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Physicochemical and Minerological Evaluation of Clay Deposits in Parts of Buan, Southern Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author BK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ACT and KI managed the analyses of the study. Author KI managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Some clay soil samples from the Buan in parts of the southern Nigeria were analyzed for their geochemical composition, mineralogy and geotechnical characteristics. This research was carried out using modern methods of analysis such as Index properties tests, x-ray fluorescence analysis and x-ray diffraction analysis to determine the physicochemical, elemental composition and mineralogical nature of the clay. The moisture content of the sample fall between 23.6% to 67.79%, the atterberg limits values fall between 20.8% to 51.5%, the activity series show normal clay to active clay, the swelling potentials for the samples show low to high swelling potential, the linear shrinkage of the soil fall between 5.35% to 16.40%, the particle size distribution (PSD) curve for samples L1, L5 and L10 shows a high percentage of sand (58-75%) and a relatively lower percentage of the clay sizes (12-19%). The pH of the samples tested gave relatively high acidity of between 4.7 and 5.9, compared to the typical range of pH of Nigerian soils of 4.8 – 6.9. The XRF study showed that silica and alumina were predominantly in the analyzed samples, with weight ranging from 42.4 to 57.8% and from 9.7 to 28.3% respectively. Alkali oxides Na_2O, CaO and K_2O occurred in subsidiary amounts. A low proportion of alkali metal oxides indicate the possibility of producing refractory products. The XRD results showed that quartz is the dominant mineral while

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clay minerals are in a lower proportion. The properties of these clays make them suitable for use in refractory bricks and in sanitary landfills.

Keywords: Physicochemical; geotechnical; mineralogy; ignition and landfills.

1. INTRODUCTION

Clay occurrences are being discovered and reported from many locations across Nigeria. Some of the clay deposits have also been identified and characterized. Clays are usually identified physically by their white, pink, gray or brown colours; and soft, sticky or greasy feel when they are wet. What constitutes clay as mineral or soil has been determined by many authors, but it is generally accepted, especially among geoscientists, that clay is a general term given to any earth material with particle size less than 0.002mm (2µm).

The term clay is given to materials that have particle size less than 2µm, and to other forms of materials which have chemical compositions and crystal build similar to the clay [1,2]. The physicochemical, geotechnical index properties and other characters exhibited by clay as a soil, mineral or rock, warrant its unending demand for use in the many sectors including those of manufacturing, agriculture, medicine, geotechnical engineering and environmental management. Different varieties of clay exist and so their areas of application vary from one type of clay to another. The purpose of utilizing one type of clay material in a special usage is that, the physical characters and chemical constituents of that clay material, to a great extent, depend on its build and composition. Fundamental soil properties such as cation exchange and shrink – swell properties, as well as practical considerations such as how well a particular soil will attenuate a specific pollutant, or how much fertilizer phosphorus will be fixed and unavailable, are all influenced by molecular-scale differences in soil clay minerals [3]. For instance, the structure and buildup of minerals like smectite, palygorokite, kaolinite, including sepidite, are not similar even if each of them has tetrahedral and octahedral sheets in their structure [4]. Marine clay is microcrystalline in nature. Clay minerals such as kaolinite, chlorite and illite as well as non-clay minerals like quartz and feldspar are present in them [5]. The clay deposits in Buan are spread across the coastal areas and on mud flats around the sea coast, some are also located in streams and low-lying areas across the area.

Lucas et al. [6] studied the clay in the northern depobelt of the Niger Delta and concluded that kaolinite is the dominate clay mineral in the area. Fakolujo et al. [7] had also noticed that clays occur in deposits of greatly varying nature, and that no two separate clay deposits have exactly identical clay types, and frequently different clay samples from same deposit differ, hence the need for thorough investigation of each deposit. The range of applicability/ industrial potential, hence, the economic value of the deposit is invariably influenced significantly by the proportion and clay mineral type, the quantity of the non-clay minerals, content of organic matter in the clay and some other prevailing factors. These factors impart on the physical or geotechnical engineering properties such as grain size distribution, swelling potential and the clay's shrinkage [8], making its characterization paramount to put them in limelight for the various industries to explore more and subsequently exploit them.

The aim of this research is to determine the geotechnical index properties, physicochemical characteristics and mineralogy of some clayey soil deposits in the area for environmental use in construction, industrial application and in waste management.

2. GEOLOGIC SETTING

The Niger Delta's stratigraphy is divided into three main Formations; the lower Akata Formation consisting mainly of shale, the middle Agbada Formation with alternate of sandstone and shale, and the upper sandy Benin Formation. The Akata, Agbada and Benin Formations have an estimated thickness of 7000m, 3700m and 2000m respectively, and they range in geologic age from Tertiary to Recent [9]. The Niger Delta's landmass or geomorphology consists of three zones; the Coastal or Lower delta zone, the Transition or Mangrove zone and the Upper deltaic plain or Freshwater zone [10] (Fig. 2). The clay study samples were obtained from Muisi and Nwideekil sections of Buan which fall within the Transition zone. The study location, Buan, is situated in the southern part of Nigeria. The sample location falls within the coordinates of 4^{o} 35' 20'' and 4^{o} 37' 00'' North and 7^{o} 27' 00'' and 7^{o} 31' 00'' East.

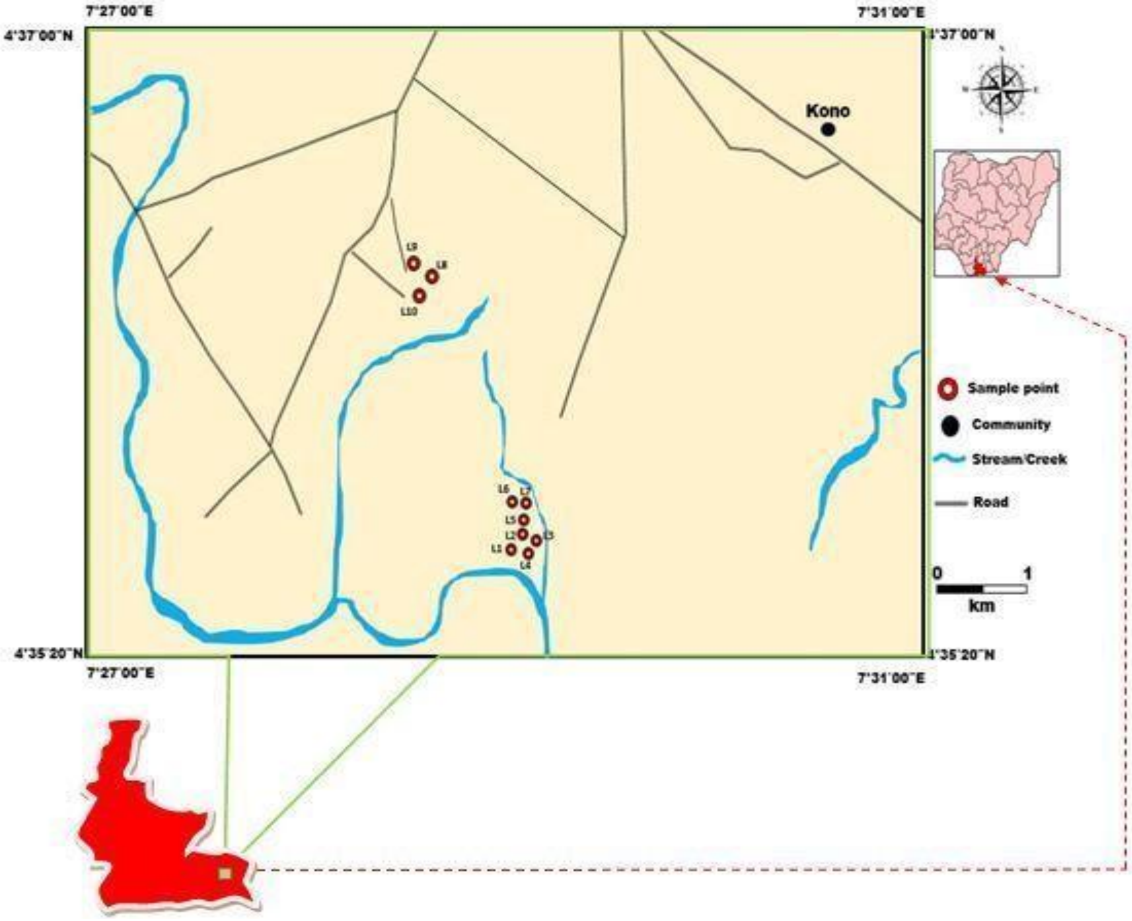

Fig. 1. A study location map showing part of Buan, Southern Nigeria

3. MATERIALS AND METHOD

3.1 Sample Collection

A total of ten clay samples were fetched from the Muisi and Nwideekil sections of Buan in sealed plastic containers to avoid loss of moisture and contamination. All the samples were labeled and visually described at their point of collection before taken to the engineering geology laboratory of the University of Port Harcourt. The ten samples were collected from freshly dug-out surfaces along water inlets using a hand auger.

