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GEOTECHNICAL AND GEOCHEMICAL ASSESSMENT OF AHOKO CLAY OF THE PATTI FORMATION FOR USE AS COMPACTED LANDFILL LINER

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ABSTRACT

Geotechnical and geochemical characteristics of clay within the Patti Formation, which is widespread around Ahoko in the Southern Bida Basin, were assessed to determine their suitability as landfill liners. The methods employed included field operation and laboratory analyses. The samples collected were subjected to grain size analysis, Atterberg limits, geochemical and cation exchange capacity determination. The chemical tests include determination of the percentage of oxides including SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O and TiO_2. The results of the analyses revealed that the percentage of fines in the sample is >50%, the plasticity index is >10%, the activity ranges from 0.34 to 0.56 and the compressibility of the compacted clay was low which implies that kaolinite (a low activity clay mineral) is the dominant mineral in the samples that were analyzed. The samples have cation exchange capacity values ranging from 8.9mEq/100g to 12.4mEql/100g which indicate a low negative charge of the clay fraction and hence, a low heavy metal sorption capacity. The results also indicate that SiO_2 content is high, ranging from 54.5% to 81.6%, which is in support of the high clay content of the samples. These characteristics indicate that Ahoko clay satisfies the property of a good clay liner.

Keywords: Ahoko clay, landfill liner, geotechnical and geochemical analyses.

INTRODUCTION

Virtually all the waste disposal sites across the length and breadth of Nigeria are open dump. Recent researches have shown that the rate of domestic, industrial and municipal wastes are increasing due to rapid population growth, expanding urbanization and increased human activities (Yahia *etal*, 2005; Okunlola *et al* 2014 and Mohammed *et al*, 2107). In addition, there has been a growing concern about the effect of landfills in public health, because leaching water can contaminate nearby surface and groundwater. The conversion of the open dumps characteristic of many cities in Nigeria, to engineered and sanitary landfills is a critical step towards safeguarding the health of the nation.

Landfill is not just a place where waste is disposed, but it is a technological plant designed, constructed, operated and managed to minimize negative effects. Sanitary landfilling is a fully engineered disposal option that avoids the harmful effects of uncontrolled dumping by spreading, compacting and covering the waste on land that has been carefully engineered before use.

The leakage from a landfill liner can cause adverse and harmful impact on the environment. It is because of the aforementioned that strict specifications were imposed on the selection of liner materials, design and construction of compacted clay liners. Mitchell *et al,* (1995) opined that the compacted clay liners must have low hydraulic conductivity to control leachate from the decomposed waste. The liner must be designed to accommodate landfill settlement and have the strength to prevent slope failure. Daniel, 1993: Rowe *et al*, 1995 recommended after extensive research and observation of the performance of existing facilities that, soils that possess the properties shown in Daniel, 1990 on specification for liner materials will be suitable for use as liner

Erguler and Ulusay 2003 and Sabtan, (2005) reported that although the expansive soils are very important in their wide usages as impermeable and containment barrier in landfill areas and other related applications.

Akinyemi *et al.*, (2018) carried out geochemical investigation of shale and claystone samples from two different sections of the exposed Ahoko claystone-shale sequence along the Koton-Karfe/Abaji highway. The concentration of major elements of samples taken from Ahoko were determined and the results reveal that the oxides of the major elements were in the order ; SiO_2> TiO2> Al_2O_3> Fe_2O_3> MgO,> MnO> CaO> Na_2O> K_2O> Cr_2O_3 an> P_2O_5

Okunlola and Idowu (2012) carried inorganic geochemical study of a claystone and shale sequence from the Patti Formation around Ahoko in the Southern Bida basin, Nigeria to determine the basin's depositional conditions, provenance and tectonics.

Alege, and Alege, (2013) analyzed clay samples selected from four different locations within the Anambra and Bida Basins of Nigeria. The study area covered four-selected sites within Kogi State of Nigeria including Eniji, Ahoko, Ajelele and Itobe village. The samples were characterized in accordance with American Society of Testing and Material (ASTM). The samples contained only clay, clean and free of lateritic soil and other contaminants

Tijani and Bolaji (2007) analysed some shale deposits from Anambra Basin to determine their sorption and engineering properties for the purpose of their potential use as landfill liners. The result of their analysis shows that the samples have engineering properties for an earth material that can be used as component of barrier system and retention capacity for toxic materials.

Yahia *et al.*, 2005 considered the possibility of using crushed shales as landfill liner in Oman. For both compacted shales analysed, the hydraulic conductivities were in order of 10^{-7}cm/s, which satisfies the specification for landfill liners. The results of the XRD and SEM support the low value of hydraulic conductivity. Their results also reveal that the crushed shales satisfy the other criteria related to Atterberg limits and grain size.

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The health risk and the effects on the quality of livelihood caused by open dumping of wastes in Nigeria, calls for comprehensive approach to the assessment of the materials that will be used, as liner for engineered landfill. The basic objective of this research therefore, is to determine some engineering and geochemical properties of Ahoko clay, for the purpose of its potential use as clay liner.

Geological setting of the study area

The study area (Ahoko and its environs) falls within the Lokoja Sub-basin of the Bida Basin. Ahoko and its environs occur within the Patti Formation between longitudes 6^0 5^lE and 6^0 53^1E and latitudes 8^0 18^lN and 8^0 19^1N. Outcrops of the Patti Formation occur between Koton-Karfi and Abaji. This formation consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones. Argillaceous units predominate in the central part of the basin. The siltstones of the Patti Formation are commonly parallel stratified with occasional soft sedimentary structures (e.g. slumps), and other structures such as wave ripples, convolute laminations, load structures. Trace fossils (especially Thallasanoides) are frequently preserved. Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous.

The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quiet low energy environment probably in a restricted body of water (Braide, 1992). The abundance of woody and plant materials comprising mostly land-derived organic matter, suggests prevailing fresh water conditions. However, biostratigraphic and paleoecologic studies by Petters (1986) have revealed the occurrence of arenaceous Foraminifera in the shales of the Patti Formation with an assemblage of Ammobaculites, Milliamina, Trochamina and Textularia which are essentially cosmopolitan marsh species similar to those reported in the Lower Maastrichtian marginal marine Mamu Formation (the lateral equivalent) in the adjacent Anambra Basin (Gebhardt, 1998). Shales of the Mamu Formation on the south side of the Anambra Basin are commonly interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north side of the basin (Akande *et al*., 1992). The Patti Formation therefore appears to have been deposited in marginal shallow marine to brackish water condition identical to the depositional environments of similar lithologic units of the Mamu and Ajali Formations in the Anambra Basin (Ladipo, 1988; Adeniran, 1991; Nwajide and Reijers, 1996).

