GEOTECHNICAL CHARACTERISTICS OF SOME SOUTHWESTERN NIGERIAN CLAYS AS BARRIER SOILS

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ABSTRACT

The geotechnical characteristics of some southwestern Nigeria clays were evaluated with a view to determining their suitability for use as barrier soils in waste disposal sites. Clay soils (consisting of twenty disturbed and twenty undisturbed samples) were subjected to grain size, consistency limits and permeability tests. In addition the clay mineralogy and major oxide composition of the soils were determined. The clays are well-graded soils of low plasticity containing adequate percentage clay size fractions and amount of fines showing soils with high specific surface which allow low migration of leachate. The coefficient of permeability ranges from 1.18×10^{-4} to 1.45×10^{-7} cm/s indicating low to practically impermeable soils. Clay mineralogy revealed the presence of mixed clays - kaolinite-bentonite and kaolinite-illite, hence, their capabilities to attenuate and contain leachate. The studied clays are good barrier soils.

Keywords: Permeability, Barrier Soils, Clays, Leachate, Containment, Attenuation

INTRODUCTION

Engineered waste disposal sites also referred to as sanitary landfill according to UNEP-IETC (1996) are structures for disposal of solid waste on land, in a manner that meets most of the standard specifications, including sound siting, extensive site preparation, proper leachate and gas management and monitoring, compaction, daily and final cover, complete access control, and record-keeping. They can provide a safe, efficient, and aesthetic method of burial and disposal at a site if soil and geologic conditions are favorable. Thus, as noted by Jones et al. (1995), their main purpose is the safe containment of waste and control of leachate to mitigate ground and groundwater pollution and the protection of public health. In other to achieve the aforementioned objectives, there is need to put in place barriers (or liners) that will help achieve fail safe conditions required of landfills. Hence the knowledge of the engineering properties of soil required to ascertain the usefulness of a particular soil as barrier material has become imperative owing to the large volume of waste generated by the ever increasing population, particularly in the less developed countries of the world. In Nigeria, the problem of waste disposal is a priority due to poor management and indiscriminate disposal at unsuitable locations. According to Nwankwo (1994), growing populations, rising incomes, and changing consumption patterns combine to complicate waste management problems in Nigeria. Failure to properly dispose these wastes in well constructed sanitary landfills poses a threat to both the groundwater and surface water through contamination by leaching of pollutants generated.

The geotechnical characteristics and of very great concern the permeability characteristic of clays is an important parameter in the design of waste disposal facilities involving burial in natural clay deposits or the use of clay liners in underground reservoirs. Permeability is one of the most important soil properties of interest to geotechnical engineers because low permeability soils are the overriding requirement for landfill barriers. According to Siddique and Safiullah (1995), permeability governs important engineering problems such as consolidation of clay foundation under applied load and the flow of water through or around engineering structures. In very fine-grained impervious soils such as clay, with low values of permeability, the process of consolidation takes place over a very long period of time. Kayadelen (2007) noted that the suitability of clay soils as barriers depends on its permeability characteristics. Soils with slow permeability are the most desirable because in them the probability of groundwater pollution by vertical or lateral seepage is minimized. Sites to be avoided include those whose soils have rapid permeability and poor workability.

Several authors including Asiwaju-Bello and Akande, 2001; Olayinka and Olayiwola, 2001; Abimbola et al., 2005; Shonuga, 2008 and Onianwa et al, 1995 have indicated significant inputs were noticed from waste dump sites into the surrounding environment in sites improperly established. Jones et al. (1995) further noted that the careful selection of materials to form low permeability barriers is essential in engineered waste disposal. Hence establishment of waste disposal sites requires the use of soils with suitable geotechnical characteristics to ensure adequate engineering design with fail safe conditions in place. This study thus investigates the geotechnical characteristics of some clay soils from southwestern Nigeria to ascertain their suitability for use as barrier materials.

DESCRIPTION OF THE STUDY AREA

The study area is located within longitudes 03° 27' and 03° 57' and latitudes 06° 45' and 07° 08' (Fig. 1). The sampling points are located at Olubode, Mowe, Ijebu-Ishiwo and Ijebu-Imope towns in Ogun State, southwestern Nigeria. The entire area is accessible through major roads and footpaths. The area is also well drained by major rivers such as Ogun, Odan, Ona, Ibu and other streams. The drainage pattern is dendritic with most of the streams and rivers flowing north to south. The climate is influenced by two major air masses controlling the seasons (wet and dry).