3.2 Laboratory Analysis

Laboratory analyses were carried out to determine the physicochemical properties, the elemental composition and mineralogical nature of the clay. The laboratory test and testing for the physiochemical properties were carried out according to the procedure stated in [11] and [12]. The samples were later tested for their moisture content, atterberg limits, particle size distribution, rheology, PH and cation exchange capacity, chemical composition and mineralogical constituents. Ten representative samples were taken for moisture content and atterberg limits. The moisture content test was performed following BS 1377:1990 Part 2 Section 3, while the liquid and plastic limits test was also carried out according to guidelines of BS 1377: 1990 Parts Section 4.5 and BS 1377: 1990 Parts Section 5.3 respectively. The grain size analysis was carried out on ten samples using the hydrometer method and guidelines described by BS 1377:1990 Part 2 Section 9. Rheology and pH were carried out on five samples using Brookfield CT3 texture analyzer and pH meter respectively. Cation exchange capacity was carried out on five samples and it was taken when a corona formed around the droplet placed on a filter paper. Five representative samples were chosen from the two locations (three from Muisi and two from Nwideekil sections) and prepared for X-ray fluorescence (XRF) and X-ray diffraction (XRD) analyses. The former was used for the chemical composition, while the latter was used for individual mineral identification.

4. RESULTS AND DISCUSSION

4.1 Description of the Samples

A total of ten samples were obtained from the Muisi and Nwideekil sections of Buan. The clay deposits from the two locations are completely submerged at high tide. The Muisi clay deposit samples possess colours ranging from light to dark gray, and are generally stiffer compared to samples obtained from Nwideekil which are soft. Their descriptions are as summarized in Table 1. Sample points (L9 and L10) from Nwideekil were overlain by thin layers of white sand in a gently-flowing water inlet from adjacent lands of which the direction of flow reverses at the turn of every high and low tide. This layer of sand overlying the clay deposits becomes evident as the samples obtained from there are gritty to touch, and have a high percentage of sand as seen from the grain size analysis. Samples L9 and L10 are fairly white in colour compared to L8 obtained from the same location as them. L8 on the other hand is blackish in colour and have a very soft feel, and is very pliable. The blackish nature of L8 could be due to its high carbon matter content, while L9 appears ferruginous owing to its yellow tint. Samples L1 through L7, from the Muisi section, are relatively similar by their physical characteristics; they are gray, very stiff and less pliable than L8, L9 and L10 from the Nwideekil section (Table 1).

4.2 Index Properties

4.2.1 Moisture content

The moisture content of the samples fell between 23.6% and 67.79%, with L10 having the lowest value of 23.63%, while L8 has the largest value of 67.79% (Table 2). The high moisture content obtained from the results conforms to the generally-accepted high porosity and low permeability properties of clays. As stipulated by Dedan and Paul [13], soils to be used as barrier lining materials should have moisture content less than 90%; which translates to low hydraulic conductivity. However, according to Oluwapelumi [14], the clay’s natural moisture content only helps in determining the amount of water added or removed during compaction, it does not affect its performance as liner. Therefore, all the clay samples could be used as a liner by their natural moisture content. Furthermore, the plasticity index values of L1 and L3 are 30.4% and 28.4% respectively (Table 2). These values are within the range recommended for landfill liner materials in Rahman et al. [15].

Table 1. A physical description of the clay

Sample identity	Location name	Coordinates	Sample description
L1	Muisi	4° 35’ 11.6’’N, 7° 28’ 56.8”E	Very dark gray marine clay with pieces of organic matter overlain by a thin layer of mud.
L2	Muisi	4° 35’ 11.3’’N, 7° 28’ 56.1’’E	Dark yellow marine clay that is covered by thin layer of mud.
L3	Muisi	4° 35’ 12.0’’N, 7° 28’ 57.1’’E	Dark marine clay concealed by a thin layer of mud.
L4	Muisi	4° 35’ 12.5’’N, 7° 28’ 57.2’’E	Dark marine clay containing pieces of plant matter.
L5	Muisi	4° 35’ 13.5’’N, 7° 28’ 57.3’’E	Dark marine clay mottled with lateritic soil containing plant matter.
L6	Muisi	4° 35’ 15.2’’N, 7° 28’ 56.7’’E	Bluish gray marine clay with tints of yellow, evidently, component of ferric oxide.
L7	Muisi	4° 35’ 16.6’’N, 7° 28’ 56.8’’E	Dark yellowish clay mottled with lateritic soil and pieces of ironstone.
L8	Nwideekil	4° 35’ 56.6’’N, 7° 28’ 47.3’’E	Very soft black marine clay containing plant matter and overlain by a thin layer of mud.
L9	Nwideekil	4° 35’ 57.0’’N, 7° 28’ 48.1’’E	Ferruginous soft yellowish clay concealed by a thin layer of white sand.
L10	Nwideekil	4° 35’ 56.5’’N, 7° 28’ 47.3’’E	Very sandy soft white clay that is concealed by a thin layer of white sand, submerged even at low tides.

4.2.2 Atterberg limits

Most of the clayey soil samples plotted above the A-line indicating they are clay. Samples L1 and L8 plotted in the region of CH, indicating clay of high plasticity while other samples fell to the region of CL, showing they are clay of low plasticity except for L10 which fell to the ML region, indicating silt of low plasticity (Fig. 2). These classifications are agreeable with their swelling potentials as the plasticity index tends to high swelling potentials. To a great extent, Atterberg limits can reflect the amount as well as the type of clay minerals in the samples [8]. The range of values of atterberg limit test fell between 20.8% and 51.5%, with L10 having the lowest liquid limit at 20.8% while L8 has the highest value of 83.3% (Table 2). The clay samples could be generally described as being of low to medium plasticity at the range of 10.6% to 55.2%. L8 has a higher plasticity index value of 55.2%. As recommended in Jones et al. [16], soils for landfill liners should have a liquid limit (LL) and plasticity index (IP) less than 90% and 65% respectively, with a clay fraction greater than 10%.