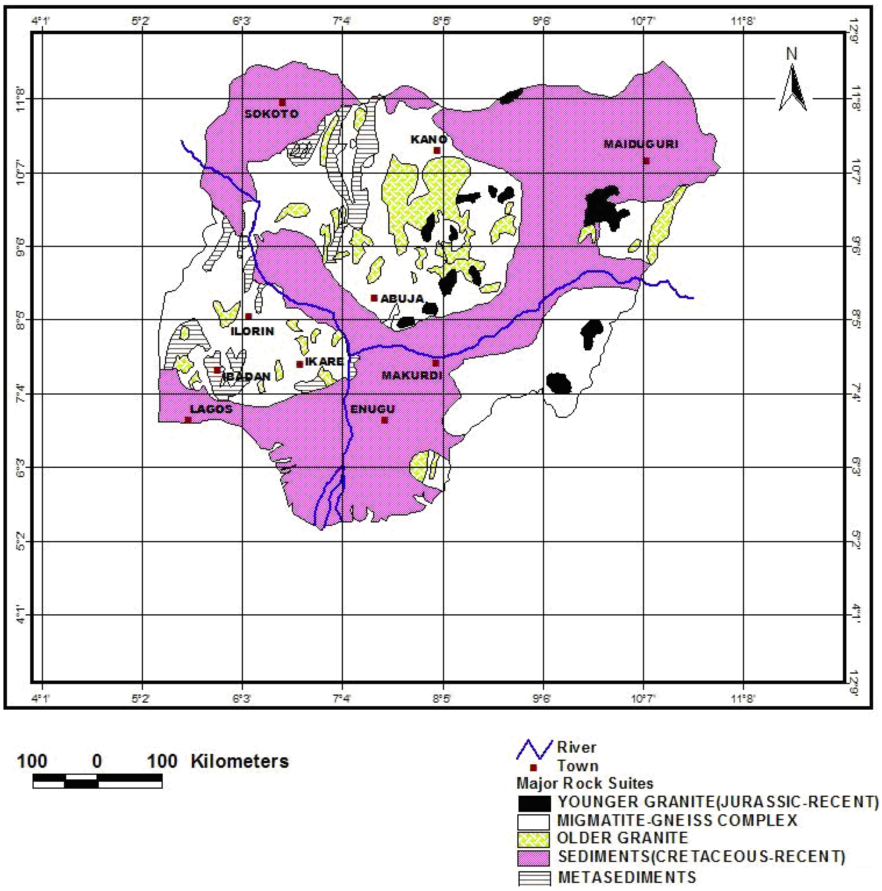

Figure 1. Generalized geological map of Nigeria (Geological Survey of Nigeria, 2004)

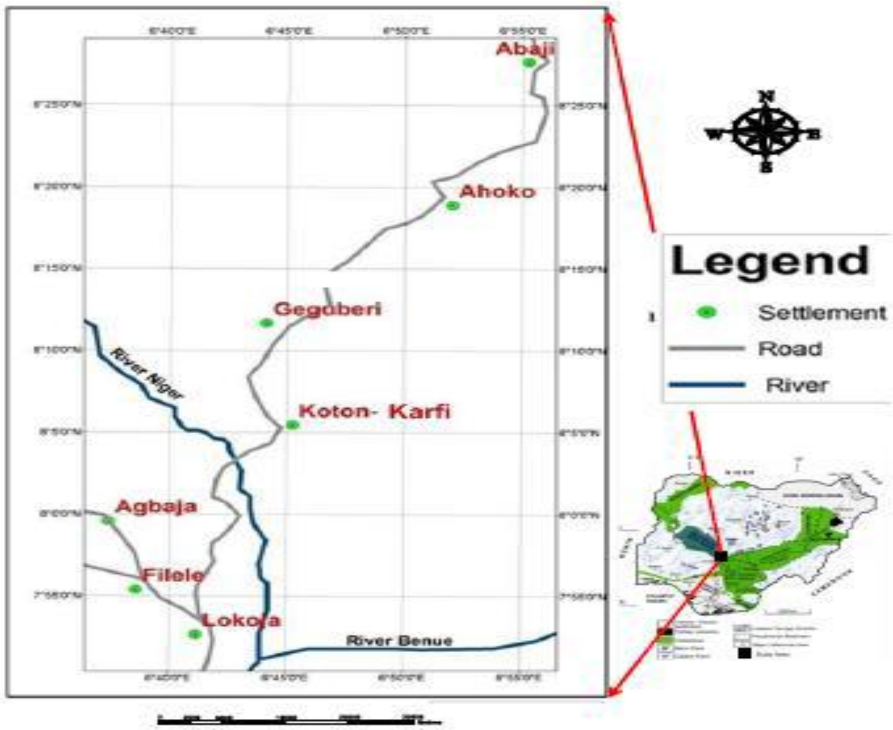

Figure 2. Accessibility Map of the study area (modified after Ohiemi, 2008)

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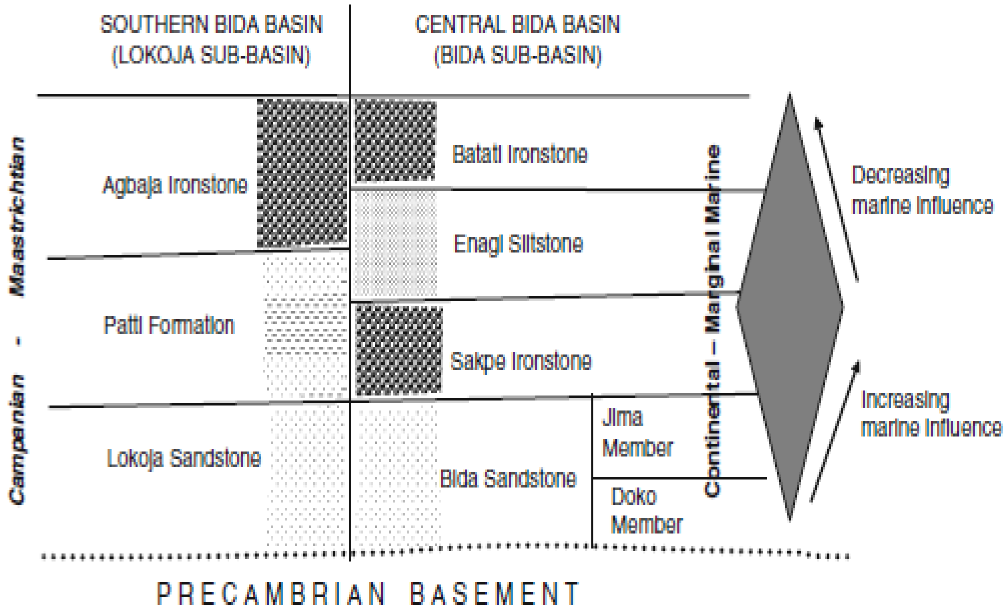