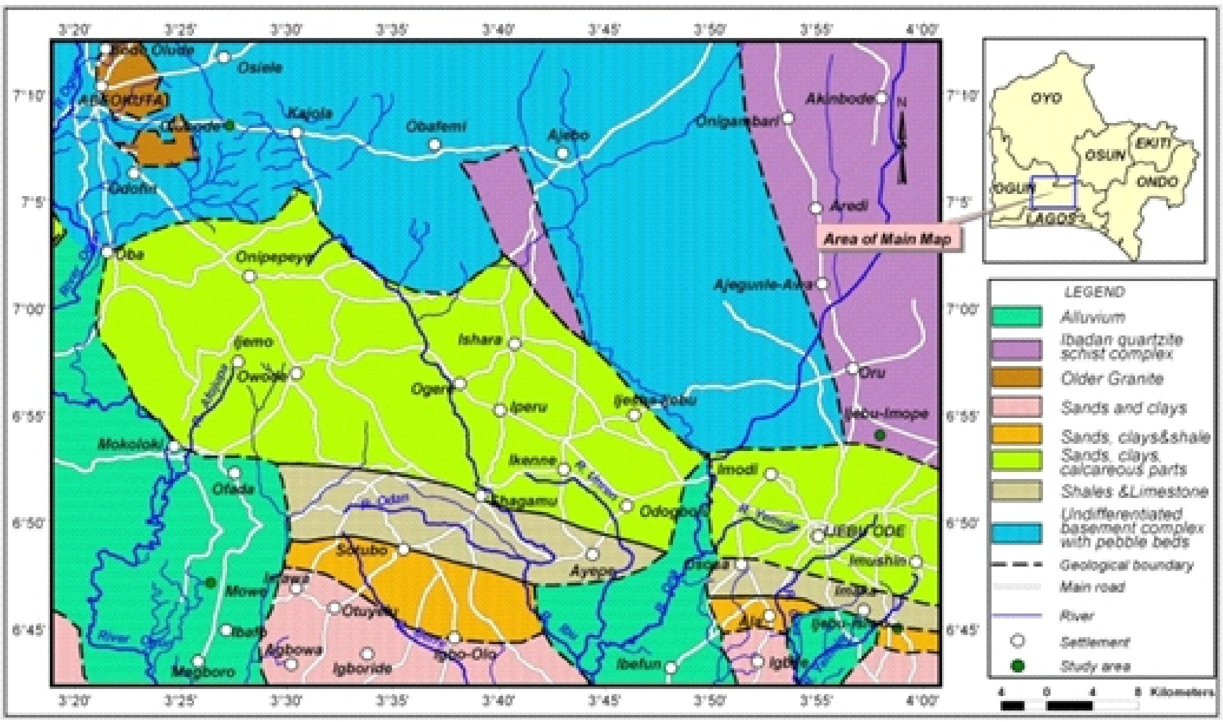

Fig.1. Geological Map of Part of Ogun State Showing the Study Area

The wet season is dominated by moisture laden southwest winds from the Atlantic Ocean. The North East trade winds dominate the dry season. The temperature is relatively high during the harmattan with a mean temperature of about 30^0C (International Institute of Tropical Agriculture, 2007) while temperatures as low as 24^0C are experienced during the rainy season.

In terms of geology, the area falls within areas underlain by the Precambrian Basement Complex rocks (Olubode and Ijebu-Imope) and the Sedimentary rocks (Ijebu-Ishiwo and Mowe) of southwestern Nigeria. The rocks which underlie the residual clay soils of the study area range from migmatite to quartzite schists as seen in the northern parts and a combination of clay, shale and sand with alluvium in the southern part.

METHODOLOGY

Twenty undisturbed and corresponding disturbed samples of clay soils were obtained from Olubode, Mowe, Ijebu-Ishiwo and Ijebu-Imope. The undisturbed samples were obtained with the use of core-cutters and sealed at both ends with wax to prevent moisture exchange. These samples were subjected to laboratory permeability tests using the falling head permeameter. The disturbed samples on the other hand were collected into sacks and later air-dried for two weeks in the laboratory. Grain size distribution analyses and consistency limits tests were conducted on the disturbed samples in accordance with BS: 1377 (1990) test procedures. The major oxide composition of the samples was determined using the AAS method while the clay mineralogy of the soils was obtained using the X-ray Diffraction method.

RESULTS AND DISCUSSION

Grain Size Distribution Characteristics

The results of the grain size distribution characteristics of the soils analyzed are displayed in Table 1. while Fig. 2. shows the combined grading curves for all the soils. Kabir and Taha (2004) suggested that the particle size distribution of a soil influences its permeability as the size of voids which conduct flow in soils is affected by the relative proportion of large and small particle sizes. The clay size fraction for all the soils range from 11 to 28 % while the silt, sand and gravel size fraction range from 31 to 49 %; 29 to 51 % and 1 to 8 % respectively. The amount of fines for the soils range from 45 to 68 %.

Elsbury et al. (1990), Benson et al. (1994) and Rowe et al. (1995) recommended materials with high clay content or a high silt and clay content as the soils that will exhibit low permeability which is an important requirement for a waste repository. All the soils analyzed meet this requirement and are expected to exhibit low permeability as a result of the high silt and clay content. The soils also satisfy the requirement by Daniel (1993b), Benson et al. (1994) and Rowe et al. (1995) that soil liners should have at least 30 % fines and less than 30 % gravel.

Table 1. Grain Size Distribution Characteristics of the Soils

Clay Soil	SIZE FRACTION (%)				
	Gravel	Sand	Silt	Clay	Fines
CL1	3	47	37	13	50
CL2	4	51	34	11	45
CL3	4	48	35	13	48
CL4	3	40	45	12	57
CL5	4	43	40	13	53
CL6	3	29	43	25	68
CL7	4	46	32	18	50
CL8	4	36	35	25	60
CL9	5	45	35	15	50
CL10	8	30	44	18	62
CL11	3	37	45	15	60
CL12	1	40	35	24	59
CL13	1	49	35	15	50
CL14	5	35	49	11	60
CL15	3	39	43	15	58
CL16	5	35	33	27	60
CL17	3	35	43	19	62
CL18	4	41	35	20	55
CL19	3	39	41	17	58
CL20	3	38	31	28	59

This requirement is further corroborated by the recommendation of Brunner and Keller (1972) for the use of finer soil as barrier materials because of high specific surface and low migration of leachate as soil texture becomes finer. These soils have high amounts of fines greater than 30 % indicating that they will have high specific surface and allow less migration of contaminants. The grading curves for the soils (Fig. 2) shows soils that are well graded which according to DoE (1995), will tend to compact to a lower porosity (and hence permeability) than uniformly graded materials. Materials with a high percentage of gravel or with excessively large particles should not be used. However suitably graded materials with a low clay fraction content can still perform acceptably. Moreover, Kabir and Taha (2004) suggested that liner soil should contain adequate amount of sand, which may offer notable protection from volumetric shrinkage and impart adequate strength as well. Furthermore all the soils satisfy the recommendation of Declan and Paul (2003) for a minimum clay content of 10 % for barrier soils.