Table 2. The index properties of the clay samples from Buan

Sample	Moisture content (%)	Linear shrinkage (%)	Liquid limit, LL (%)	Plastic limit, LP (%)	Plasticity index (%)	Sample
L1	29.18	10.14	51.50	21.18	30.40	0.41
L2	28.00	10.70	33.00	11.60	21.40	0.35
L3	28.95	10.70	42.00	13.60	28.40	0.32
L4	26.20	5.25	34.50	18.31	16.20	0.53
L5	24.48	9.28	30.00	15.50	14.50	0.51
L6	26.34	7.14	28.00	15.99	12.10	0.57
L7	24.54	6.42	24.70	11.90	12.80	0.48
L8	67.79	16.40	83.00	27.86	55.20	0.33
L9	32.20	9.28	29.00	11.92	17.08	0.41
L10	23.63	6.42	20.80	10.18	10.62	0.48

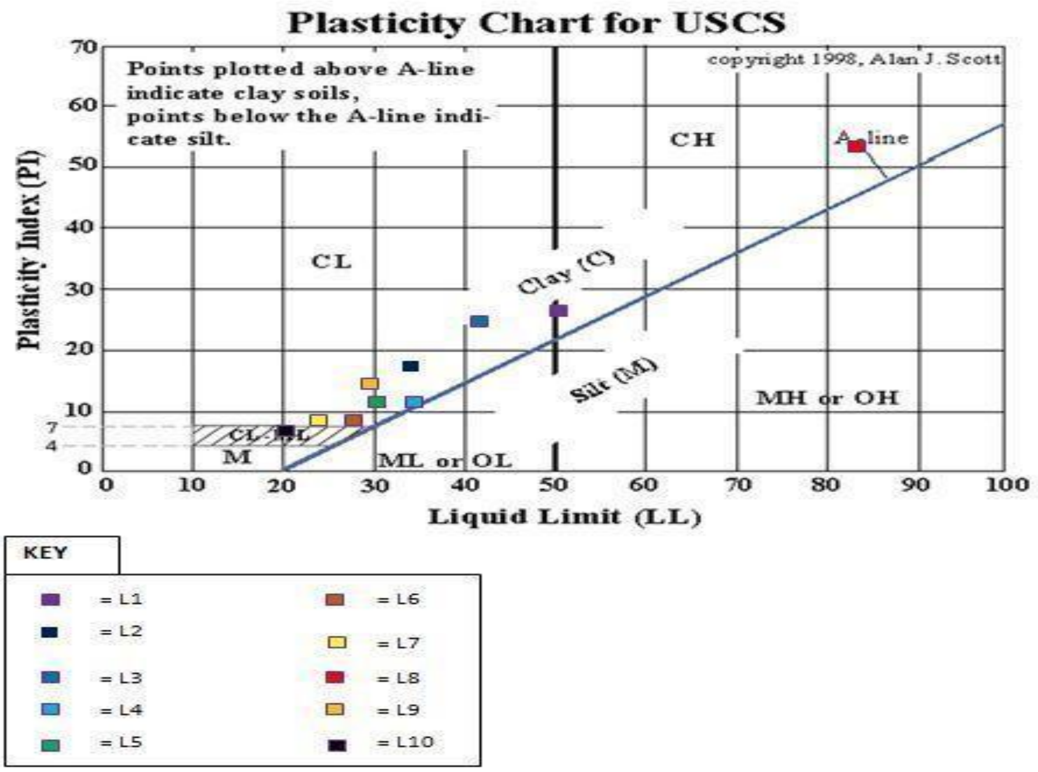

Fig. 2. A plot of Plasticity Index (IP) against Liquid Limit (LL)

4.2.3 Activity, swelling potential and linear shrinkage

The activity, swelling potential and the linear shrinkage of the clays are shown in Tables 3-5. The activity of clay is defined as its capacity or the measure of its ability to hold water. The activity, A, of L5 and L10 were normal at 0.76 and 0.84 respectively, while L1 is described as active at 1.96 (Table 3). The type of clay mineral and the quantity of that mineral that is present in a soil is crucial during classification of fine materials [17]. The swelling potentials of the samples generally portray low to medium, with few exceptions. L5, L6, L7 and L10 have low plasticity index of 14.5%, 12.1%, 12.8% and 10.6% respectively and low swelling potential and so, may be used as sand filling in construction and clay liner material when swelling potential is the main factor for consideration. L2, L4 and L9 having medium plasticity at 21.4, 16.2 and 17.1% respectively, might be unsuitable for sand filling purpose. L1, L3 and L8, with plasticity index of 30.4, 28.4 and 55.2% respectively (Table 4) are not suitable for use as sand filling and as landfill liner materials due to their high swelling potential. The linear shrinkage results of the samples (Table 5) gives the values ranging from 5.35% to 16.40% with L4 having the lowest value of 5.35%, and L8 also having the highest value for linear shrinkage at 16.40%. The shrinkage behaviours of clay soils also help in delineating clay mineral series (montmorillonitic-illitic-kaolinitic), and the shrink/swell potential of a soil deposit [18]. L4, L6, L7 and L10 with lower shrinkage values of 5.35%, 7.14%, 6.42% and 6.42% respectively, may be used as subgrade in road construction. Also, the low shrinkage limit values of samples L4, L6, L7 and L10, indicate thermal stability, and therefore the clay can be processed and used as low refractory furnace lining. Other samples, L1, L2, L3, L5, L8, and L9, may not be too good as they may cause structural failure in construction, and be thermally unstable due to their relatively high swelling potential (Table 4).

4.2.4 Grain size distribution

The grain size distribution analyses of L1, L5 and L10 are as shown in Figs. 3-5. The grain size distribution results deduced from the curve (Fig. 4) reveals that sample L1 is composed of 40% fines, while L5 has 38% fines. Sample L10 has the lowest proportion of fines at 20% (Table 6). L1, with 40% fines, meet the amount required for use as a liner material suggested in [19] and [20]. Soils with high clay and silt content usually exhibit low permeability which is a key factor for consideration when a soil is to be used as liner for sanitary landfill. Kabir and Taha [21] suggested that soils for landfill liners should contain adequate amount of sand, which would provide enough strength and inhibit volume change of the. L10 with 20% fines meet up to Nigeria's Federal Ministry of Works and Housing's specification of ≤20% fines if the soil is to be used as general filling for highway construction [22].

Table 3. Activity series of samples L1, L5 and L10

Sample	Activity	Classification
L1	1.96	Active clay
L5	0.76	Normal clay
10	0.84	Normal clay

Table 4. Swelling potential of the clay samples

Sample	Plasticity index (%)	Swelling potential
L1	30.4	High
L2	21.4	Medium
L3	28.4	High
L4	16.2	Medium
L5	14.5	Low
L6	12.1	Low
L7	12.8	Low
L8	55.2	Very high
L9	17.1	Medium
L10	10.6	Low

Table 5. Linear shrinkage results of L1 through L10

Sample	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Original Length (mm)	140	140	140	140	140	140	140	140	140	140
Dry length (mm)	123	125	125	132	127	130	131	117	127	131
Linear shrinkage (%)	10.14	10.70	10.70	5.35	9.28	7.14	6.42	16.40	9.28	6.42