Figure 3. Lithostratigraphic units in the Northern Bida Basin and the Southern Bida Basin. (after Akande et al., 2005)

MATERIALS AND METHODS

During the fieldwork stage of the study, clay samples were obtained using digger and shovel along road cut and mining sites from different locations around Ahoko. The samples were excavated with digger and shovel from the sides of roadcuts. The samples were crushed into fine-grained soils with a maximum size of about 4.75mm. Benson and Daniel (1990) concluded that soil particles with large size clods have increased hydraulic conductivity of compacted clay liners. Therefore, by reducing the maximum size of the material to 4.75mm, the effect of clods on the hydraulic conductivity will be enhanced. The undisturbed and disturbed samples were subjected to analyses and laboratory tests.

The laboratory tests performed were grain size, liquid limit, plastic limit, compaction test and cation exchange capacity test. The grain size distribution tests were performed in two-stage process. First, the coarser particles (>0.067mmm) were separated from finer fraction (<0.067mm) through sieve analysis before the finer fraction was subjected to hydrometer analysis.

Experimental procedures

Grain size analysis

The soil particles gently separated from each other. The sieve set (stack of sieves) are arranged in descending order from the top with a retainer beneath it. 100 g of the soil was weighed and poured into the sieve stack. The sieve stack was then placed on the mechanical sieve shaker for about 10 minutes. The sieve stack was separated one by one retrieving the soil fraction retained by the mesh of each sieve. The soil fraction retained by each sieve was then weighed.

The Atterberg limits procedure

The Atterberg limits test were carried out in accordance with ASTM D 4318. Fines retained by the pan during sieve analysis was used for liquid and plastic limits determinations. 300g of the sample was weighed and water was added to it until a stiff paste (mud) was produced. The stiff paste was packed into the Casagrande apparatus and then the surface is leveled and smoothened using the spatula. A groove in the soil was made with the cutting groove and rotated the handle (blows) until the groove closes. The minimum number of blows is 10 while the maximum is 50. A small paste was scooped into the moisture can with the spatula, weighed and dried in the drying oven for about 24 hours and then reweighed in order to determine its water content. The soil was then emptied from the cup unto the glass plate and water is added to the soil and the process was performed all over again. This was repeated until the soil behaves like a liquid, that is, the number of blows to close the groove is lesser than 10 blows.

Compaction test procedures

Compaction test were carried out in accordance with the ASTM D 698. 3kg of soil sample was weighed and poured into the mixing pan. 120cm³ (4%), of water measured, added and mixed with the soil in the mixing pan using the hand trowel. The cylinder mould was then placed on a base plate, then a representative specimen of the soil was put into the mould and compact with 25 evenly distributed blows of the rammer. This represents the first layer. After the compaction, the volume of the soil in the mould reduced, more soil specimen was added into the mould and compacted with another 25 evenly distributed blows. The extension collar is then fixed unto the mould. This is mainly for the last layer and removed after the last layer was made so as to be able to achieve a smooth level surface of the last layer. The mould was filled with more of the soil specimen and compacted to make the third layer. This is for standard Proctor, but five layers of the soil specimen with 55 evenly distributed blows of the rammer makes the modified Proctor. The mould with the soil was weighed and the soil was sampled at the top and bottom of the mould for water content and the dry density determination. The mould was emptied into the mixing pan and another 120cm³ (4%) of water is added to the soil and mixed. This process is now carried out five more times. Curves are then gotten by plotting the various values of dry densities against water contents for the standard Proctor and modified Proctor respectively in order to get the maximum dry densities and optimum moisture contents of the soil samples in each situation.

Chemical test procedures

Chemical analyses include the determination of the percentage of cations including Ca^{2+}, Mg^{+}, Na^{+}, K^{+} and major oxides such as SiO_2, Al_2O_3, CaO, MgO, Na_2O and TiO_2. The cation exchange capacities of the samples were also determined. The cation exchange capacities of Ahoko clay were examined by measuring the Ag remaining in the solution after Ag-thorium (Ag-Tu) extraction. All Ag determinations were carried out by flame atomic absorption spectrometry.

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RESULTS AND DISCUSSION

Index properties

Table 1 presents the index properties of the soil samples from Ahoko. These samples contain 20.1 to 25.6% clay (CL) and 50.7% to 65.34% silt. Also observed is the fact that the silt + clay fraction as obtained from grain size analysis exceeded 50% (Figure 4). The natural moisture content of the samples ranges from 11.89% to 21.0%. The Liquid limit (LL) and Plastic limit of the samples ranges from 26.1 to 36.51% and 14.3 to 21.7% respectively while plasticity index ranges between 10.1 and 16.23% (Table 2). All the samples analyzed satisfy the requirements for grain size and Atterberg limits presented in Table 3. An appreciable content of fines is desirable in soil that is to be used as the hydraulic barrier (Bello 2012). Jones et al. (1993) cited that the suitable material for liners should contain clay of greater than 10%. EPA (1990) recommended that soils used as liner material should have at least 20% fines (fine silt and clay size particles) to achieve hydraulic conductivity values of or less than 1×10^{-7} m/s.

Rahman *et.al* (2013) suggests that Liquid limit values less than 50% indicate the presence and dominance of Kaolinite. The liquid limit (LL) values obtained are less than 50%, which implies that the dominant clay mineral in the samples is kaolinite

The plasticity index (PI) values were used to determine the degree of plasticity, it was found to be low to medium plasticity (10.1 to 16.3%). These values conform to Daniel, 1990, Modified specification for liner materials (Table 3). As shown in figures 5 and 6, and according to United Soil Classification System, the clay samples are inorganic clay of low to medium plasticity and medially compressible inorganic clay of low plasticity.

