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Geotechnical Assessment of Clay Deposits in Minna, North-Central Nigeria for Use as liners in Sanitary Landfill Design and Construction

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Abstract Sanitary landfills are waste disposal method that functions without creating nuisance to the environment. It confines waste to the available area, reduce waste to the minimum practical volume. The waste in a landfill reacts to release a cocktail of contaminants called leachate, which posses treat to the surrounding environment (soil and groundwater). Therefore, barrier soils are required for the lining of a landfill to prevent seepage of leachate into the surrounding groundwater and subsequent contamination of the groundwater system. Some clay in Minna was assessed using geotechnical techniques to determine its suitability as barrier soils. Five samples of clay were subjected to grain size analysis, atterberg limits, compaction tests and mineralogy test. From the grain size analysis and the atterberg limit, the soil is classified as a clayey material. The liquid limit ranged from 45.5%-61% with a mean value of 51.8% which is an indication of high plasticity and low hydraulic conductivity, the plastic limit ranged from 29.2%-35.8% with a mean value of 32.44% and its plasticity index ranged from 13.7%-25.2% with a mean value of 19.37% which implies that the clay can withstand volumetric shrinkage on drying and exhibit a low to medium swelling potential when wet. The compaction test reveal an optimum moisture content(OMC) ranging from 17.7% to 24% with a mean value of 19.94% and a maximum dry density (MDD) that varied from 1.59g/cm^3 to 1.76g/cm^3 with a mean value of 1.7g/cm^3. This results of these geotechnical analysis suggests that the clay in the area meets the requirement for a barrier soil. The X-ray diffraction analysis reveals the presence of kaolinite dominated clay and mixed clay (kaolinite-illite). These minerals have the capability to attenuate and contain leachates from wastes. Hence, the studied clays are good barrier soils.

Keywords: *clay, geotechnical assessment, landfill design, barrier soils, containment, contamination, minna, north-central Nigeria*

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1. Introduction

Wastes may be defined as unwanted material in solid, liquid or gaseous form, which can be hazardous or non-hazardous. Since the origin of man, waste generation is a daily affair. The way and manner in which these wastes generated are disposed in developing countries are disturbing and worrisome (Amadi *et al*., 2012). The disposal of this waste has been a problem in the urban areas due high population and industrialization. A waste disposal method that functions without creating nuisance or hazard to the public health is a sanitary landfill and this can be achieved through modern technology. According to Amadi (2011) the purpose of landfill is to serve as a proper safe waste containment and control of leachate to mitigate groundwater pollution and the protection of the public health. There is need to place clay liners or barriers that will assist in the design and construction conditions required of a modern sanitary landfill. Hence the knowledge of the engineering properties of the barrier soil to ascertain its usability has become imperative owing to the large volume of waste generated in urban and semi-urban area, especially the state capitals in Nigeria.

In Nigeria today, the problem of waste disposal has become a priority due to poor management and indiscriminate disposal at unsuitable locations (Jones *et al*., 1995). According to Nwankwo (1994), growing populations, rise in income, and changing pattern of consumption combine to complicate waste management problems in Nigeria. Failing to properly dispose these wastes in well designed sanitary landfills poses a threat to soil, groundwater and surface water through contamination as a result of leaching of the contaminants generated by the waste. Hence, the barrier soil used in the design of sanitary landfill need to be assessed by using soil index properties (geotechnical properties) in order to determine its suitability as landfill liners (Amadi and Nwankwoala, 2013).

The permeability (hydraulic conductivity) of barrier soils is an important parameter in the design of waste disposal facilities involving burial in the natural clay deposits or the use of clay liners in underground reservoirs, low permeable soils are used in landfill as barriers (Oyediran and Iroegbuchu, 2013). Jones et al. (1995) emphasized on the careful selection of materials to form low permeability barriers, which is essential in engineered waste disposal system. Hence, the establishment of a landfill requires the use of soils with suitable geotechnical properties to ensure adequate engineering design and construction of a landfill. The mineralogy of the barrier soil is another factor which helps to determine the shrinkage and swelling potential of the barrier soil. This study assessed the geotechnical properties of clay in parts of Minna, North-Central Nigeria to ascertain their suitability for use as barrier soil for containment of leachates in future landfill sites.

2. Description of the Study Area

Minna is capital of Niger State and falls on Sheet 164. It lies between Latitude 09°24'N to 09°44'N and Longitude 06°25'E to 06°45'E (Figure 1). The study area is part of the North-central part of the Nigerian basement complex which comprises of the following lithological units: granodiorite, granite, schist, gneiss and quartzite (Figure 2). The area experiences distinct dry and wet seasons with annual rainfall varying from 1,100mm to 1,600mm (Truswell and Cope, 1963). The maximum temperature is recorded usually between March and April while the minimum is usually between December and January due to harmattan. The people in the study area are mainly farmers and civil servants.