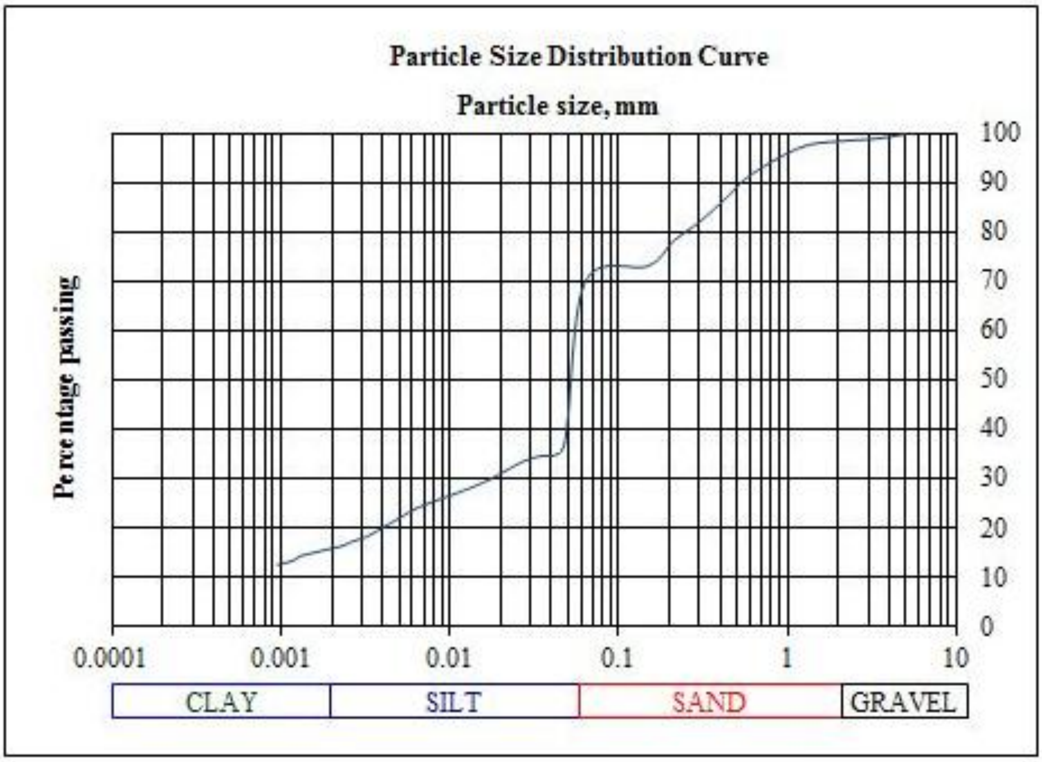

Fig. 3. The grain size distribution curve of L1

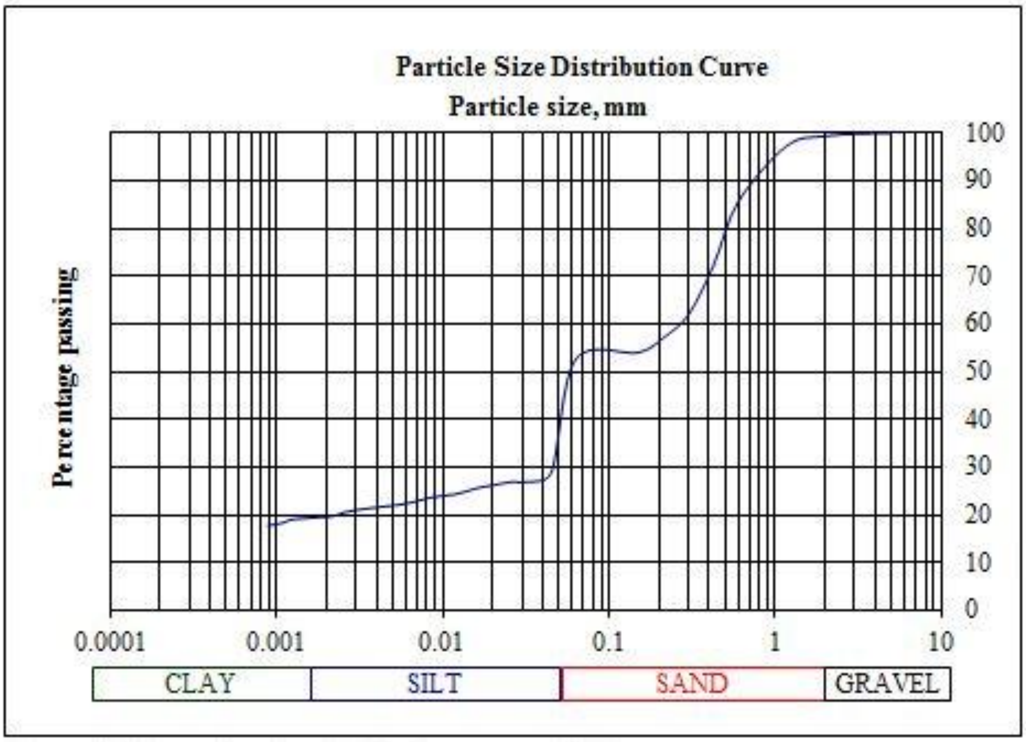

Fig. 4. The grain size distribution curve of L5

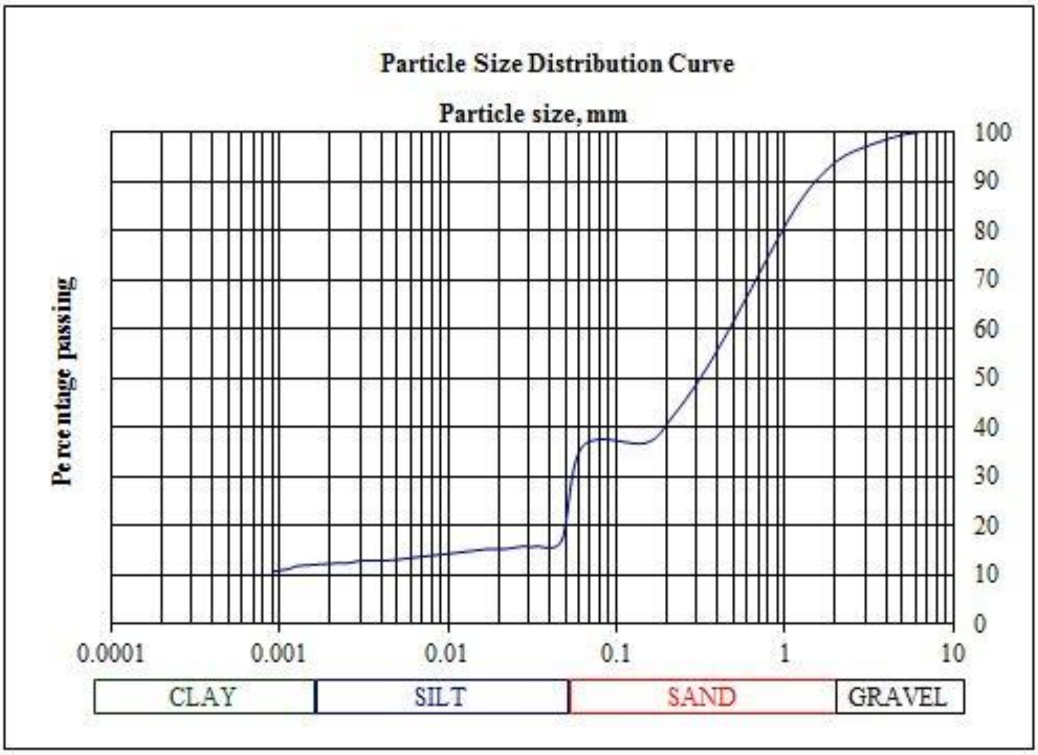

Fig. 5. The grain size distribution curve of L10

Table 6. The grain size distribution summary of L1, L5 and L10

Sample	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Fines (%)
L1	20	15	35	1	35
L5	1	51	39	0	52
L10	10	27	63	5	37

4.3 Rheology and pH

The viscosity of clay is a crucial rheological property measured during its analysis, because it determines the suitability of the clay for use as a raw material demanded by the drilling industry and also industries that produce paper and paint. The adhesive slurry provided by clay improves smooth surface for the paper coating, and this smooth flow relies on the viscosity of the clay material [8]. Yield point depends on the surficial properties of the mud solids and also the concentration of the volume of the solids [23]. The test results reveal that the Buan clay sample has apparent viscosity of between 3.5 and 7.2 poise (Table 7). The plastic viscosity fell within the range of 1.9 and 5.5 poise. Only sample L8, with 5.5 poise of plastic viscosity, met the requirements by the paint industry which has a preferable range from between 5 and 6 poise [8]. The pH measurement of the samples generally showed relatively high acidity (low pH) with values ranging from 4.7 to 5.9 (Table 7). However, a higher pH value gives rise to more negative charge which, in turn, leads to a higher cation exchange capacity value [24]. The Nigerian soil, according to Abii and Nwosu [25], has an acidity of between 4.8 and 6.9. However, the high acidity of some of the samples from this locality, comparing it to the values expected for the soils from other regions of the Nation might have been induced by its proximity to gas-flaring activities around the sample locations [26].However, apart from removing impurities, L1, L5, L7, L8 and L10 could be employed in drilling mud formulation by increasing the pH to between 8.5 and 12.5, and also increasing its specific gravity to meet the American Petroleum Institute standard of 2.83, by adding weighing agent such as barite [27]. The pH is significant because it affects the dispersion of the clay in the mud, and it also affects the organic thinner's solubility [28].