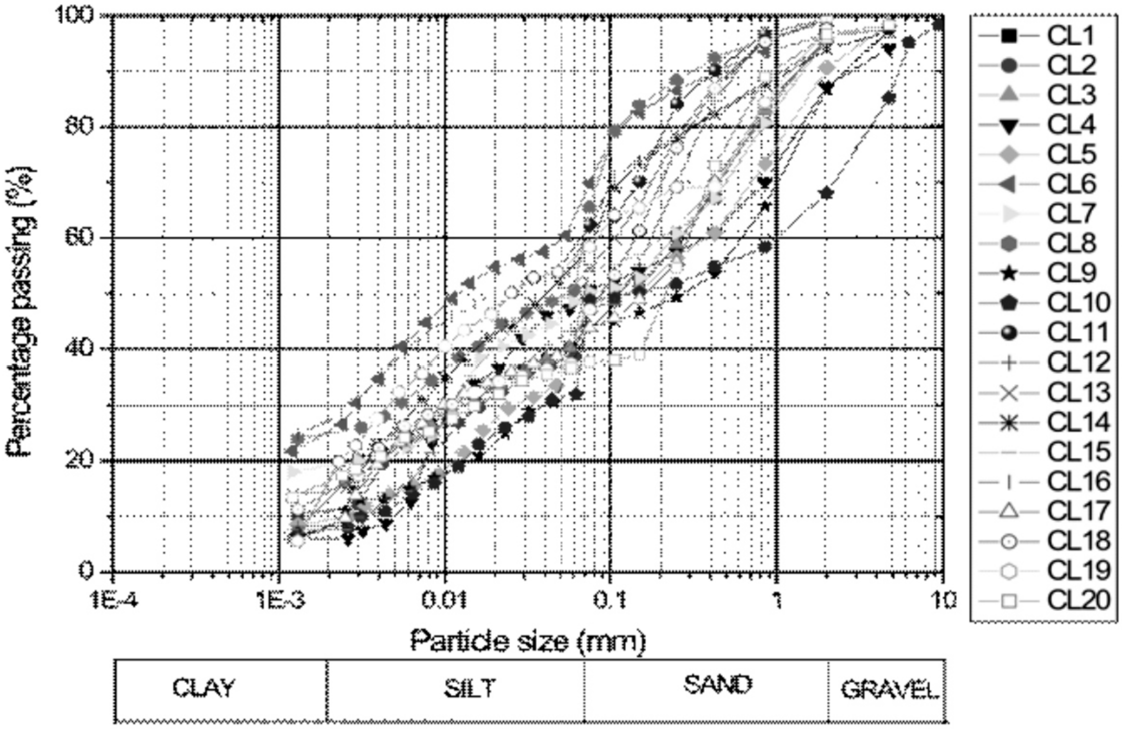

Fig. 2. Grading Curves of the Studied Soils

Consistency Limits

Consistency depicts the behaviour of soils upon addition of water. A soil is said to be highly plastic if it has the tendency to take in large quantity of water. The results of the consistency limits test (Table 2) shows that the Liquid limit ranges from 28.00 to 48.00% while the plastic limit and plasticity index range from 12.00 to 26.00% and 12.50 to 25.00% respectively.

Liquid limit is an important index property since it is correlated with various engineering properties. Soils with high liquid limit generally have low hydraulic conductivity (Kabir and Taha, 2004). According to Benson et al. (1994), a minimum liquid limit of 20% is recommended for barrier materials. Declan and Paul (2003) stipulated that the liquid limit of soil barriers should be less than 90%. The determined liquid limits of the studied soils are all above 20% and are less than 90%. Thus the soils are expected to exhibit low hydraulic conductivity and are suitable for use as barrier soils.

The values of plasticity index (an indicator of soil plasticity) for the studied soils range from 12.50 to 25.00%. Daniel (1993b) and Rowe et al. (1995) indicated that plasticity index must be greater than 7% for soils to be suitable for use as barrier materials. The clay soils meet this requirement and the values show that their expansion when in contact with water is minimal, indicating their low permeability and ability to avoid the leaching of the contaminants generated in the landfill.

According to Daniel (1991) soils with plasticity index exceeding 35% are expected to display excessive shrinkage and settlement. All the soils examined possess plasticity index less than 35%. Furthermore Murray et al. (1992) suggested that there is a notable increase in permeability where materials have a plasticity index of 12% or less, hence the clay soils under consideration with plasticity index greater than 12% can be considered suitable as notable increase in permeability is not expected.

Table 2. Consistency Limits of Soils

Clay Soil	CONSISTENCY LIMITS (%)		
	Liquid Limit	Plastic Limit	Plasticity Index
CL1	33.00	16.00	17.00
CL2	46.00	23.00	23.00
CL3	42.00	24.00	18.00
CL4	39.00	26.00	13.00
CL5	48.00	24.00	24.00
CL6	28.00	16.50	12.50
CL7	29.00	15.00	14.00
CL8	31.00	17.00	14.00
CL9	38.00	25.00	13.00
CL10	44.00	22.00	22.00
CL11	47.00	22.00	25.00
CL12	42.00	23.00	19.00
CL13	41.00	23.00	18.00
CL14	30.00	16.00	14.00
CL15	41.00	21.00	20.00
CL16	36.00	20.00	16.00
CL17	40.00	24.00	16.00
CL18	46.00	22.00	24.00
CL19	31.00	12.00	19.00
CL20	33.00	19.00	14.00

On the basis of the relationship specified by Ola (1982) between plasticity index and the swelling potential of clays (where soils with plasticity index between 0 and 15, 15 and 25, 25 and 35, possess low, medium and high swelling potentials respectively) the studied clay soils are expected to exhibit low to medium swelling potential. Furthermore, the Casagrande chart classification of the soils shows that the soils are CL (clays with low plasticity), CL+ML (clays or silts with low plasticity), ML (inorganic silts of low plasticity) or OL (organic silts and clays) and hence are relatively stable.

