5	62.87	2.06	30.51	4.56	-
	Ger 6	22.34	3.86	64.85	5.24	0.57

5. Conclusion

The value of the specific gravity of the samples ranges from 2.55 to 2.70 with a mean value of 2.65, therefore the soil (clay) can only be used as subgrade material for low load construction. The liquid limit ranges from 46.00% to 56.00%, while the plastic limit and plasticity index range from 16.95% to 29.10% and 20.20% to 35.40% respectively. Therefore, the Gerinya clays samples exhibit intermediate to high compressibility and medium to high plasticity. The shear strength reveals that the Gerinya clays as a low bearing capacity. The particle size distribution and the corresponding curve reveal that the samples contain low amounts of sand-sized particles with a mean value ranging from 0.8% to 5.8%, while the mean values of fines range from 94.2% to 99.2%.

Based on the particle size analysis the Gerinya clays are predicted to cause field compaction difficulties and the materials do not qualify as general filling and embankment materials however, the clays can be used as landfill liners in a waste disposal facility. Based on the mineralogical analysis (XRD) kaolinite is the clay mineral present in the examined Gerinya clays, which makes the soil less reactive unlike soils composed of the montmorillonite group. It also implies that the clay will exhibit low to moderate shrinkage on drying and low to moderate expansion. Quartz ranges from 21.15 to 64.85 wt%, the significant amounts of quartz give strength and durability, hence this makes the soil a suitable raw material for brick manufacturing. In summary, the soil within the study area has high clay content hence it will pose a problem for construction purposes as sub-base or sub-grade materials. However, the clays can be employed as raw materials for bricks manufacturing and landfill liners in a waste disposal facility.

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