Table 7. Showing rheological properties of some Buan clay samples

Sample	Apparent viscosity (poise)	Plastic viscosity (poise)	Yield point (kN/m2)	Gel strength (KN/2) at 10 secs	Gel strength (KN/2) at 10 mins	Specific Gravity (Gs)	pH
L1	3.8	2.2	2.34	0.86	0.95	2.55	5.9
L5	4.0	2.3	0.81	1.0	1.10	2.65	4.9
L7	4.4	2.6	2.58	0.62	0.72	2.50	4.8
L8	7.2	5.5	4.21	0.67	0.81	2.45	5.3
L10	3.5	1.9	0.96	0.47	0.57	2.60	4.7

4.4 Cation Exchange Capacity (CEC)

The CEC of a soil is the capability of the soil to retain cations from other substances that are in contact with that soil. The quantity of the cations so retained is usually expressed as milli-equivalents/100g (Meq/100g) or centimole/kilogram (cmol/kg) of the soil. Both parameters have equal numerical values. This particular quality of clay becomes paramount when the soils are to be applied in environmental studies as liners in landfill for the containment of hazardous wastes or barring leachate from reaching underground water. The greater the CEC of soil, the greater the potential of the soil to retain many charged waste constituents, and the more effective the soil would be for waste treatment [14]. The cation exchange capacity values of samples L1, L5, L7, L8 and L10 ranged from 11.18 and 26.21cmol/kg (Table 8). The pH of the clay is a key factor for consideration when the CEC of the soil is the prime criterion for the soil's selection for use in landfill liners. Since clay soils with a high pH value (that is, more basic soils) tend to have high negative charges on the colloids thereby raising the CEC of the clay. The CEC values, which fell within 11.18 and 26.21cmol/kg, meet the minimum requirement of 10cmol/kg for use as liners in landfills suggested in [29] and [30], hence, the clays are up to standard for use as liners in sanitary landfills.

Table 8. PH and cation exchange capacity values of L1, L5, L7, L8 and L10

Sample	pH	Cation exchange capacity (cmol/mg)
L1	5.9	26.61
L5	4.9	23.10
L7	4.8	15.60
L8	5.3	25.33
L10	4.7	11.18

The Buan clay has some economic, industrial and manufacturing application. Table 9 shows the summary of Buan clay from its index and physicochemical properties.

Table 9. Summary of Buan clay samples against their areas of application

Parameter	Liner	Refractory bricks	Filling	Paint production	Ceramics	Pottery
Viscosity				L8		
CEC	L1, L5, L7, L8, L10					
Linear shrinkage			L4, L6, L7, L10			L1, L2, L3, L4, L5, L6, L7, L9
Atterberg limit	L1, L5, L10					
Swelling potential	L5, L6, L7, L10		L5, L6, L7, L10			
PSD	L1, L5		L10			
Moisture content	L1, L3					

Table 10. Major oxides and elemental composition of five clay samples from Buan

Oxide (wt %)	Composition	L1	L5	L7	L8	L10
SiO_2		49.9	57.40	44.20	42.40	57.80
TiO_2		3.58	4.81	3.51	3.24	3.53
Al2O3		11.33	9.75	28.34	27.10	22.73
Fe2O3		4.61	9.76	9.12	2.20	1.34
SO_3		10.50	1.00	Nd	2.40	Nd
Cl		Nd	Nd	Nd	1.08	Nd
Br		Nd	Nd	Nd	0.049	Nd
CaO		0.23	0.55	0.20	0.40	0.14
MgO		0.15	0.15	0.08	0.10	0.061
Na_2O		0.82	1.21	0.51	0.97	0.084
K_2O		0.52	0.94	0.28	1.36	1.32
MnO		0.13	0.11	0.01	0.039	<0.001
V2O5		0.12	0.15	0.084	0.086	0.12
Cr2O3		0.061	0.075	0.039	0.033	0.072
CuO		0.11	0.13	0.059	0.073	0.086
ZnO		0.035	0.036	0.018	0.042	0.020
SrO		0.095	0.12	0.041	0.086	0.091
BaO		Nd	Nd	Nd	Nd	Nd
Loss on ignition		17.81	13.81	13.51	18.34	12.61

Nd = not detected

4.5 Chemical Composition

The chemical composition of clay samples L1, L5, L7, L8 and L10, analyzed for their major oxides and elemental composition, put silica (SiO_2) contents at between 42.4 – 57.8% with L10 having the highest at 57.8% (Table 10). L5 and L10, with a silica content of 57.4% and 57.8% can be used for refractory bricks since they meet the industrial recommended value of between 51 – 70% silica [31]. Their alumina (Al_2O_3) content values range of 9.75 and 28.34% however, fall below the recommended value range of 25 – 44% [32], but they can be supplemented through the addition of more alumina in form of flux.

Fe_2O_3 is comparatively high in the samples as they range between 1.34 and 9.76%, especially L7 at Muisi with a high of 9.76%. This is expected because during sampling, the clay was mottled with pieces of iron stones. L5 at Muisi and L10 at Nwideekil, both have CaO content of 0.5% and 0.14% respectively. Sample L10's CaO value of 0.14% falls below standard value recommended for brick production, while L5 is up to the amount required for brick production [32]. The occurrence of CaO, Na_2O and K_2O, which are major constituent of feldspar, in clay soils seem to indicate that the clays are granitic in origin [2], and low proportions of these alkali metal oxides help to signal the clay's potentials in making refractory products. High alumina content and the absence of alkali metal content would, to a great extent, improve the refractiveness of clays thereby making them suitable for use as furnace lining material [33]. Also, the relatively large amount of silica, iron and alumina in the samples seem to suggest that the clays could be used as raw materials in many industrial applications [34]. The relatively low LOI of samples L5, L7, and L10, ranging from 12.61 to 13.81%, suggests low organic content of the clays and therefore, suitable to be used as raw material for ceramic production [35]. L1, L5 and L10, after further processing to reduce the LOI, could be used in structural block production since they meet the required amount of silica (48.67%) and alumina (9.45%) proposed in Murray [36]. Samples L7 and L8 could also be used for refractory bricks if their silica values were increased to 51% since their alumina values is up to the recommended value of 25-44% proposed in Parker [37]. Clays which do not have the required proportion of oxides can be augmented through the addition of fuller earth with the right proportion [2]. The presence of the elements, Cl and Br, put at 1.08 and 0.049% respectively in sample L8 seem to suggest the elements were sorbed from their environment of deposition, hence, an absorptive nature of the clay. A high LOI value indicates a potential for carbonaceous compounds [2], especially L1 with 17.81%.

4.6 Mineralogy

The mineralogical compositions of samples L1, L5, L7, L8 and L10 are displayed in Fig. 6 through Fig. 10. The XRD analysis of L1, L5, L7, L8 and L10 show a high proportion of quartz, ranging from 81.6 to 86.9%. L10 has a higher amount of quartz at 86.9%, while L7 recorded the lowest at 86.1%. The high proportions of quartz in the clay samples should be responsible for their gritty feel. In L1, quartz was put at 86.1%, birnessite (9.6%), and cadmium dicyanide at 4.3% (Table 11). L5 put quartz at 86.2% while volborthite is put at 13.8% (Table 12). Other minerals/ compounds such as siderite, potassium iodate, potassium selenide, caesium nickel oxide, palladium oxide and calcium per oxide also occurred in lower proportion (Tables 13-15). The high proportion of quartz in all the samples indicates that they could be utilised as raw materials in structural blocks/ bricks production as this quartz would give them strength and durability. This is because, during vitrification, quartz combines with the fluxes's basic oxides that are released from clay minerals upon being fired to form glass which improves the strength [38]. Also, this significantly high amount of quartz in the clay would translate to low compressibility and low expansibility. These are key factors of consideration when clay is to be employed as liners. The clay's properties against their industrial application areas are as summarized in Table 10.