Permeability Characteristics

The permeability characteristic of a soil is a very important parameter in its evaluation for use as a barrier soil. The coefficients of permeability of the clay soils (Table 3.) range from 1.45×10^{-7} cm/s to 1.18×10^{-4} cm/s.

Based on the classification by Lambe (1954), a permeability of 10^{-5} to less than 10^{-7} cm/s indicates a very low to practically impermeable soil which is a requirement for barrier soils. Clayton and Huie

(1973), Daniel (1993a) and Rowe et al. (1995) agreed that a soil should have a permeability of less or equal to 1 x10^{-7}cm/s to qualify for use as isolation barrier. Furthermore, Allen (2000) stipulates 10^{-6} to 10^{-8} cm/s as the optimum permeability range to be possessed by geological barriers which are clay rich geological units for attenuation of contaminants in landfills.

All the clay soils exhibit very low to practically impermeable degree of permeability as specified by Lambe (1951). Low permeability clay soils provide natural barriers to contaminant migration (Workman and Keeble, 1989) hence the clay soils under consideration can be classified as suitable barrier soils.

Table 3. Coefficients of Permeability of the Studied Soils

Clay Soil	Permeability, k (cm/s)
CL1	3.31 X 10^{-6}
CL2	1.18 X 10^{-4}
CL3	4.28 X 10^{-6}
CL4	1.27 X 10^{-5}
CL5	8.40 X 10^{-5}
CL6	3.52 X 10^{-6}
CL7	1.87 X 10^{-6}
CL8	4.63 X 10^{-5}
CL9	3.42 X 10^{-6}
CL10	5.35 X 10^{-5}
CL11	1.86 X 10^{-6}
CL12	4.47 X 10^{-6}
CL13	1.45 X 10^{-7}
CL14	8.29 X 10^{-6}
CL15	4.59 X 10^{-5}
CL16	2.02 X 10^{-6}
CL17	2.28 X 10^{-6}
CL18	6.21 X 10^{-6}
CL19	4.42 X 10^{-6}
CL20	1.33 X 10^{-6}

Clay Mineralogy

The clay minerals and their relative abundance in the clay soils are shown in Table 4. The most abundant clay mineral type found in most of the clay soils is kaolinite, implying that the clays will exhibit low to moderate shrinkage on drying and low to moderate expansion on wetting since kaolinite has the least affinity for water among the clay minerals. Mixed clay assemblages consisting of kaolinite and bentonite and a combination of kaolinite and illite were also noticed. The most abundant clay-forming mineral is albite while other minerals identified include cordierite, cacoxenite, clinocrysotite and nacaphite. The presence of the different clay minerals in the studied soils implies that the clay soils are likely to perform effectively as barrier soils in containment and attenuation of contaminants generated (Allen, 2000).

Batchelder et al. (1998a) found out that high swelling clays such as the smectites are more prone to mineral transformation and collapse than mixed clay mineral assemblages and low swelling illite and kaolinite clay groups. The soils CL1, CL7 and CL8 contain mixed clay of kaolinite and bentonite while CL9 and CL10 contain mixed clay of kaolinite and illite. Hence, their abilities to perform both attenuation and confining functions, by combining the attenuation properties of the smectite group to which bentonite belongs with the greater stability and confining ability of the kandite group to which kaolinite belongs, can be seen.

Of the clay soils examined, CL2, CL11, CL12, CL13, CL16, CL19 and CL20 do not contain any amount of kaolinite, bentonite or illite which calls to question their ability to perform either attenuation or containment functions if used as barrier soils. Although the presence of albite and other clay forming minerals makes the formation of clay mineral assemblages a possibility. The other soils including CL1, CL3, CL4, CL5, CL6, CL7, CL8, CL9, CL10, CL14, CL15, CL17 and CL18 contain appreciable amounts of kaolinite and can be associated with well drained environment and low swelling potential.

Table 4. Mineralogical Composition of the Studied Soils

Clay Soil	Mineralogy (%)								
	Q	K	B	A	N	C	O	I	CL
CL1	71.70	23.97	4.33	-	-	-	-	-	-
CL2	42.20	-	-	57.80	-	-	-	-	-
CL3	59.04	40.96	-	-	-	-	-	-	-
CL4	69.07	30.93	-	-	-	-	-	-	-
CL5	35.15	64.85	-	-	-	-	-	-	-
CL6	89.50	10.50	-	-	-	-	-	-	-
CL7	64.30	29.80	5.90	-	-	-	-	-	-
CL8	66.10	30.40	3.50	-	-	-	-	-	-
CL9	63.55	20.88	-	-	-	-	-	15.57	-
CL10	59.29	17.14	-	-	-	-	-	23.57	-
CL11	-	-	-	65.40	34.60	-	-	-	-
CL12	-	-	-	35.50	64.50	-	-	-	-
CL13	-	-	-	-	-	100	-	-	-
CL14	58.95	41.05	-	-	-	-	-	-	-
CL15	67.63	32.37	-	-	-	-	-	-	-
CL16	-	-	-	-	60.90	-	39.10	-	-
CL17	63.40	36.60	-	-	-	-	-	-	-
CL18	69.20	30.80	-	-	-	-	-	-	-
CL19	24.71	-	-	8.04	-	4.51	-	-	62.75
CL20	33.20	-	-	-	57.02	-	-	-	9.07

Q- Quartz, A- Albite, O- Offretite, K- Kaolinite, N- Nacaphite, I- Illite, B- Bentonite C- Cacoxenite, CL- Clinochrysotite.