According to the charts below (figures 5 and 6), the samples are of medium compressibility and toughness and they belong to plastic kaolin group. Large expansion and contraction with changes in water content are characteristics of clays. The small size, flat shape, and mineral composition of clay particles combine to produce a material that is both compressible and plastic. Generally, the higher the liquid limit of a clay, the more compressible it will be. At the same liquid limit, the higher the plasticity index, the more cohesive the clay. With respect to how this substance affects construction, hard dry clay, for example may be suitable as liner for landfill so long as it remains dry but become unstable when wet. In addition, many of the fine soils shrink on drying and expand on wetting, which may adversely affect the containment facility, which in its simplest form consists of the clay liner, a cover and the waste (Daniel, 1993; Yahia *et al*., 2005). Even when the water content does not change, the properties of fine soils may vary considerably between their natural condition in the ground and their state after being disturbed. The activity of the Ahoko clay ranges from 0.34 to 0.54 (Figure7). The clays are generally inactive clays according to Skempton classification (Perloff and Baron, 1976). According to Benson and Trast (1995), the liquid limit w_L and plastic limit w_P values are directly related to mineralogy and clay content. The presence of high content of clay, especially active clay minerals generally corresponds to a decrease in the size of microscale pores that subsequently lower the hydraulic conductivity of the soil

Compaction test

The laboratory compaction was done to simulate an on-field situation of strength increase and reduction in permeability. The compaction tests conducted show that the samples did not have the tendency to compress unduly under load and shrink excessively when dried, which could be linked to their low to medium plasticity.

The samples when compacted at standard proctor have a lower maximum dry density than when it was compacted under Modified proctor (table 4 and figure 8 to 19). The percentage decrease in optimum moisture content (OMC) and increase in maximum dry density are low which implies that there is no significant difference between the two levels of compaction

The result of the compaction tests showed that the dry unit weight increased with increase in moisture content until the maximum dry unit weight was reached and decrease thereafter with further increase in moisture content. According to the test result, the maximum dry unit weight (standard proctor) and the optimum moisture content (standard proctor) value ranges from 15.5 to 20.30KN/$m^3$and from 11.92 to 15.34%, respectively. The maximum dry unit weight (modified proctor) and the optimum moisture content (modified proctor) value ranges from 18.1 to 22.8KN/m3and from 8.9 to 13.5%, respectively.

The modified proctor test results in an increase of the maximum dry unit weight of the soil. The increase of the maximum dry unit weight is accompanied by a decrease of the optimum moisture content because there is increase in compactive effort for modified proctor test.

The grain size distributions of soil affect their maximum dry unit weight and optimum moisture content. The increase in the optimum moisture content is due to finer particles, depending on their contents, increased the total particle surface area of the soil samples. The increase in the particle surface areas caused an increase in the optimum moisture content. The increase in the finer particle content decreased the maximum dry unit weight and increased the optimum moisture content because the compaction parameters are controlled to a great extent by index properties of soil (Adekalu and Osunbitan (2001); Gidigasu (1983); Mohan and Paul (1975); Saha and Chattopadhyay (1988)

Chemical analysis

The results of the chemical analysis performed on the clay samples are presented in table 4. The results indicate the presence of a high percentage of SiO_2 oxide for all the samples analyses. The high silica content of the samples is indicative of the appreciable percentages of clay fraction in the samples. The cation exchange capacity (CEC) of the clay sample ranges from 8.9 to 12.4mEq/100g. Batchelder and Joseph, (1997); Perloff and Baron, (1976) opined this range of CEC obtained are typical of soil dominated by kaolinite and possibly Illite. Taha and Kabir, (2003) also reported that high cation exchange capacity value would result in a greater amount of contaminant removed from leachate

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flowing through the clay liner. There are no universal acceptable criteria for a minimum value of CEC for landfill liner. However, Taha and Kabir, (2003) recommended a minimum cation exchange capacity (CEC) value of 10mEq/100g. Going by the aforementioned, the CEC value of the samples analyzed are marginal but can be considered acceptable considering the other favourable properties of the samples such as low compressibility and low activity clay minerals present.

Table 1. Grain size distribution

Grain size distribtion

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Gravel (>2mm)	1.3	1.2	1.5	1.3	1.3	0.9	0.8	0.8	1.1	1.3	0.8	0.9
sand (0.067-2mm)	14.7	13.3	14.5	12.3	11.2	12.3	15.3	13.8	11.2	12.4	13.3	12.1
silt (0.067-0.002mm)	50.7	59.9	59.84	63.1	65.34	63.7	64.3	63.74	63.4	64.13	65.1	64
clay (<0.002mm)	23.3	25.6	24.16	23.09	22.16	20.01	21.1	22.16	23.1	22.27	20.8	23