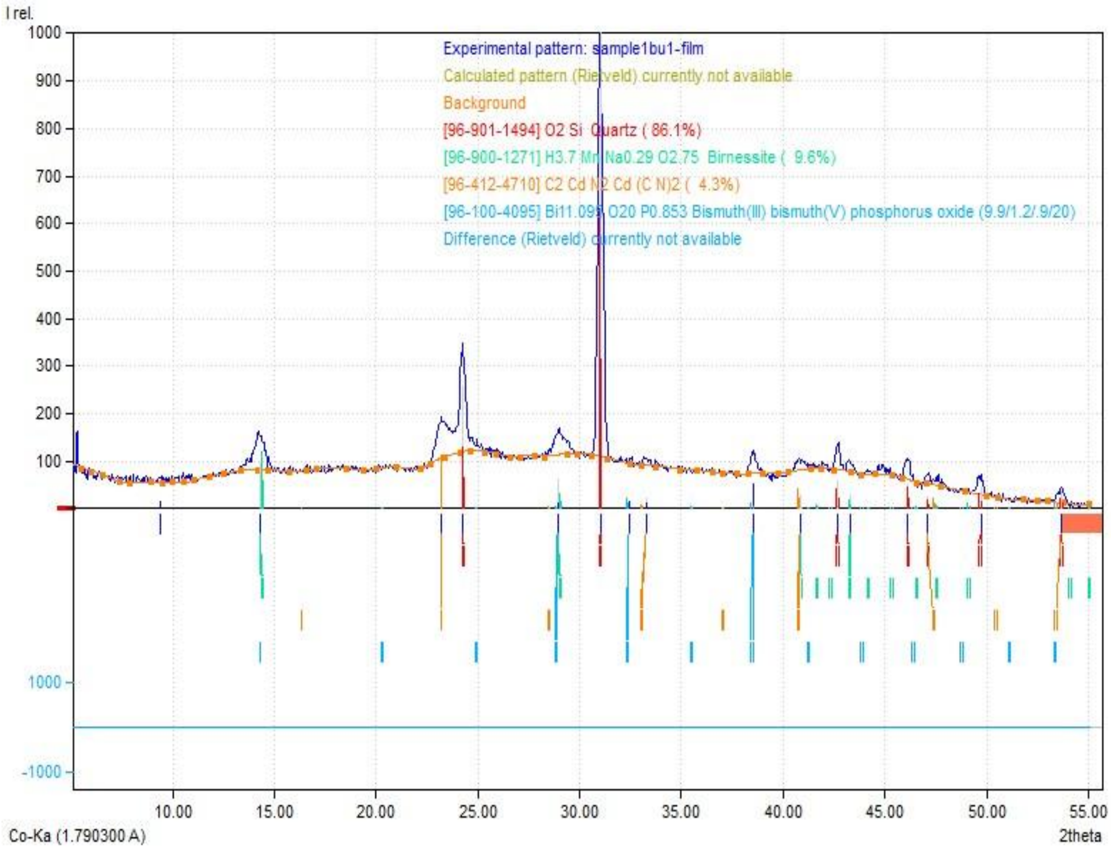

Fig. 6. X-ray diffractogram result of L1

Table 11. Mineral composition of L1

Mineral	Chemical formula	Amount (%wt)
Quartz	SiO_2	86.1
Birnessite	MnNa0.29H3.7O2.75	9.6
Cadmium cyanide	$Cd_2C_2N_2(CN)$	4.3
Bismuth(III) bismuth(V) phosphorous oxide	Bi11.095P0.853O20	trace