In addition, the high quartz content revealed by the X-ray diffraction accounts for the high percentage of sand size fraction observed in the grain size distribution. Figures 3-8 show some representative diffractograms of the studied soils.

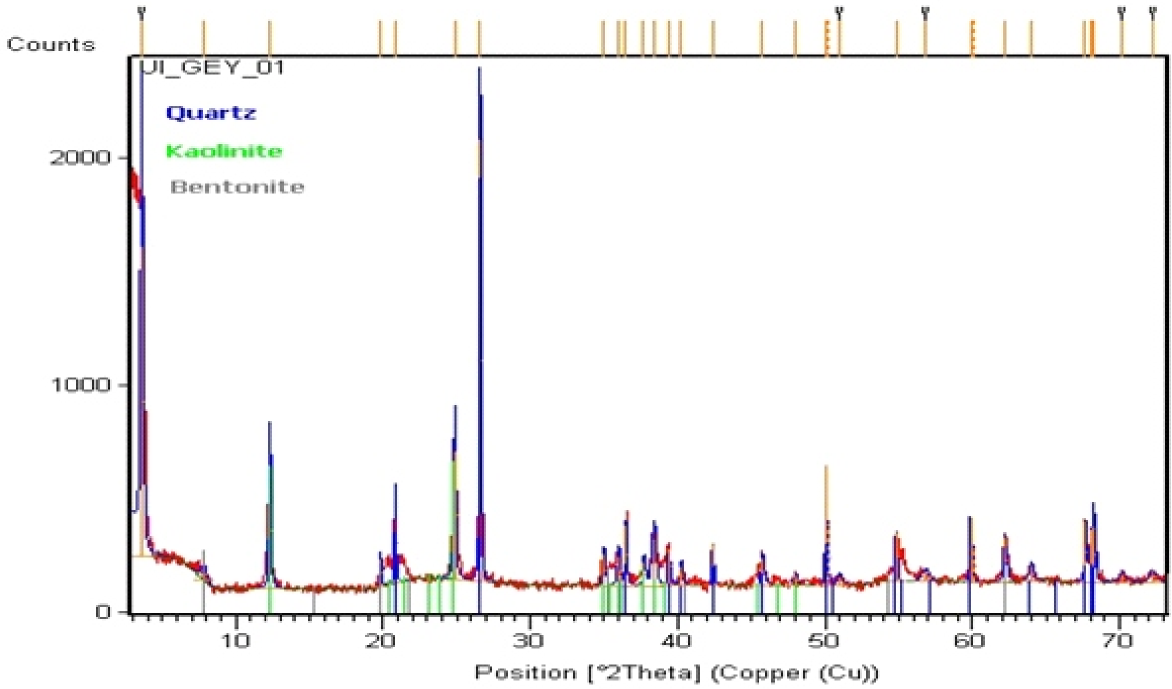

Fig. 3. X-Ray Diffractogram for CL1

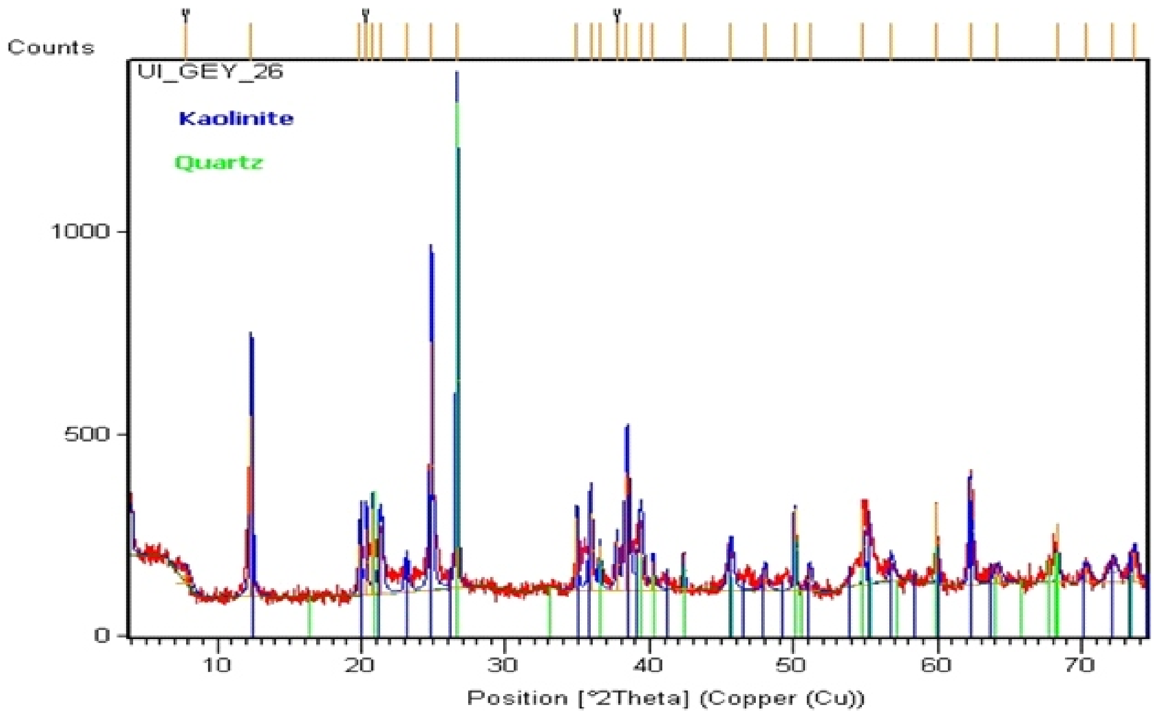