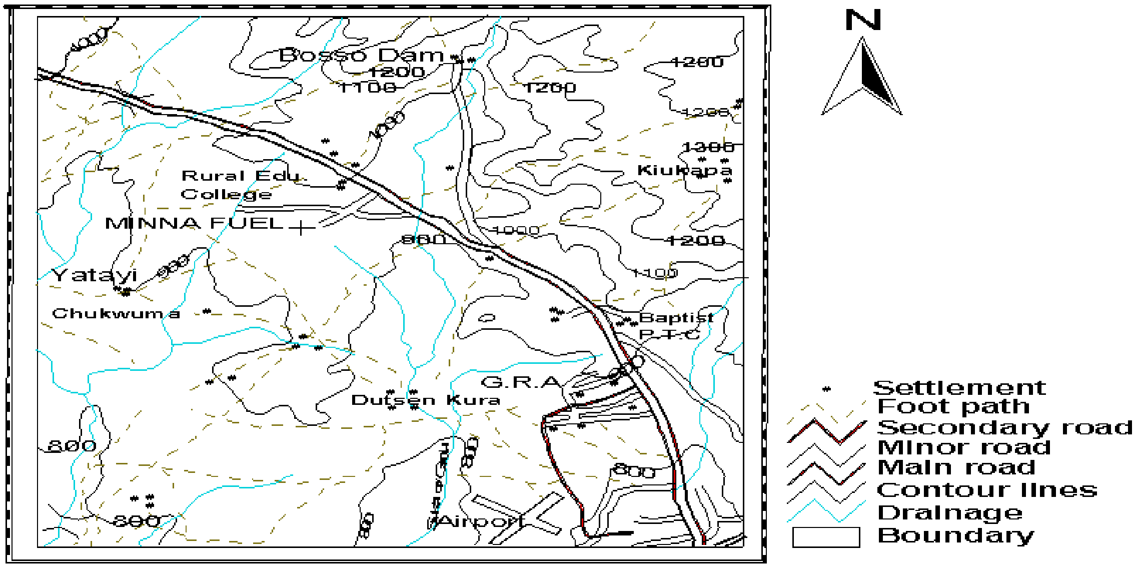

Figure 1. Topographical map of Minna

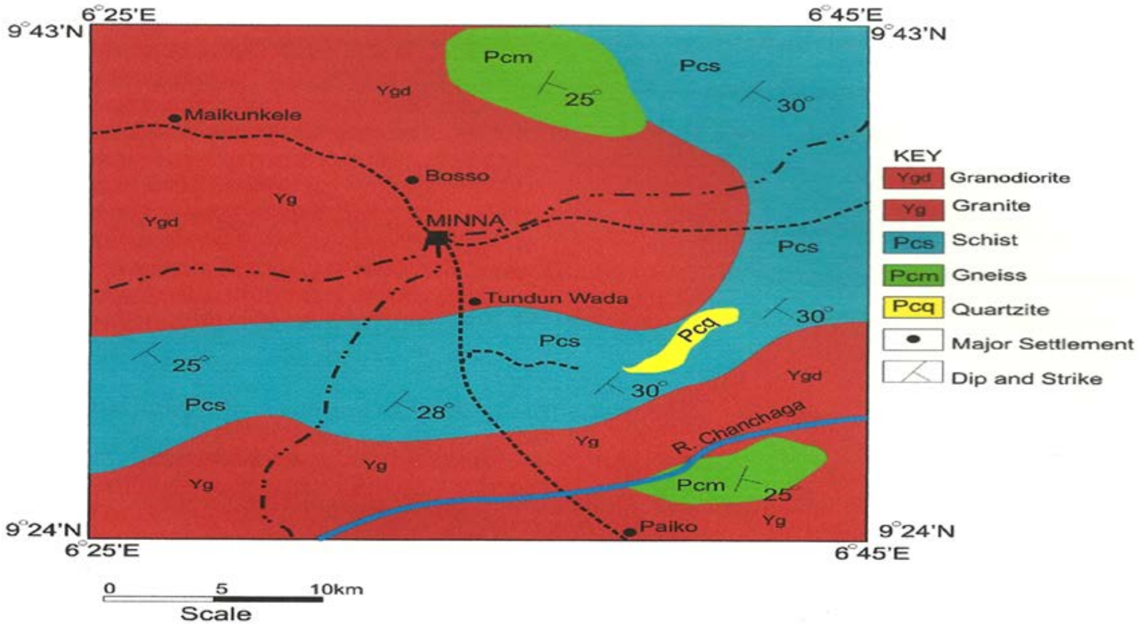

Figure 2. Geological map of Minna

3. Methodology of Investigation

The sub-soil conditions was investigated by excavating five trial pits from existing ground level to a maximum of 4.5m according to British standard code of practice for site investigation (1981), depending on topography and overburden. Disturbed samples soil samples were collected from the trial pits and analyzed at civil engineering laboratory, Federal University of Technology, Minna, Nigeria for relevant geotechnical analysis. The laboratory analysis was performed according to British standard methods of test for soil for civil engineering purposes (BS 1377: Part 1-9, 1990). Dry sieve analysis was performed in order to determine the soil particle size distribution.

The liguid limit was carried out with the Casagrande cup. Plastic limit test was performed by kneading and rolling soil samples between fingers and thumb into 6mm diameter thread. Each thread was further rolled between fingertips on a clean flat glass paste with sufficient pressure to reduce the diameter into 3mm. At exactly 3mm, the soil paste starts to crumble and cannot roll further. The the process was repaeted untill longitudinal and transverse cracks appear at a rolled diameter of 3mm. Immediately, the moisture content of the crack thread was determined. The mineralogy of the clay was determined using the X-ray diffraction method.

4. Results and Discussion

4.1. Field Observations

A typical soil profile of a trial pit is shown in Figure 3. The soil profile of the trial pit revealed the soil in the study area is made up of reddish-brown, sandy, silty-clay. The rate of excavating trial pits 1, 3and 5 was very slow thereby indicating a very stiff clay consistency while the durtion of excavating trial pits 2 and 4 was moderate which is a reflection of a medium dense relative density (Clayton *et al.*, 1995).