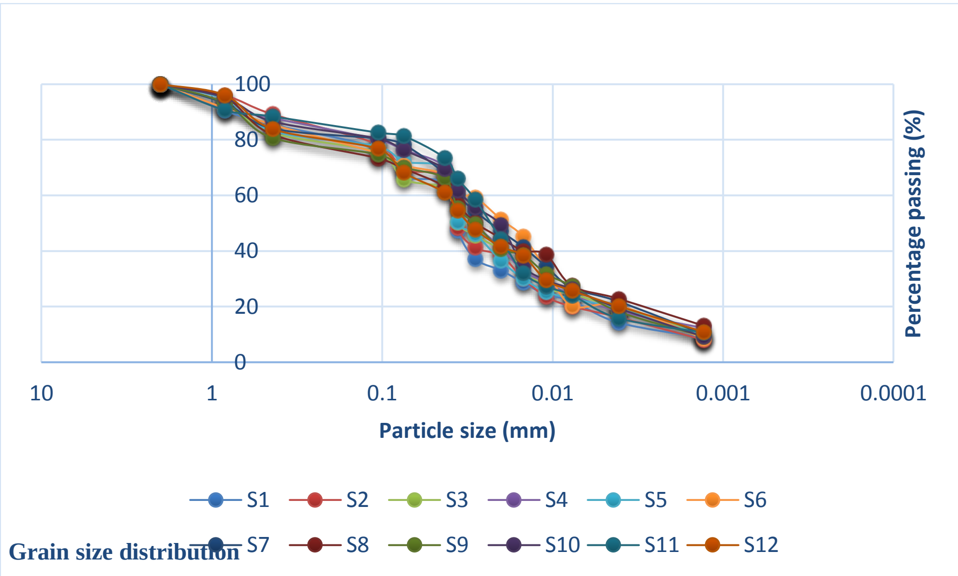

Figure 4. Grain size distribution curve

Table 2. Atterberg limits of the Samples

Samples	Plastic limits (%)	Liquid limits (%)	Plasticity index (%)
S1	14.3	29.6	15.3
S2	16	26.1	10.1
S3	21.36	33.81	12.5
S4	19.4	34.4	15
S5	16.9	27.3	10.4
S6	15.7	28.2	12.5
S7	20.28	36.51	16.23
S8	19.3	31.9	12.6
S9	21.7	34.8	13.1
S10	15.2	26.4	11.2
S11	22.7	37.2	14.5
S12	19.6	30	10.4

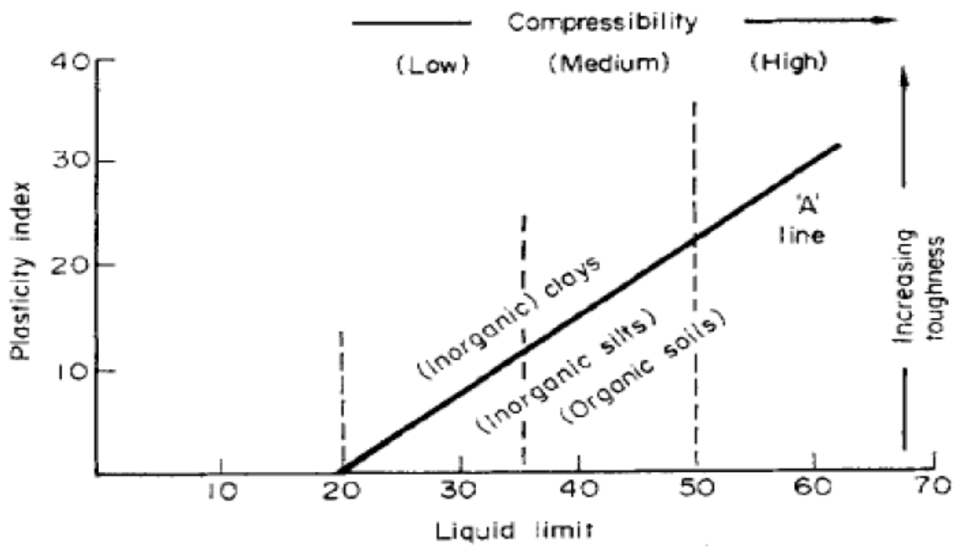

Figure 5. Clay identification chart (after A. casagrande, 1932)

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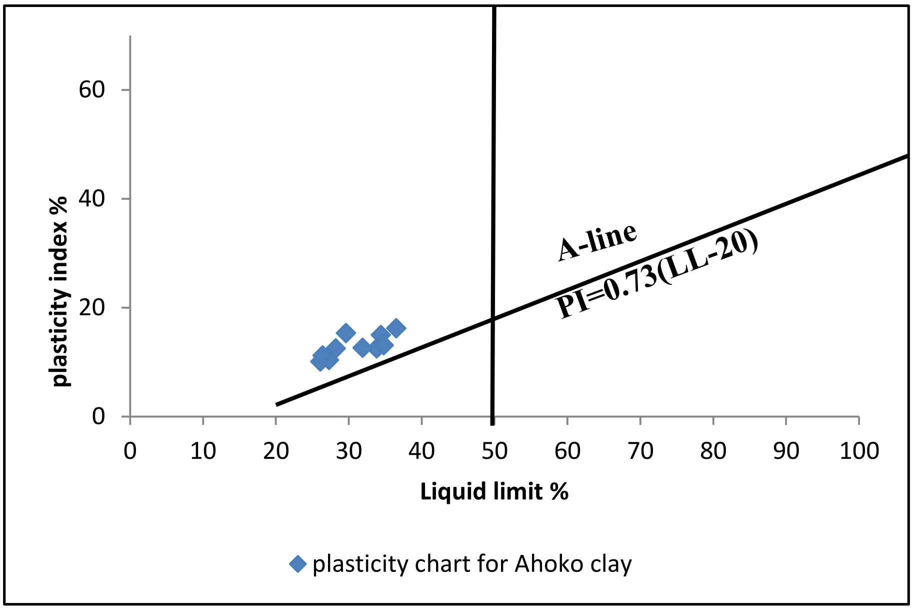

Figure 6. Clay identification chart of the samples (after A. casagrande, 1932)

Table 3. Specification for liner materials (modified after Daniel, 1990)

Property	**Limiting value**
Plasticity index (%)	>10
Activity	>0.3
Percentage of fine (%)	>30
Percentage of coarse particles	<30
Maximum particle size(mm)	25
Maximum thickness of the liner	For a domestic waste facility, it will generally be about 0.9-1.0m For industrial/toxic facility, it will generally be about 3-4m, although some specification require up to 15m or multiple composite liner system

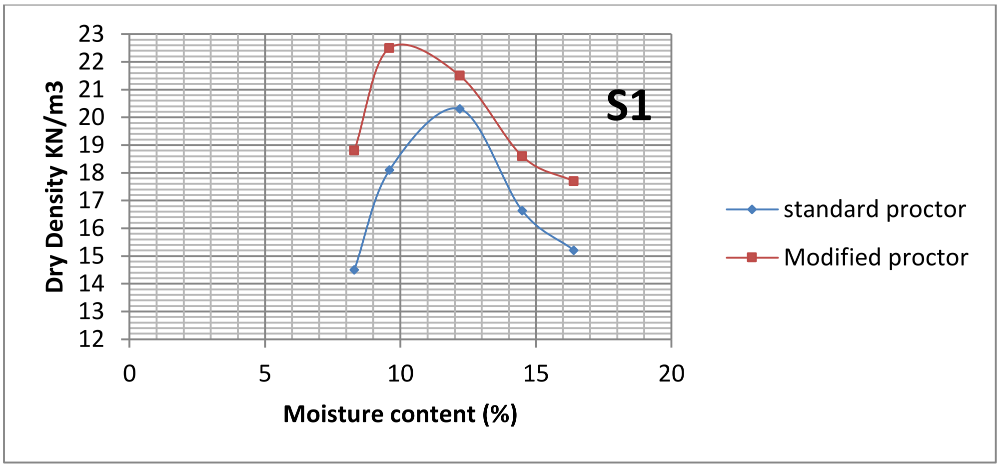

Figure 8. Compaction curves of sample 1 (S1)