Fig. 4. X-Ray Diffractogram for CL5

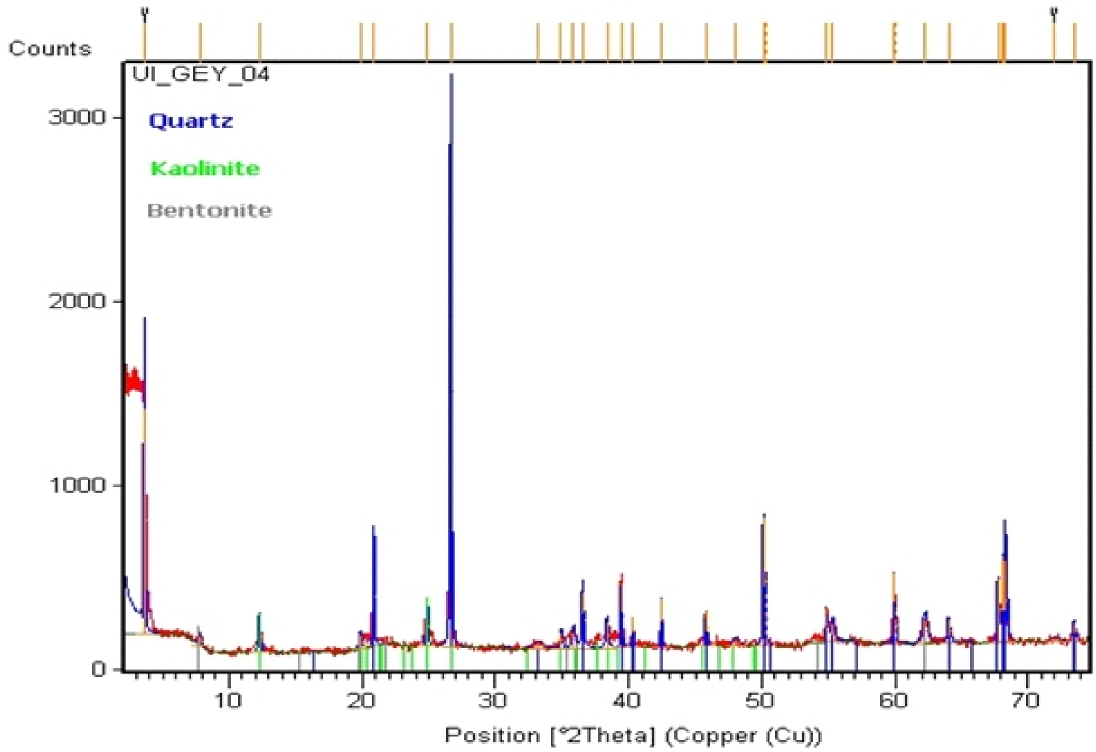

Fig. 5. X-Ray Diffractogram for CL7

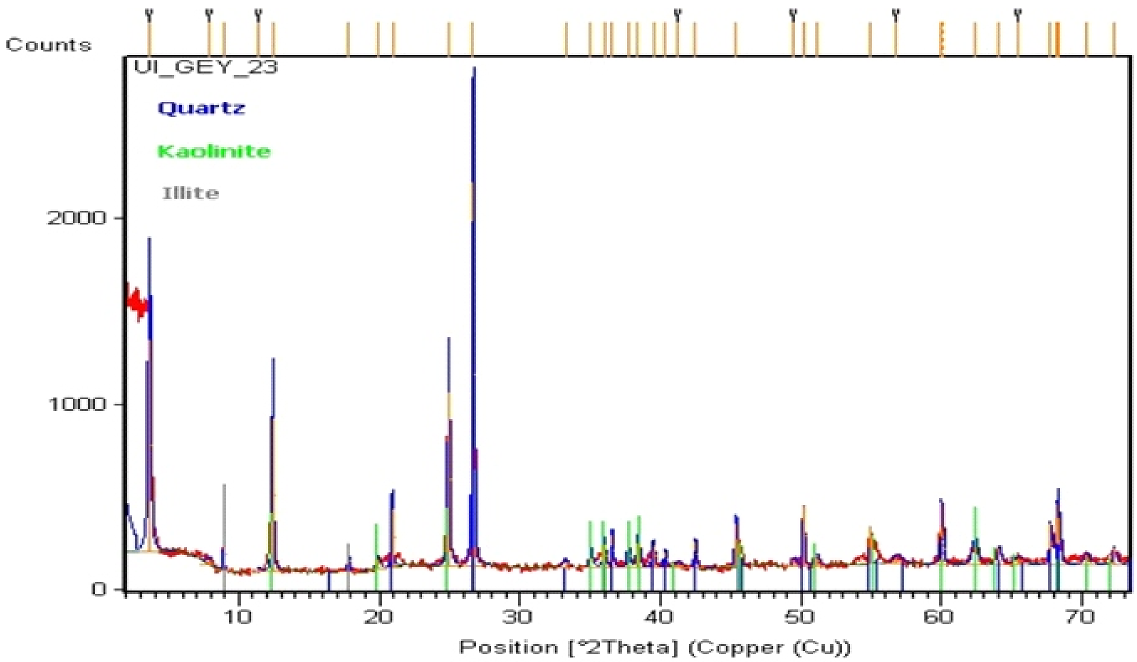

Fig. 6. X-Ray Diffractogram for CL9

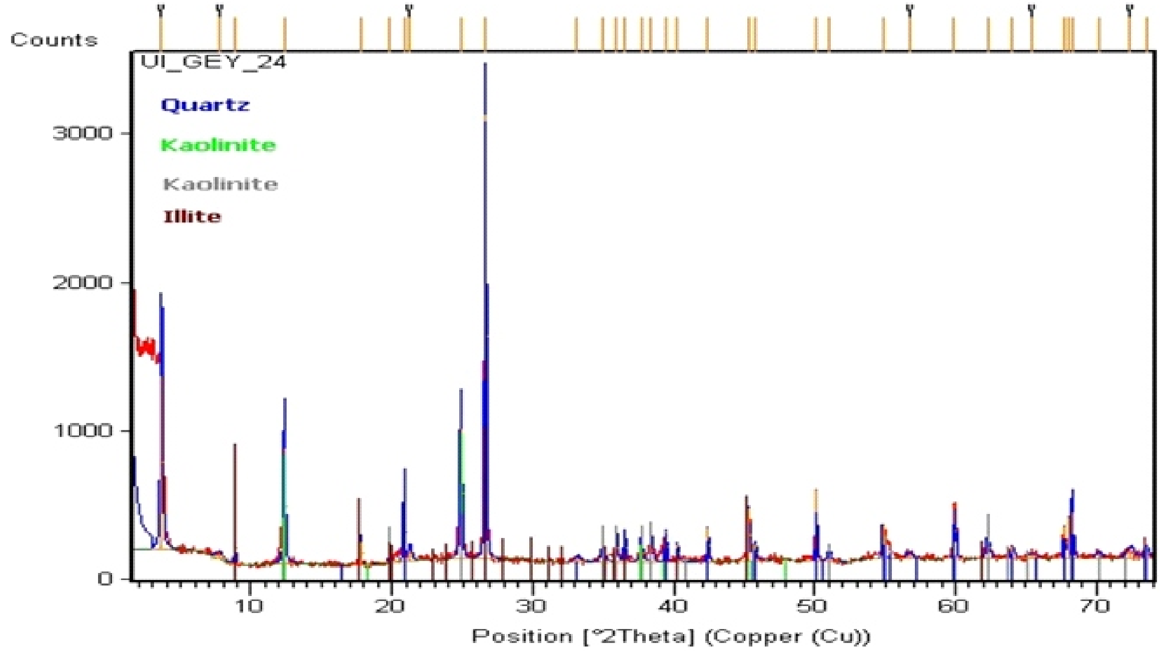

Fig. 7. X-Ray Diffractogram for CL10

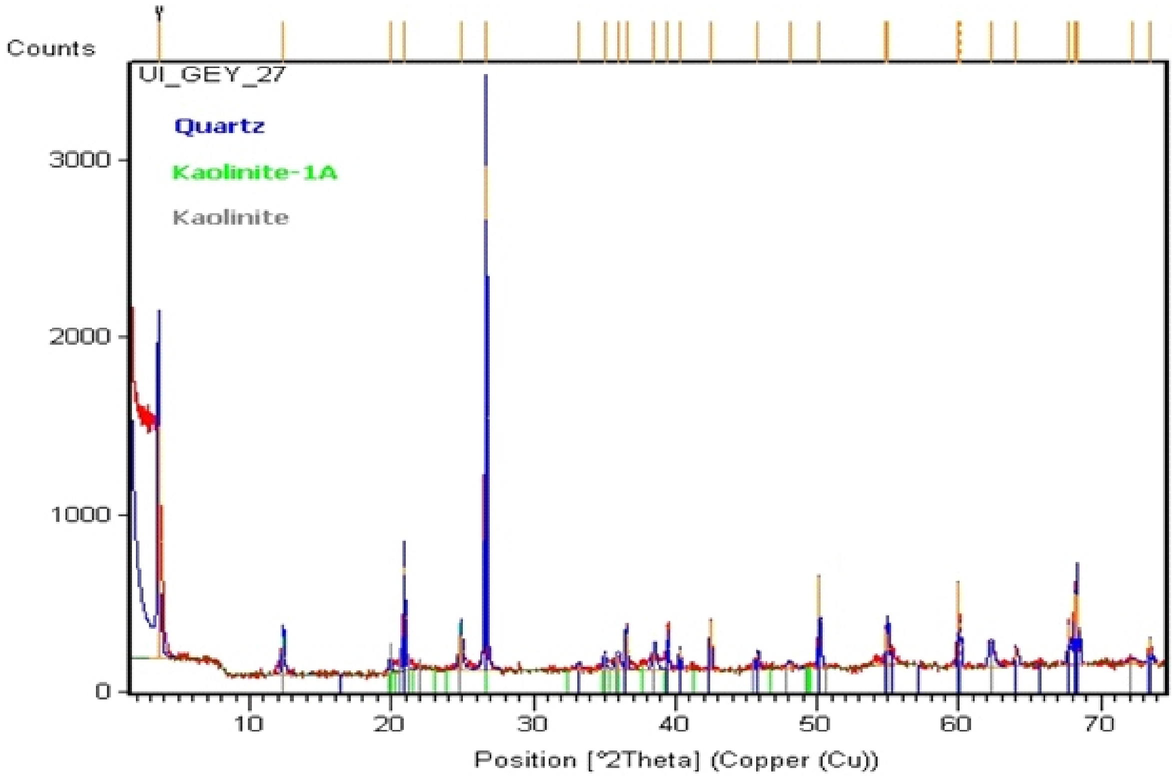

Fig. 8. X-Ray Diffractogram for CL14

Major Oxide Composition

The major oxide compositions of the clay soils are displayed in Table 5. It was observed that SiO_2 and TiO_2 have very high concentrations ranging from 51.56 to 59.33% and 11.54 to 16.21% respectively. Al_2O_3 and Fe_2O_3 also have relatively low concentrations of 5.78 to 7.21% and 3.41 to 7.33% respectively, while the sesquioxide ratio range from 8.89 to 11.77.