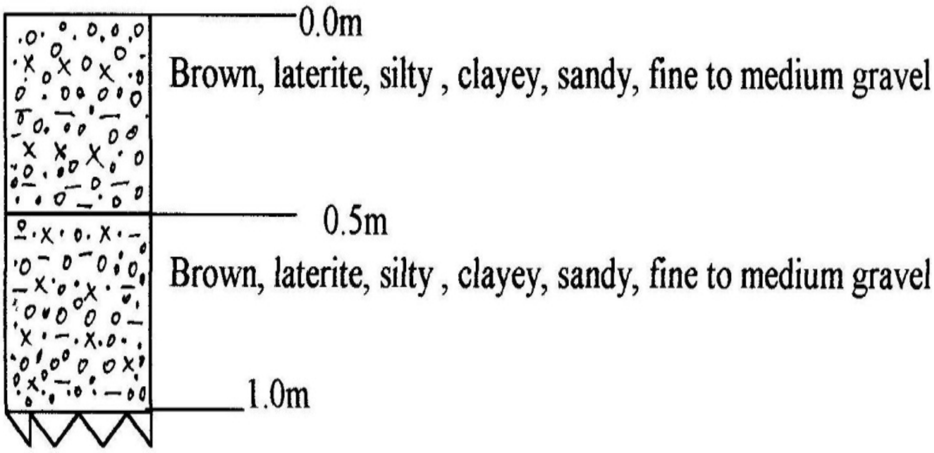

Figure 3. Typical Soil Profile of the trial pit

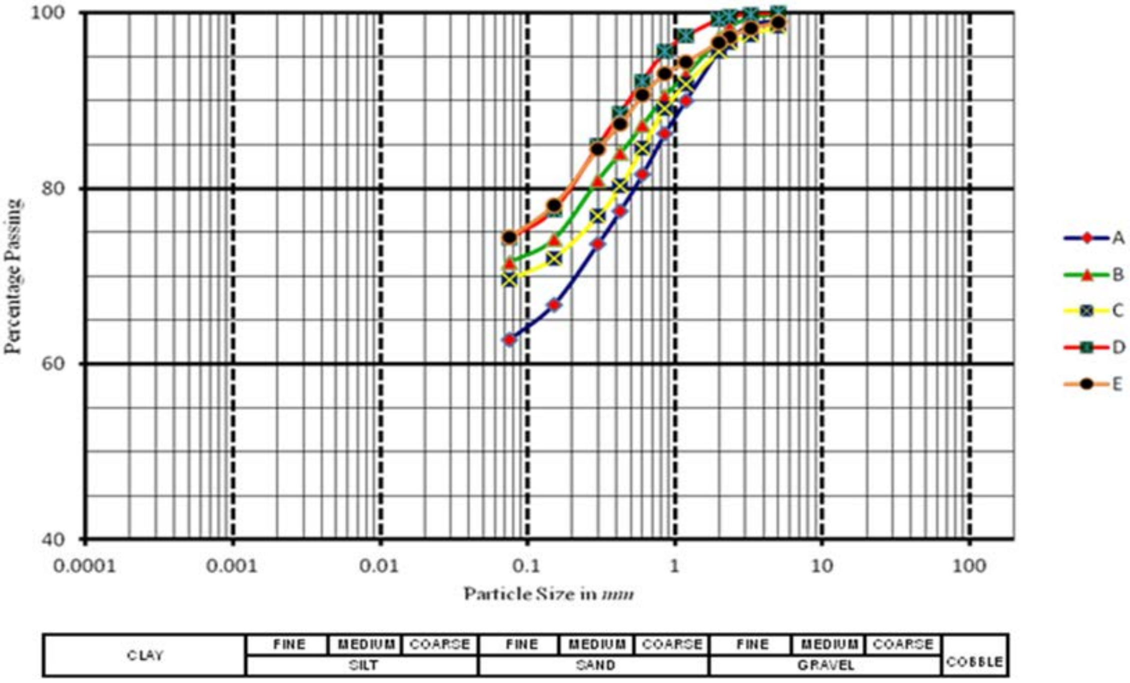

Figure 4. Particle Size Distribution Curve

4.2. Laboratory Results

4.2.1. Sieve Analysis

The results of the dry sieve analysis are summarized in Table 1 while the corresponding particle size distribution curve is shown in Figure 4. The curve had the ratio of sand > gravel > fines (clay + silt). This result may be attributed to the washing of the soil samples in order to remove the organic matter component of the soil and subsequent drying before sieveing. In the process of washing, it is possible that the clay and silt component of the soil were also removed as no hydrometer test was carried out due to lack of equipment. The soils samples under close observation are clayey soils, and consist of very fine grained. Fine grained soil with clay content above 10% implies low permeability. Soil samples meant for use as barrier soils in landfills should have at least 30% of fines (Benson *et al.*,1994; Daniel, 1993; Rowe *et al.*, 1995) and clay content greater than 10% (Declan and Paul, 2003).

Table 1. Summary of the Sieve Analysis results

Sample	Percentage passing (%)										
	Sieve size (mm)										
	5.000	3.250	2.360	2.000	1.180	0.850	0.600	0.425	0.300	0.150	0.075
A	99.13	98.67	97.00	95.80	90.00	86.23	81.57	77.47	73.70	66.77	62.77
B	99.83	99.50	98.47	97.13	93.00	90.53	87.23	84.03	81.00	74.23	71.57
C	98.50	97.53	96.57	95.63	91.87	89.13	84.63	80.27	76.87	72.07	69.63
D	99.97	99.83	99.53	99.27	97.33	95.57	92.23	88.60	84.87	77.53	74.30
E	98.90	98.23	97.30	96.63	94.37	93.03	90.60	87.30	84.50	78.07	74.43

4.2.2. Atterberg Limits

The results of the Atterberg limits are summarized in Figure 5 while the plasticity chart are illustrated in Figure 6. The Liquid limit ranged from 45.5% to 61% with a mean value of 51.8% which indicates high plasticity, the plastic limit varied between 29.2% - 35.8% with an average value of 32.44% and its plasticity index is of the order of 13.7% to 25.2% with a mean value of 19.37%. This is an indication that the clay can withstand volumetric shrinkage on drying and exhibit a low to medium swelling potential when wet. The shrinkage potential of soil samples 1 and 3 are ranked medium while remaining ones are of low shrinkage potential.