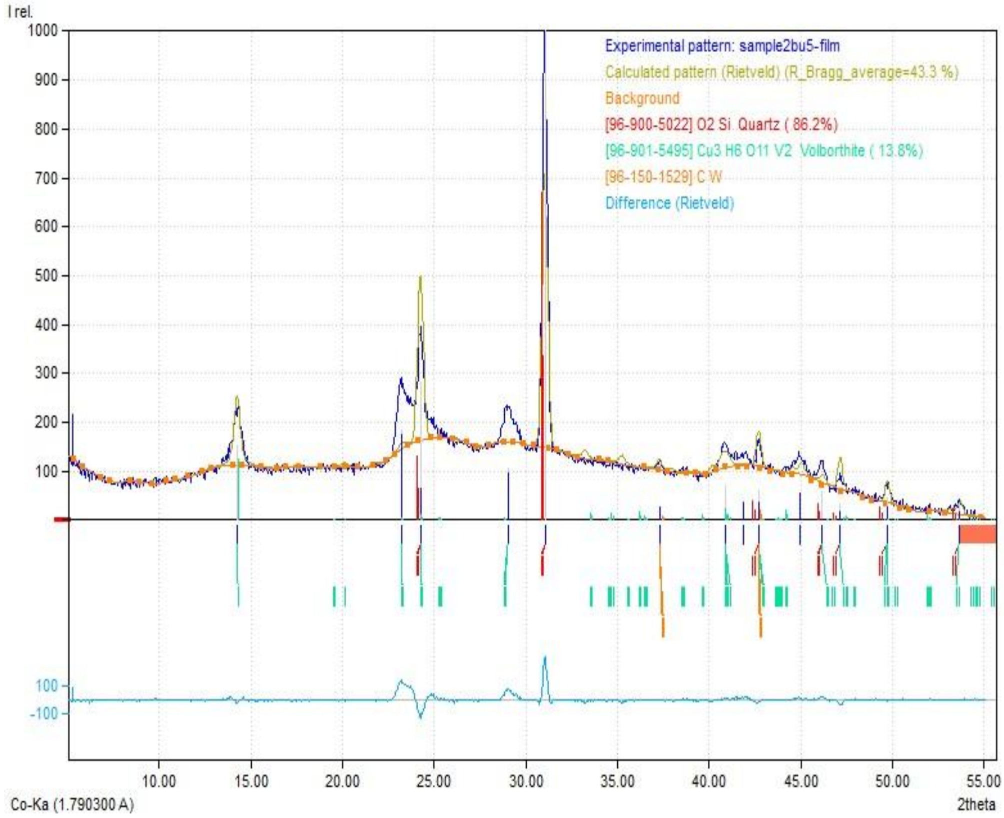

Fig. 7. X-ray diffractogram result of L5

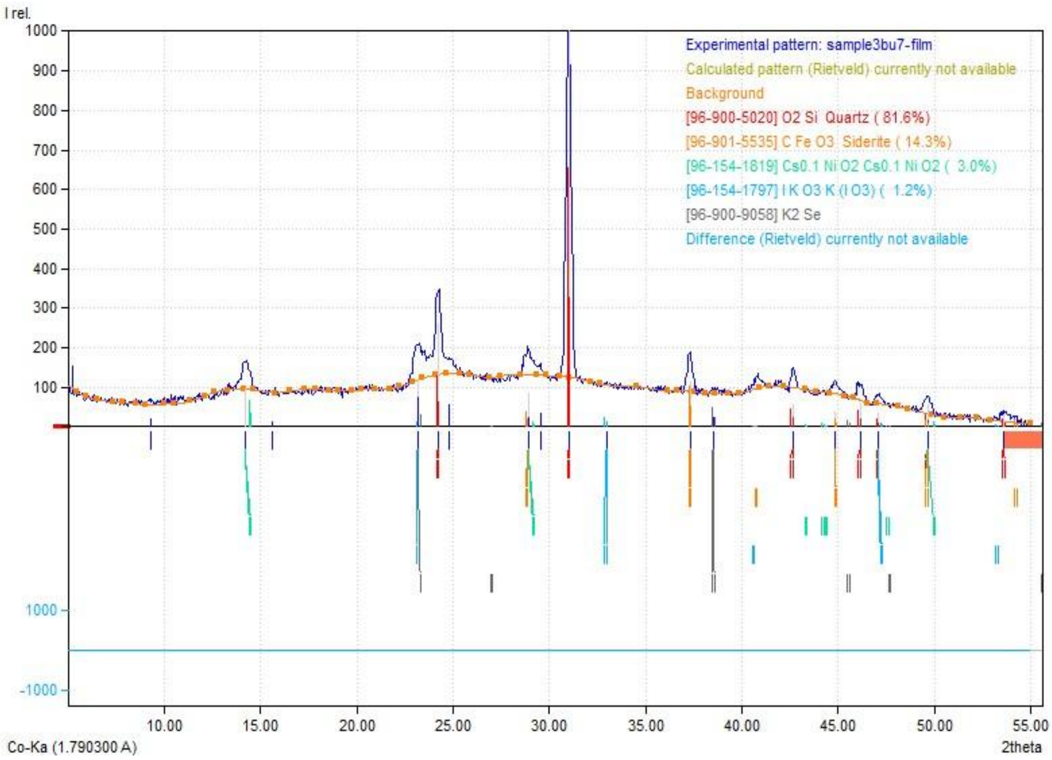

Fig. 8. X-ray diffractogram result of L7

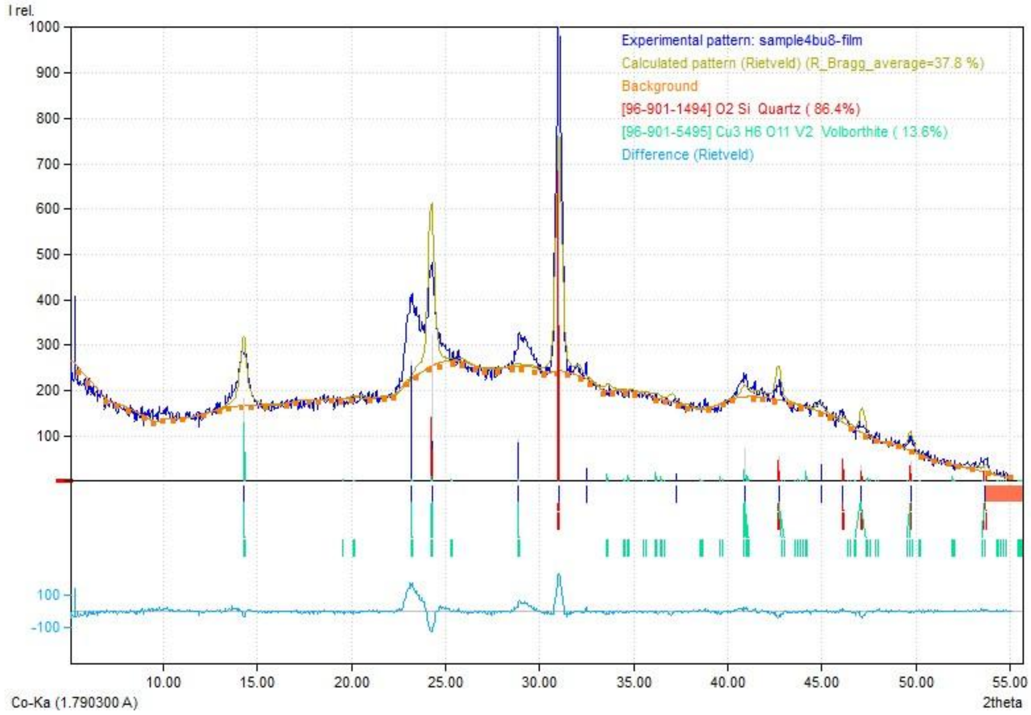

Fig. 9. X-ray diffractogram result of L8

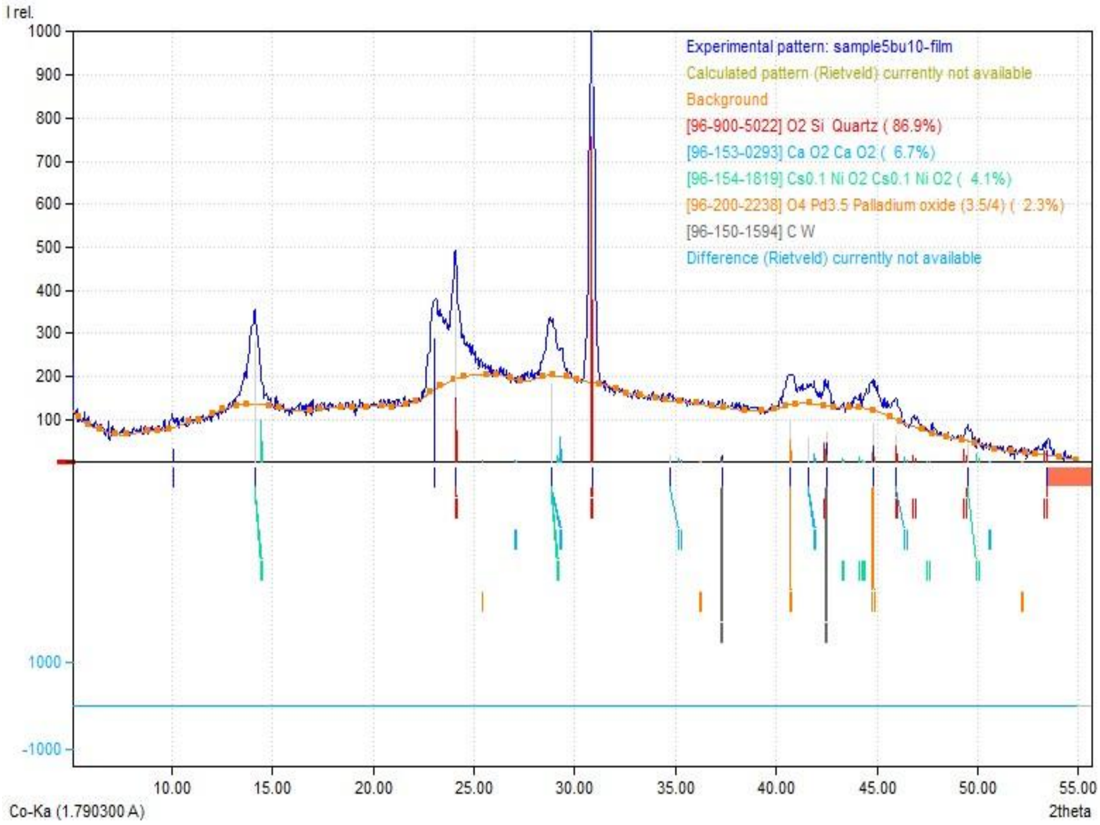

Fig 10. X-ray diffractogram result of L10

Table 12. Mineral composition of L5

Mineral type	Chemical formula	Amount (%wt)
Quartz	SiO_2	86.2
Volborthite	Cu3V2H6O11	13.8
Tungsten carbide	WC	Trace

Table 13. Mineral composition of L7

Mineral	Chemical formula	Amount (%wt)
Quartz	SiO_2	81.6
Siderite	$FeCO_3$	14.3
Caesium Nickel oxide	2Cs0.1NiO2	3.0
Potassium Iodate	$2KIO_3$	1.2
Potassium Selenide	K_2Se	Trace

Table 14. Mineral composition of L8

Mineral	Chemical formula	Amount (% wt)
Quartz	SiO_2	86.4
Volborthite	Cu3V2H6O2	13.6

Table 15. Mineral composition of L10

Mineral	Chemical formula	Amount (%wt)
Quartz	SiO_2	86.9
Calcium per oxide	$2CaO_2$	6.7
Caesium nickel oxide	2Cs0.1NiO2	4.1
Palladium oxide	Pd3.5O4	2.3

5. CONCLUSION

The aim of this work was to determine the geotechnical index properties, physicochemical and mineralogical characteristics of the soil obtained from Muisi and Nwideekil sections of Buan situated in the southern part of Nigeria. The clay has low to medium percentage of fines (20 to 40%). The sand percentage is fairly high in the clay, which would provide enough strength and inhibit volume change when the clay is used as landfill liners. The cation exchange capacities (CECs) of the two clay deposits fall between 11.18 and 26.21cmol/kg, which meet the minimum requirement of 10cmol/kg suggested in Taha and Kabir [29] and Tijani and Bolaji [30], and so could be used as liners in sanitary landfills. The clays samples have low, medium, high and very high swelling potential in the two deposits investigated, with a fairly high amount of silica at 42 to 57.9%, and alumina with a range of 9.75 to 28.34%. With CaO, NaO and K_2O present, it could be deduced that the clays are granitic in origin. The relatively low proportion of the alkali metal oxides indicates the potentiality of the clays in making refractory products.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Velde B. Composition and mineralogy of clay minerals. In: Velde B. (eds) Origin and Mineralogy of Clays. Springer, Berlin, Heidelberg; 1995. DOI:https://doi.org/10.1007/978-3-662-12648-6_2
2. Alege TS, Idakwo SO, Alege EK, Gideon YB. Geology, mineralogy and geochemistry of Clay Occurrences within the Northern Anambra Basin, Nigeria. Current Journal of Applied Science and Technology. 2014;841-852. DOI: 10.9734/BJAST/2014/6968
3. Schulze DG. Clay minerals. © 2005, Elsevier Ltd. All Rights Reserved; 2005.
4. Aramide FO, Alaneme KK, Olubambi PA, Borode JO. Characterization of some clay deposits in South West Nigeria. Leonardo Electronic Journal of Practices and Technologies. 2014;25:46-5.
5. Basack S, Purkayastha RD. Engineering properties of marine clays from the eastern coast of India. Journal of Engineering and Technology Research. 2009;1(6):109-114.
6. Lucas FA, Itiowe K, Avwenagha EO, Eruebi BT. Lithofacies characterization and quantitative mineralogical analysis of the sediments from sahaiawei-1 Well in the Northern Delta Depobelt of the Niger Delta Basin. Journal of Applie Sciences and Environmental Management. 2020;24(10): 1795 - 1800. DOI: 10.4314/jasem.v24i10.13
7. Fakolujo OS, Olokode OS, Aiyedun PO, Oyeleke YT, Anyanwu BU, Lee WE. Studies on the Five (5) Selected Clays in

Abeokuta, Nigeria. The Pacific Journal of Science and Technology. 2012;13(1):83-90.