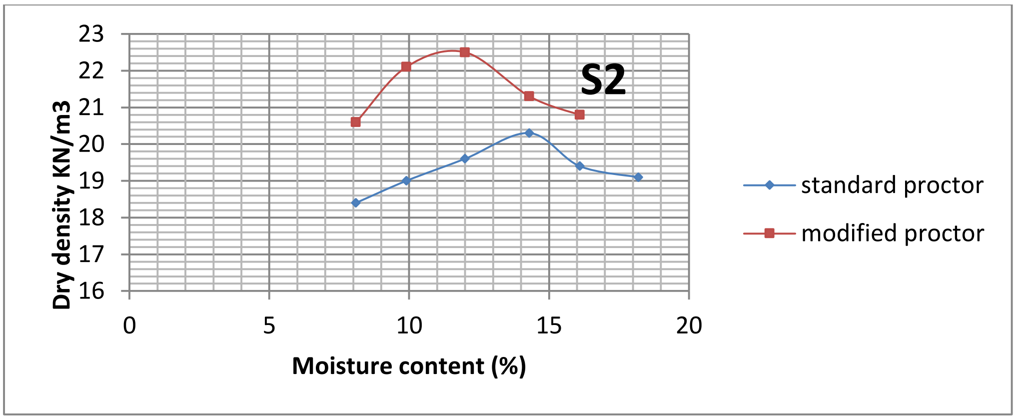

Figure 9. Compaction curves of sample 2 (S2)

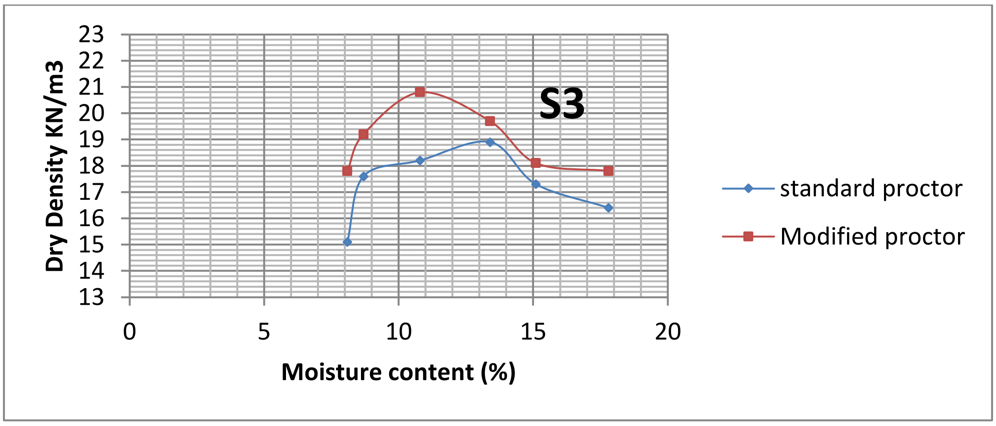

Figure 10. Compaction curves of sample 3 (S3)

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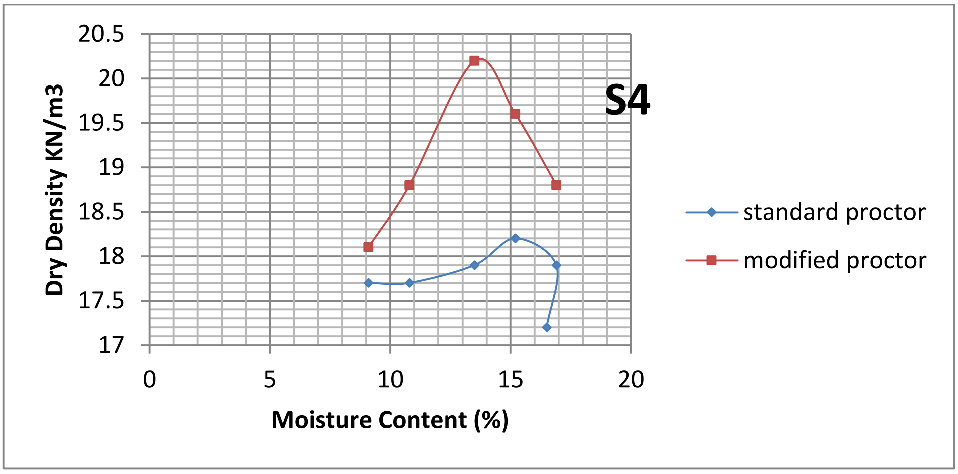

Figure 11. Compaction curves of sample 4 (S4)

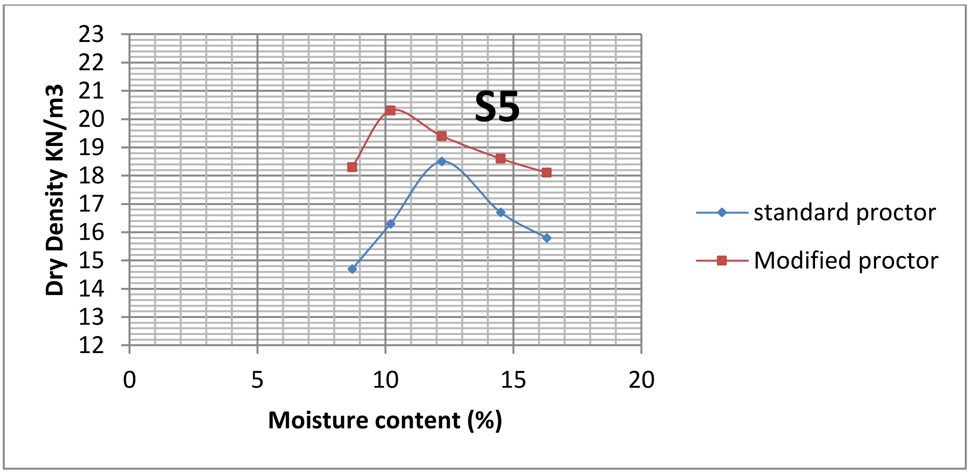

Figure 12. Compaction curves of sample 5 (S5)