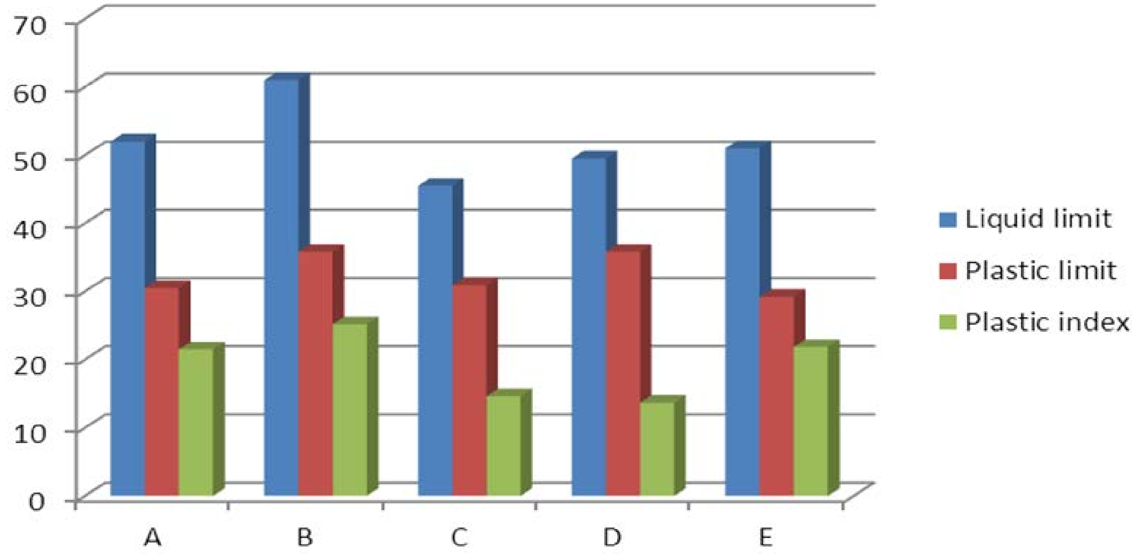

Figure 5. Atterberg limit results on soils from the area

Soils with high liquid limit generally have low hydraulic conductivity. Studies have shown that soils to be used as barrier soils in landfills should have minimum liquid limit of 20 (Benson *et al.*, 1994; Kabir and Taha, 2004). Liquid limit of less than 90% was recommended for landfill barrier soils by Declan and Paul (2003). The results of the liquid limit were more than 20% but less than 90%. The climatic conditions in the study area are similar to that of Kabir and Taha (2004). The result findings conform to that of Benson et al. (1994) and Kabir and Taha (2004), and therefore the soil in the study area can be recommended as landfill barrier soil.

Furthermore, soils with a very low plasticity index exhibit increase in hydraulic conductivity while a very high plasticity index exhibit excessive shrinkage. For soils to be used as barrier soil in landfills, a minimum plasticity index of 7% is required (Rowe et al., 1995; Daniel, 1993). Plasticity index of less than 65% was recommended by Declan and Paul (2003). The result of the plasticity index where greater than 7% and less 65%. The result conforms to the findings of Rowe et al. (1995) and Daniel (1993). Therefore the soil can be used as a landfill barrier soil. Strong correlations exist between plasticity index and the shrinkage potential of clays (Figure 5 and Figure 6). The clay soils exhibit low to medium shrinkage potential and this qualifies the soils as landfill barrier soil.

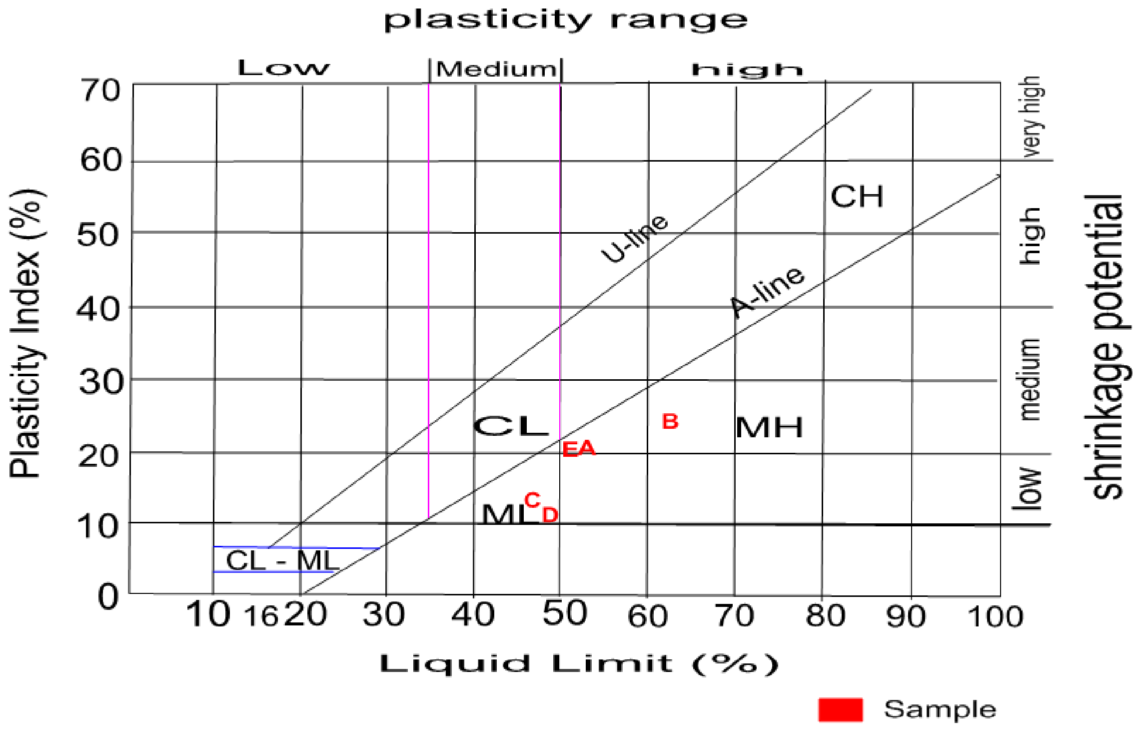

Figure 6. Plasticity Chart of the soil samples (After Casagrande, 1948)

4.3. Compaction Test

The compaction test results are summarized in Table 2. The optimum moisture content (OMC) ranged from 17.7% to 24% with a mean value of 19.94% while the corresponding maximum dry density (MDD) varied from 1.59g/cm^3 to 1.76g/cm^3 with an average value of 1.7g/cm^3. According Kabir and Taha (2003), all the samples met compaction test requirement and can be used as landfill barrier soil (MDD > 1.45g/cm^3 for soils derived from basement rocks). While according to Onorms (1990), soils from location A, B and C meets the MDD conditions for soils to be used as barrier soils in landfills (MDD ≥ 1.71g/cm^3).