Joachim and Kandiah (1941) suggested that true laterites have sesqui-oxide ratio less than 1.33, with soils tending to true laterites having a sesqui-oxide range of 1.33 to 2 while tropically formed soil through weathering has sesqui-oxide ratio of greater than 2. The value of the sesqui-oxide ratio of the soil samples suggests a low degree of laterization.

The oxide composition shows that the high SiO_2 content observed in the composition of the soils accounts for the high quartz content noticed from the X-Ray Diffraction and the high amount of sand size fraction in the grain size distribution analyses.

Table 5. Major Oxide Composition of the Soils

Clay Soil	% CaO	% MgO	% K_2O	% Mn_2O_3	% Mn_3O_4	% Na_2O	% FeO	% Fe_2O_3	% SiO_2	% TiO_2	% Al_2O_3	% P_2O_5	% LOI	A/B+C
CL1	0.001	0.02	0.006	0.006	0.006	0.003	4.11	3.41	57.24	16.21	7.21	4.23	5.38	10.338
CL2	0.004	0.09	0.024	0.429	0.415	0.081	6.02	3.98	51.64	14.28	6.31	3.18	3.94	9.892
CL3	0.002	0.60	0.003	0.078	0.006	0.054	5.82	4.01	54.38	13.01	6.54	3.67	3.23	10.132
CL4	0.0008	0.01	0.004	0.005	0.005	0.021	3.98	4.43	56.55	14.15	6.55	4.15	6.34	10.224
CL5	0.003	0.63	0.02	0.057	0.055	0.054	6.59	7.33	59.33	12.66	6.21	4.58	4.96	9.239
CL6	0.004	0.01	0.004	0.010	0.009	0.018	2.25	6.10	58.25	13.21	6.47	3.28	4.88	9.531
CL7	0.001	0.01	0.008	0.009	0.008	0.025	4.97	4.87	59.07	15.16	6.48	3.52	4.18	10.445
CL8	0.001	0.01	0.12	0.001	0.001	0.039	5.43	5.81	58.15	11.76	6.56	5.31	6.51	9.602
CL9	0.0007	0.19	0.10	0.004	0.004	0.036	3.20	3.56	56.69	12.25	6.61	3.25	7.21	10.821
CL10	0.0007	0.02	0.55	0.001	0.001	0.046	4.05	4.50	55.28	12.36	5.78	4.22	6.28	10.833
CL11	0.004	0.70	0.036	0.011	0.010	0.070	6.36	4.18	51.56	13.28	5.24	2.34	5.93	11.055
CL12	0.005	0.62	0.04	0.018	0.017	0.108	5.45	3.67	56.96	14.25	5.86	4.29	5.76	11.773
CL13	0.0003	0.46	0.013	0.012	0.012	0.053	7.32	4.34	58.56	12.54	6.34	3.56	5.52	10.898
CL14	0.0007	0.19	0.10	0.004	0.004	0.035	3.20	3.56	58.32	14.08	6.15	4.06	8.21	11.740
CL15	0.0007	0.02	0.55	0.001	0.001	0.046	4.05	4.50	54.21	11.54	6.76	3.21	4.33	9.542
CL16	0.002	0.10	0.09	0.009	0.008	0.032	2.38	5.04	56.72	13.51	6.29	2.39	4.86	10.116
CL17	0.002	0.26	0.24	0.011	0.010	0.046	3.57	4.89	56.88	15.52	6.11	4.51	3.66	10.447
CL18	0.002	0.36	0.34	0.013	0.013	0.052	5.90	4.75	58.33	14.06	6.39	3.69	3.85	10.497
CL19	0.0008	0.01	0.005	0.005	0.005	0.021	3.98	4.43	57.31	15.06	6.44	2.82	3.67	10.485
CL20	0.003	0.63	0.02	0.057	0.055	0.054	6.58	7.33	57.46	12.18	6.28	3.58	6.48	8.891

CONCLUSIONS

Evaluation of the geotechnical characteristics of some clay soils from southwestern Nigeria for use as barrier soils shows that the soils are generally well graded possessing the required amount of fines, clay content and gravel size fraction. The consistency parameters of all the clay soils meet the requirement of soil barriers with the soils having low plasticity which is an indication that they are not likely to exhibit excessive shrinkage. The permeability coefficient of the soils suggests very low permeability with all the soils falling within the range of optimum permeability for attenuation. X-ray diffraction suggests that five soils contain mixed clay assemblages of kaolinite/bentonite and kaolinite/illite which is an indication that the soils can be used for both attenuation and containment purposes. Thirteen of the clay soils contain appreciable amounts of kaolinite and can be associated with well drained environment and low swelling potential which make them suitable as barrier soils. However, seven of the clay soils do not contain any amount of kaolinite, bentonite or illite hence the soils are not likely to perform either attenuation or containment functions if used as barrier soils. These soils however contain appreciable amounts of clay forming minerals, exhibit desirable plasticity characteristics and have coefficients of permeability which meet minimum stipulated requirement for soils used as barrier soils, hence their suitability. The oxide composition indicates that from the sesqui-oxide ratio the soils are non-lateritic tropically formed soils.

It can be concluded that the studied clay soils are suitable for use as soil barrier having met all requirements for barrier soils.

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