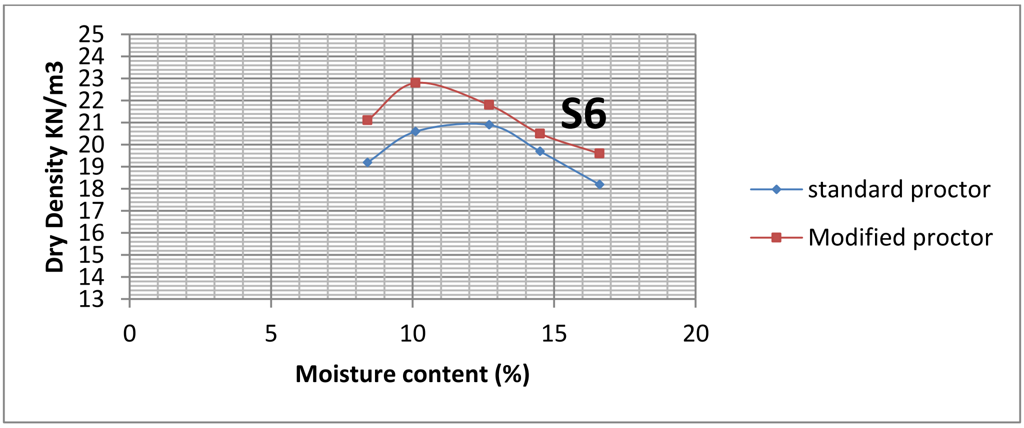

Figure 13. Compaction curves of sample 6 (S6)

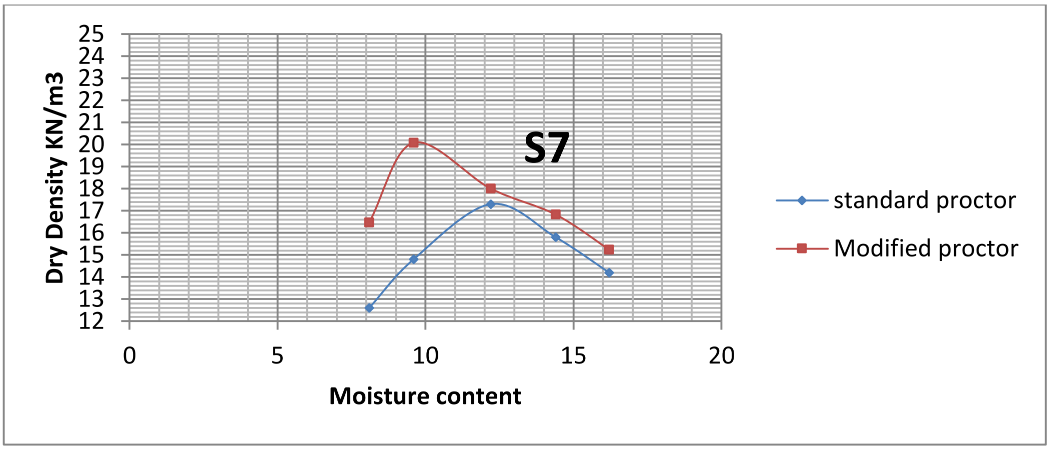

Figure 14. Compaction curves of sample 7(S7)

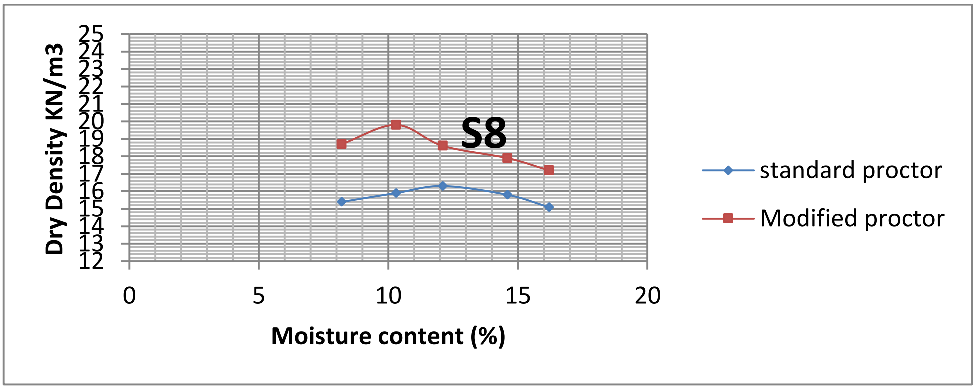

Figure 15. Compaction curves of sample 8 (S8)

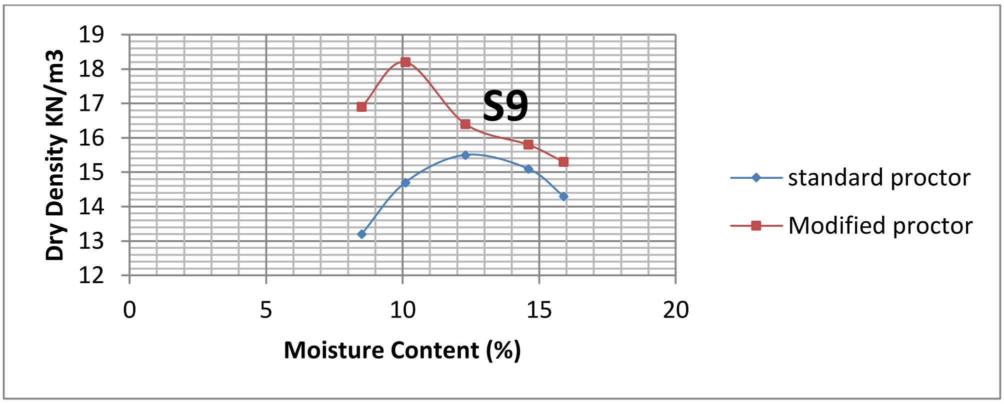

Figure 16. Compaction curves of sample 9 (S9)