Table 2. Results of optimum moisture content and maximum dry density of the soil samples

Sample	A	B	C	D	E
Depth (m)	3.0	3.0	3.0	4.5	5.0
OMC (%)	20.5	17.7	18	24.0	19.5
MDD (g/cm^3)	1.72	1.76	1.74	1.59	1.64

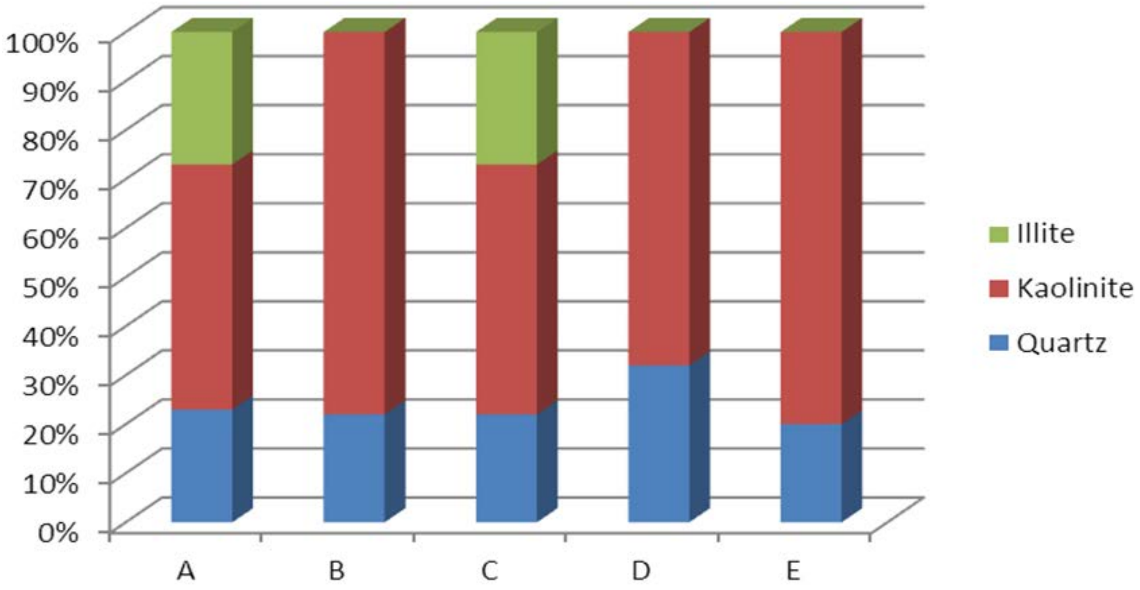

Figure 7. Mineralogical composition of the soil samples

4.4. Clay Mineralogy

Clay are effective landfill barrier system because of low hydraulic conductivity (low permeability), which is the rate at which a liquid passes through a material. The type and quality of the clay used affects the movement of leachates into the soil and groundwater system**.** The clay minerals and their relative abundance are shown in Figure 7.

The most abundant clay mineral in soil samples is Kaolinite. Mixed clay assemblages consisting of kaolinite and illite were noticed in sample A and sample C. kaolinite exhibit a low to moderate shrinkage on drying and a low to moderate expansion on wetting. Kaolinite is also non-reactive when in contact with chemicals. Illite is a non-expanding clay mineral. According to Batchelder *et. al*., (1998), Kabir and Taha (2006), Withlow, (1998), kaolinite rich clay tend to perform effectively as barrier soil. Allen (2000), Batchelder *et al*., (1998) stated that the combination of kaolinite and illite will serve best as barrier soils because they perform containment function and attenuation of contaminants. The studied soils meet the clay mineralogy requirement for landfill barrier soils. The typical diffractogram of the studied clay from each location are shown in Figure 8 and Figure 9.