8. Ojo GP, Igbokwe UG, Egbuachor CJ, Nwozor KK. Geotechnical properties and geochemical composition of kaolin deposits in parts of Ifon, Southwestern Nigeria. American Journal of Engineering Research (AJER). 2017;6(3):15-24.
9. Short KC, Stauble AJ. Outline of Geology of Niger Delta. AAPG Bulletin. 1967; 51(5):761-779. DOI: https://doi.org/10.1306/5D25C0CF-16C1-11D7-8645000102C1865D
10. Tse AC, Ogunyemi AO. Geotechnical and chemical evaluation of tropical red soils in a deltaic environment: Implications for road construction. Journal of Geography and Geology. 2016;8(3):42-51. DOI:https://doi.org/10.5539/jgg.v8n3p42
11. British Standard: BS 1377. Method of tests for soils for civil engineering purposes. British Standard Institute, W4 4AL; 1990.
12. ASTM. Standard Method for Classification of Soils for Engineering Purposes (Unified Soil Classification System): ASTM Standard D2487. American Society for Testing and Materials, West Conshohocken, Pa; 1992.
13. Dedan O, Paul Q. Geotechnical engineering and environmental aspects of clay liners for landfill projects. Technical paper 3. Fehily Timoney and Co. and IGSL Ltd.; 2003.
14. Oluwapelumi OO. Geotechnical Characterization of some Clayey Soils for Use as Landfill Liner. Journal of Applied Science and Environmental Management. 2015;19(2):211-217. Doi:http://dx.doi.org/10.4314/jasem.v19i2.6
15. Rahman ZA, Yaakob WZN, Rahim SA, Lihan T, Idris WMR, MohdSani WNF. Geotechnical characterisation of marine clay as potential liner material. Sains Malaysiana. 2013;42(8):1081-1089.
16. Jones RM, Murray EJ, Rix DW. Selection of clays for use as landfill liners. Wastes Disposal by Landfill – GREEN'93. 1993; 433-438. DOI: 10.12691/env-3-3-2.
17. Polidori E. Reappraisal of the activity of clays; activity chart. Soils and Foundations. 2009;49(3):431-441. DOI:https://doi.org/10.3208/sandf.49.431
18. Cerato AB, Lutenegger AJ. Shrinkage of clays. Proceedings of the 4th International Conference on Unsaturated Soils, at Phoenix, Arizona, April 2-6. 2006;147(1). DOI:http://dx.doi.org/10.1061/40802(189)89
19. Frempong EM, Yanful EK. Compatibility of the three tropical clayey soils with MSW landfill leachate. A paper submitted to 5th Canadian Geotechnical Conference, Quebec City, Canada, October, 24th – 27th; 2004.
20. Canadian Government Report, Manitoba (CGRM). Technical Reference Document for Liquid Manure Storage Structure. Compacted Clay Liners, February; 2007.
21. Kabir MH, Taha MR. Assessment of physical properties of a granite residual soil as an isolation barrier. Electronic Journal of Geotechnical Engineering. 2004;92(c):13.
22. Ademila O, Adebanjo OJ. Geotechnical and mineralogical characterization of clay deposits in parts of Southern Nigeria. Geoscience Research. 2017;2(2):127-137. DOI:http://dx.doi.org/10.22606/gr.2017.22006
23. Abduo MI, Dahab AS, Abuseda H, AbdulAziz AM, Elhossieny MS. Comparative study of using Water-Based mud containing Multiwall Carbon Nanotubes versus oil-based mud in HPHT fields. Egyptian Journal of Petroleum. 2015;25(4):1-6. DOI:https://doi.org/10.1016/j.ejpe.2015.10.008
24. Ma C, Eggleton RA. Cation exchange capacity of kaolinite. Clay and clay Minerals. 1999;47(2):174-180. DOI:https://doi.org/10.1346/CCMN.1999.0470207
25. Abii TA, Nwosu PC. The Effect of Oil-Spillage on the Soil of Eleme in Rivers State of the Niger-Delta Area of Nigeria. Research Journal of Environmental Sciences. 2009;3:316-320. DOI:https://dx.doi.org/10.3923/rjes.2009.316.320
26. Boisa N, Bekee D. Leaching of Potentially Toxic Metals (PTMs) from two nigerian clays and related clay pottery used locally as foodwares. Journal of Environmental Analytical Chemistry. 2017;4(4):1-5. DOI: 10.4172/2380-2391.1000222
27. Shuwa SM. Beneficiation and evaluation of the potentials of dikwa bentonitic clay for oil well drilling fluids formulation. An unpublished M.Sc Thesis, submitted to the Department of Chemical Engineering, Ahmadu Bello University, Zaria; 2011.

28. Bilal S, Mohammed-Dabo IA, Dewu BBM, Momoh OR, Funtua II, Oladipo MOA, Arabi AS, Muhammad T. Study of the physicochemical properties of nigerian bentonitic clay samples for drilling fluid formulation. Journal of Scientific and Engineering Research. 2016;3(2):171-176.
29. Taha MR, Kabir MH. Sedimentary residual soils as a hydraulic barrier in waste containment systems. Second International Conference on Advances in Soft Soil Engineering Technology, Putrajaya, Malaysia. 2003;895-904.
30. Tijani MN, Bolaji OP. Sorption and Engineering characteristics of some clay/shale deposits from Nigeria as landfill liner. International Meeting, September 17-18, Lille, France. Clays in Natural and Engineered Barriers for Radioactive Waste Confinement. 2007;367-368.
31. Adams FD, Joseph MV, Shettima B. Geochemical investigation of clay minerals in Marte, Borno State, Nigeria. Arid Zone Journal of Engineering, Technology and Environment. 2017;13(5):544-554.
32. Gushit JS, Olotu PN, Maikudi S, Gyang JD. Overview of the availability and utilization of kaolin as a potential raw material in chemicals and drug formulation in Nigeria. Continental Journal of Sustainable Development. 2010;1:17-22.
33. Omotoyinbo JA, Oluwole OO. Working properties of some selected refractory clay deposits in South Western Nigeria. Journal of Minerals and Materials Characterization and Engineering. 2008; 7(3):233-245.
34. Osabor VN, Okafor PC, Ibe KA, Ayi AA. Characterization of clays in Odukpani, south eastern Nigeria. African Journal of Pure and Applied Chemistry. 2009; 3(5):79-85.
35. Eze CL. Geological investigation of Alkaleri Kaolin Deposit, Bauchi State, Nigeria and the assessment of its ceramic properties. Journal of Emerging Trends in Engineering and Applied Sciences. 2015;6(5):346-352.
36. Murray HH. Clay industrial materials as rocks. Third Edition. Publication American Institute of Mining, Metals and Petroleum Engineers, New York, Seeley W. Mudd Series. 1960;259-284.
37. Parker EA. Materials data book for engineers and scientists. Mc Graw-Hill Book Co. New York. 1967;283.
38. Bell FG. Engineering properties of soils and rocks. Fourth Edition. Oxford, Blackwell Science. 2000;482.

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