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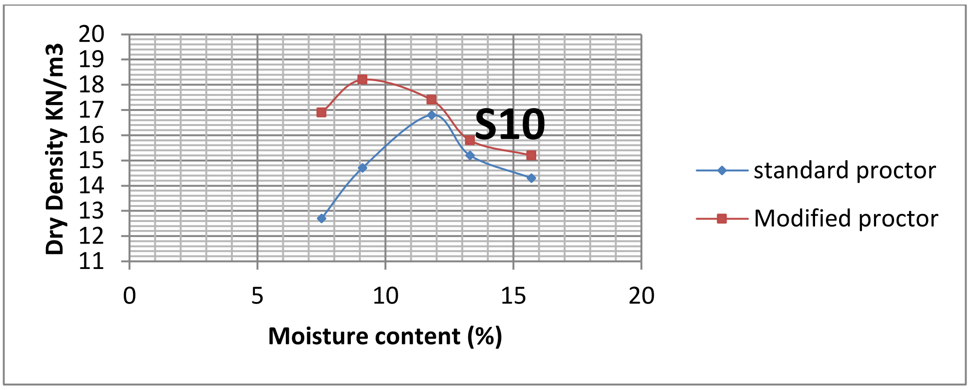

Figure 17. Compaction curves of sample 10 (S10)

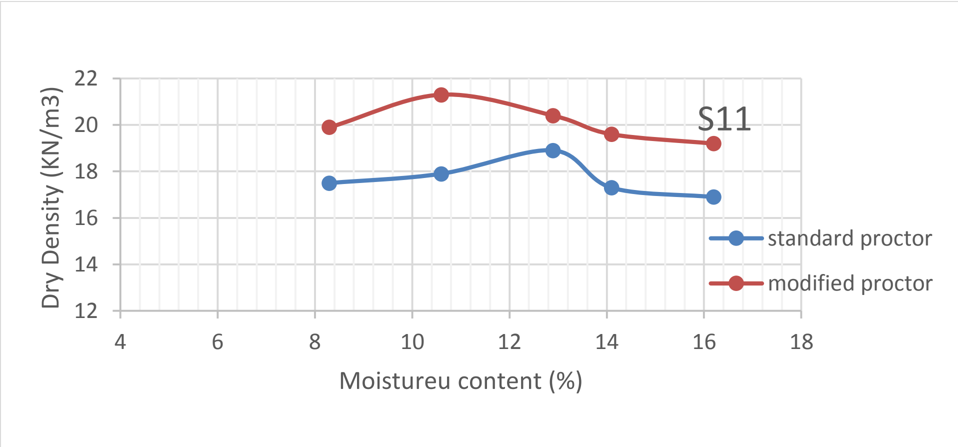

Figure 18. Compaction curves of sample 11 (S11)

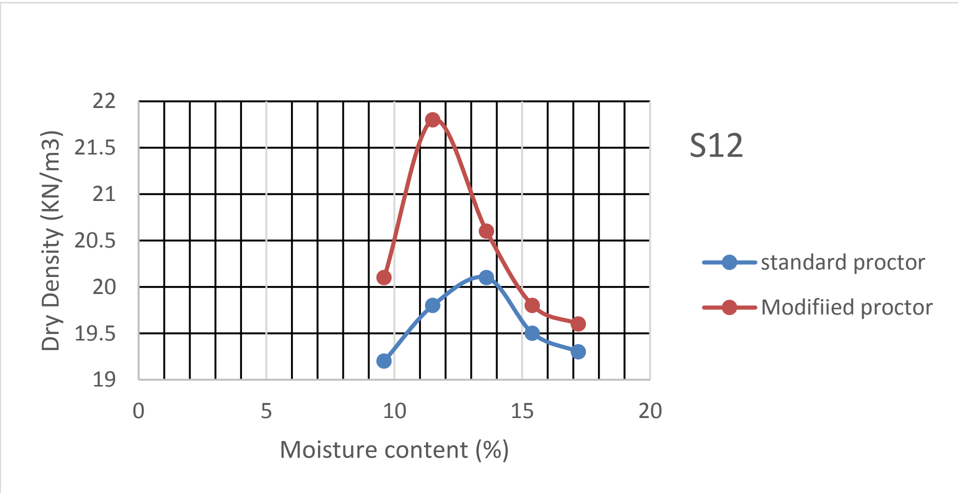

Figure 19. Compaction curves of sample 12 (S12)

Table 4. Geochemical properties of the samples

Composition	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Oxides (%)												
SiO_2	61.4	54.5	81.6	75.7	80.7	80.2	76.4	63	75.1	81.2	79	67.6
Al_2O_3	18.7	16.8	12.3	18.2	10.43	11.29	14.59	18	17.4	10.5	12.1	15.7
Fe_2O_3	11.38	5.45	2.02	5.3	2.69	3.37	4.32	6.7	5.12	3.13	4.4	3.75
MgO	8.32	1.28	1.34	2.1	0.89	0.58	2.17	3.2	0.84	0.27	4.24	4.01
CaO	9.22	1.346	2.49	2.4	0.593	2.4	2.76	11	2.12	1.346	1.6	1.23
Na_2O	4.038	3.81	4.01	2.3	0.011	2.83	4.02	2.4	3.49	2.13	2.3	1.12
K_2O	3.51	2.23	2.48	2.67	0.039	2.1	1.76	1.9	2.8	1.56	1.9	2.6
TiO_2	2.043	4.64	4.34	4.68	0.32	2.34	6.3	2.5	4.32	1.1	2.3	1.54
MnO	2.89	2.34	1.23	1.17	0.258	0.91	1.49	2.9	0.88	0.01	0.06	0.78
P_2O_5	1.77	1.44	0.49	0.23	0.045	0.31	0.82	1.9	0.27	0.22	1.23	0.02
CEC mEq/100	12.4	10.1	9.8	11.9	9.4	12.3	12.8	10.7	11.2	8.9	9.6	12.4

CONCLUSIONS

Based on the results presented in this paper, the following conclusions can be drawn;

I. The samples satisfy the basic properties for clay liner (e.g. Atterberg limits, grain size and percent of clay).

II. The grain size distribution coupled with the Atterberg limits also indicate that the samples will possess low activity which implies that the hydraulic conductivity will not increase when the soil is exposed to chemical attack.

III. The samples have low compressibility for the two levels of compaction test

IV. In addition, from the results obtained, it is safe to imply that the clay deposits found within the study may support minor structures under pristine conditions but such conditions are rarely ever present.

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