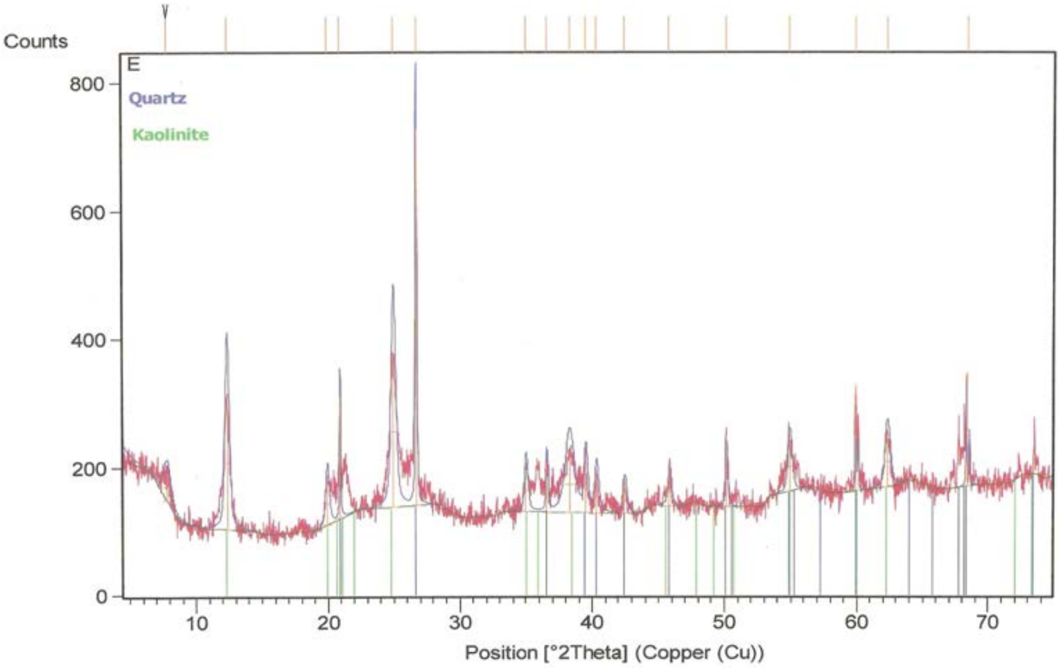

Figure 8. X-ray diffractogram for soil sample containing quartz and kaolinite

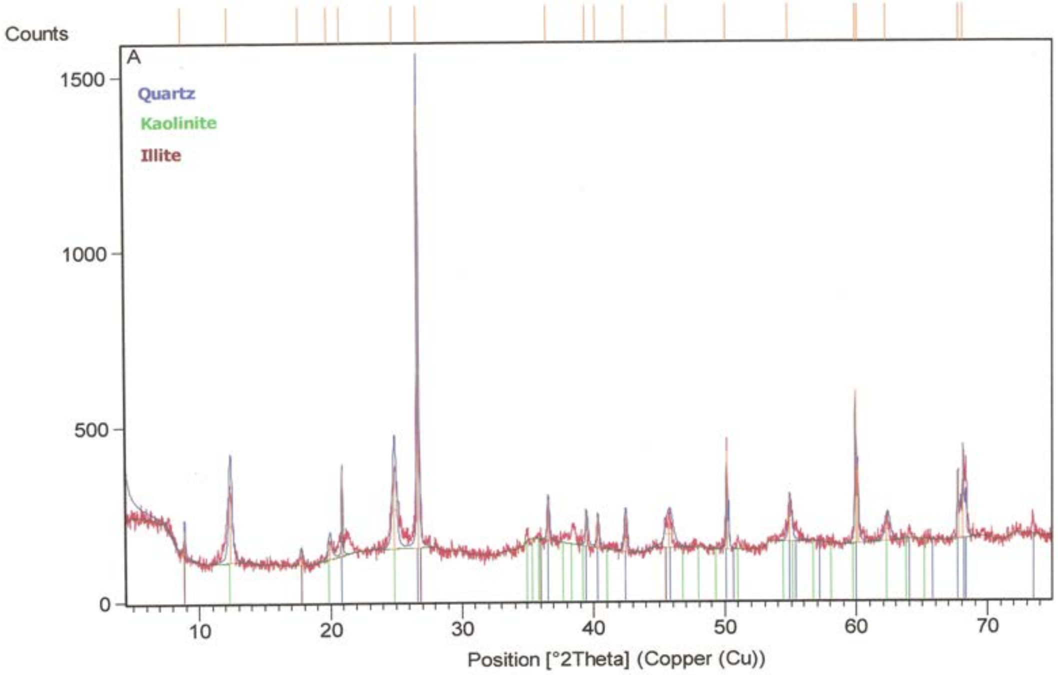

Figure 9. X-ray diffractogram for soil sample containing quartz, kaolinite and illite

4.5. Landfill Design Options for Soil and Groundwater Protection

Modern landfills are highly engineered containment systems, designed to minimize the impact of solid waste (refuse, trash, and garbage) on the environment and human health. In modern landfills, the waste is contained by a liner system. The primary purpose of the liner system is to isolate the landfill contents from the environment and, therefore, to protect the soil and groundwater from pollution originating in the landfill (Amadi et al., 2013). The greatest threat to ground water posed by modern landfills is leachate. Leachate consists of water and watersoluble compounds in the refuse that accumulate as water moves through the landfill. This water may be from rainfall or from the waste itself. Leachate may migrate from the landfill and contaminate soil and ground water, thus presenting a risk to human and environmental health. Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. This is done to prevent the uncontrolled release of leachate into the environment.

The choice of a suitable landfill system depends on the geological, hydrogeological and environmental settings of the area. The nature of the geology of the area and the need to protect aquifer from contamination through various human activities in the study area engineered the design of a sanitary landfill for the area (Amadi, *et al.*, 2012). The technique will ensure that the aquifers are not polluted by leachate from landfills as currently experienced in the area. The plan (Figure 10) and section (Figure 11) of the proposed modern sanitary landfill for the study area were designed to incorporate leachate collection chambers made of geological materials such as clay liners which are capable of impeding the downward migration of leachate (Amadi, et al., 2013).

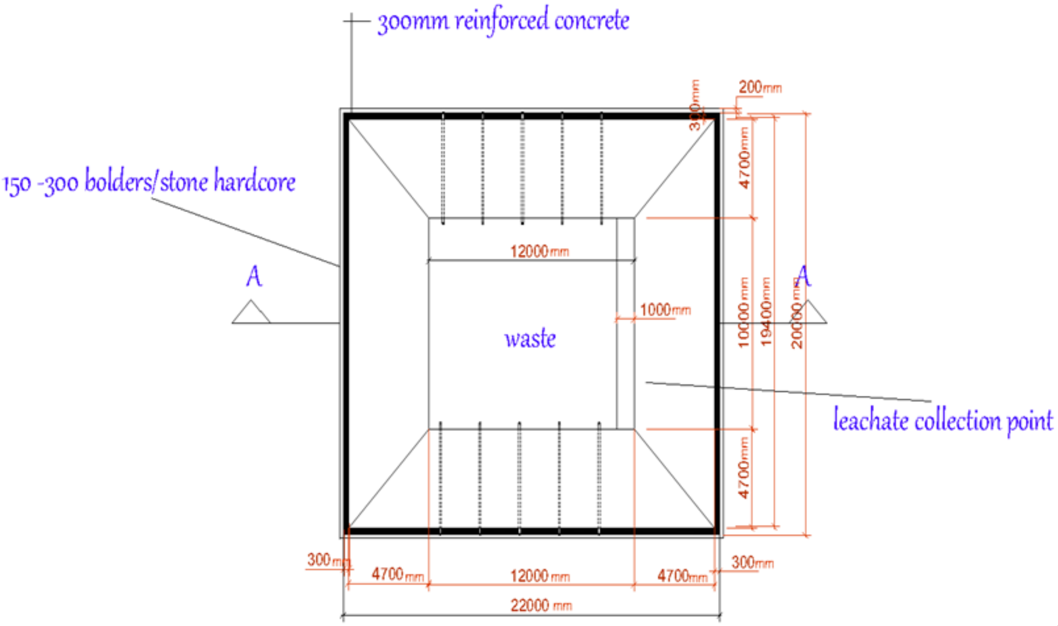

Figure 10. Section AA^I for the designed Modern Sanitary Landfill (Amadi *et al.*, 2013)

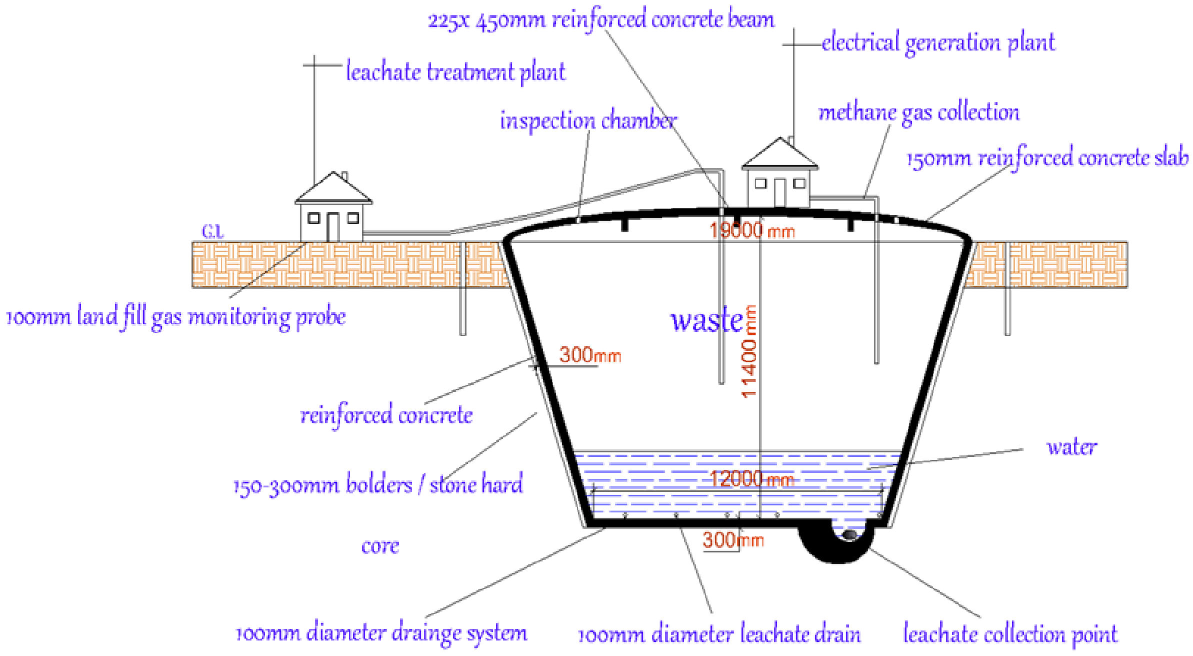

Figure 11. Plan of the Modern Sanitary Landfill for the study area (Aamdi *et al.*, 2013)

The fully constructed prototype of the recommended sanitary landfill is displayed in Figure 12 and Figure 13 for single and double clay liners respectively. Deposited waste should be compacted to enhance its density and stability and covered to prevent the activities of flies and rodents. Gas extraction systems are installed to extract the landfill gas which can be used to generate electricity.

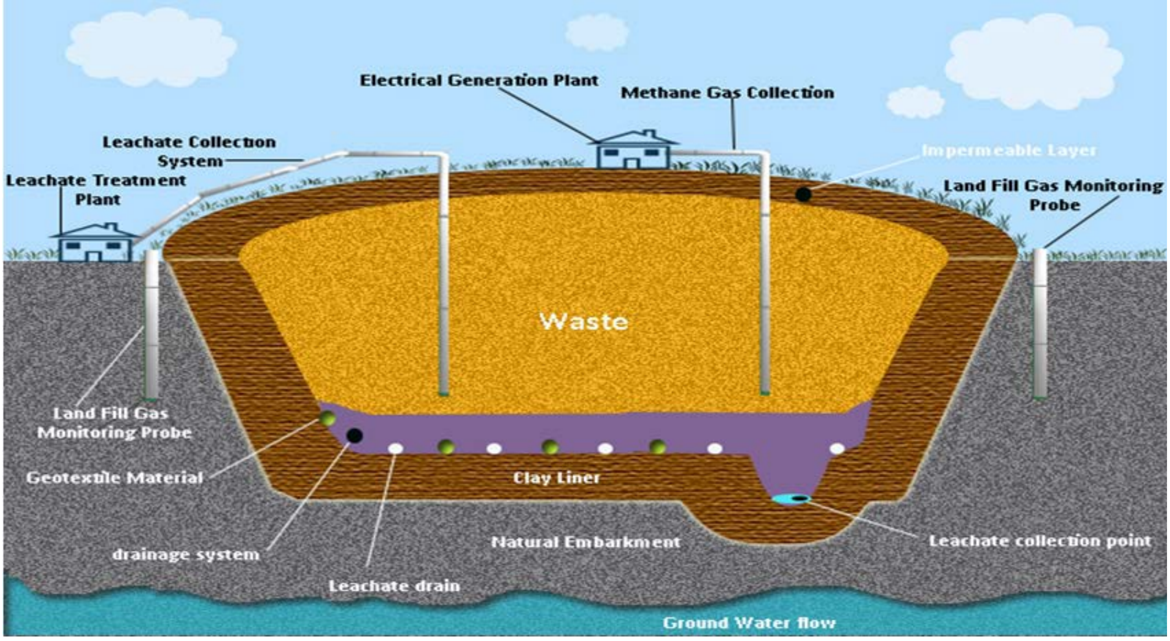

Figure 12. Single Clay-Liner Systems for low Vulnerability Area (Amadi *et al*., 2013)

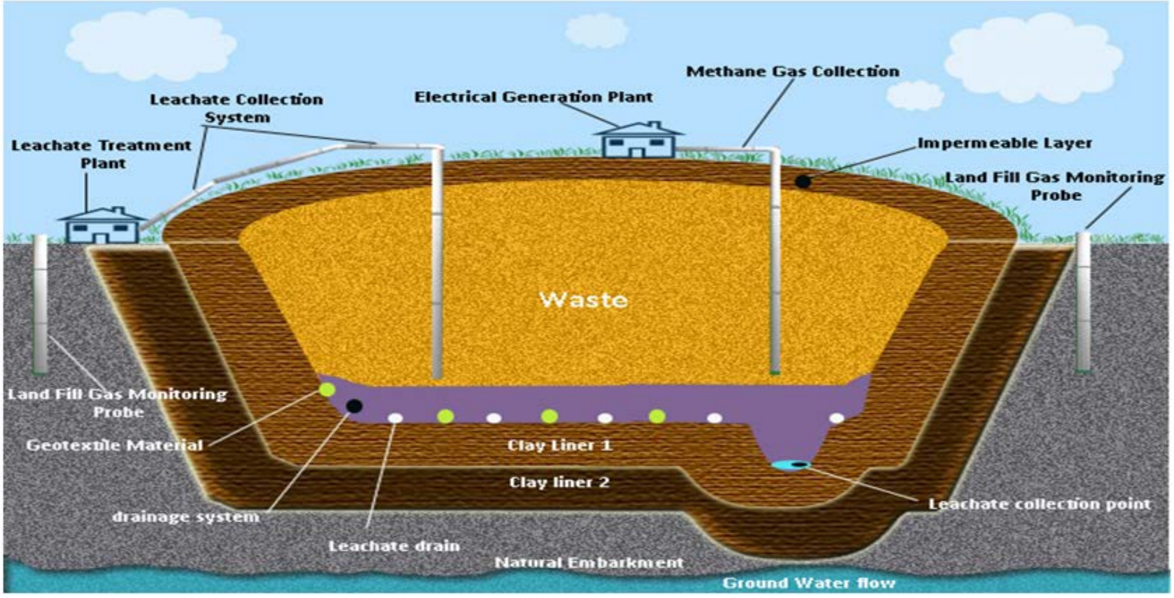

Figure 13. Double Clay-Liner Systems for high Vulnerability Area (Amadi *et al*., 2013)

4.6. Single Clay-Liner Systems

Single liners (Figure 12) consist of a clay liner (geosynthetic clay liner). Single liners system is used in landfills designed to hold construction and demolition debris. Construction and demolition debris results from building and demolition activities and includes concrete, asphalt, wood, bricks, paints, allumium or zinc roof and glass. These landfills are not constructed to contain paint, liquid tar, municipal garbage, or treated lumber; consequently, single-liner systems are usually adequate to protect the environment.

4.7. Double Clay-Liner Systems

A double liner consists of either two single liners (Figure 13). The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills. Hazardous waste landfills (also referred to as secure landfills) are constructed for the disposal of wastes that once were ignitable, corrosive, reactive or toxic (U.S. EPA, 2006).

These wastes can have an adverse effect on human health and the environment, if improperly managed. Hazardous wastes are produced by industrial, commercial, and agricultural activities. Hazardous waste landfills must have a double liner system with a leachate collection system above the primary composite liner and a leak detection system above the secondary composite liner. The landfill with double clay liners provides additional monitoring capabilities for the environment and the community.

To protect the ground water from landfill contaminants, clay liners are constructed as a simple liner that is two- to five-feet thick. In composite and double liners, the compacted clay layers are usually between two- and five-feet thick, depending on the characteristics of the underlying geology and the type of liner to be installed. Regulations specify that the clay used can only allow water to penetrate at a rate of less than 1.2 inches per year. The effectiveness of clay liners can be reduced by fractures induced by swelling, cracking and presence of some chemicals.

In theory, one foot of clay is enough to contain the leachate. The reason for the additional clay is to safeguard the environment in the event of some loss of effectiveness in part of the clay layer. The efficiency of clay liners can be maximized by laying the clay down in four- to six-inch layers and then compacting each layer with a heavy roller. The efficiency of clay liners is impaired if they are allowed to dry out during placement. Desiccation of the clay during construction results in cracks that reduce the liner efficiency. In addition, clays compacted at low moisture contents are less effective barriers to contaminants than clays compacted at higher moisture contents. Liners that are made of a single type of clay perform better than liners constructed using several different types.

The society produces many different solid and liquid wastes that pose threats to the environment and to human health. The way and manner in which these wastes generated are disposed in many state capitals in Nigeria is worrisome and disturbing. Clay liners may be single or double liners depending on the local geology, type and configuration of the barrier system. Clay liners such as bentonite or geotextile can provide considerable shear strength and structural integrity needed to contain landfill leachate thereby offering protection to the underlying soil and groundwater system. An important criterion for selecting an effective landfill barrier system is hydraulic conductivity. The plasticity, shrinkage potential and permeability are the properties of clay that determines it application as landfill liner.

5. Conclusion and Recommendation

The evaluation of the geotechnical properties the soil samples shows that it contains the required amount of clay suitable for use as barrier soils. The atterberg limits parameters (liquid limit, plastic limit and plasticity index) meets the requirement for use as barrier soils. Their low plasticity index which is an indication that their shrinkage potential is low and the high liquid limit that indicates high plasticity of the soil meets the requirement for use as barrier soil. The maximum dry density and the optimum moisture content of the soil indicates that the soil will perform well as a barrier soil regardless of the density and temperature condition of the landfill. The mineralogy of the clay further confirms that the soil will serve both containment and attenuation of contaminants. Hence, the investigated soil sample is recommended as barrier or liner in sanitary landfill for waste containment.

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