Geoscience Investigation of selected sites in Minna for siting a Sanitary Landfill

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ABSTRACT

An integrated geoscience investigation was carried out on 3 selected sites in Minna, North-Central Nigeria in order to determine their suitability for use as sanitary landfill. Geological and hydrogeological mapping of the area was executed to determine the rock type and aquifer properties of the area. Subsurface geophysical investigations of the area employing the 1-D and 2-D subsurface resistivity imaging techniques were undertaken. Four lithological layers: lateritic top soil, mottled zone, clayey soil and the weathered to fresh basement rock were delineated from the geo-electric sections. The clay layer thickness varies between 2.8m to 8.0m with resistivity range of 18 Ωm to 86 Ωm and the depth of about 3.8m to 9.3m. The 2-D resistivity images using Wenner-Schlumberger and Wenner-Alpha arrays revealed the presence of an overwhelmingly dominant clay interval in the subsurface. The grain size distribution curve showed that the soil is dominated by fines (clay and silt. The soils liquid limit, plastic limit and plasticity index values ranged between 20 % to 90 %, 13.2 % to 26.8 % and 11.3 % to 24.7 % respectively. This implies that the soil is of low hydraulic conductivity. Permeability coefficient of the soils ranged from 3.4×10^{-6} cm/s to 5.68×10^{-8} cm/s, which is within the 10^{-8} to 10^{-6} range required for attenuation of leachate by natural geological materials with no potential of lateral migration of leachate. The analysis of results from geological, hydrogeological, geophysical, geotechnical and structural investigations revealed that two out of the three sites are suitable for siting a sanitary landfill.

Keywords: *Geoscience Investigation, Sanitary Landfill, Minna, and Groundwater Pollution*

1. INTRODUCTION

The management of waste in Nigeria is yet to take a definite shape and this can be attributed to non-enforcement of existing environmental laws. Most developed nations of the world have properly managed their wastes within their domain as a result of proper planning and effective waste management policies (Oyediran and Adeyemi, 2011; Amadi *et al.*, 2012a).

Properly sited municipal solid waste sanitary landfill has been recognized as one of the environmentally friendly ways of waste disposal (Ranke, 2001; Ige, 2013). The concept of a well-engineered municipal sanitary landfill technology is aimed at minimizing soil and groundwater contamination and other associated environmental hazards. The sanitary landfill system is designed and constructed to include lined leachate containment with minimal risk of vertical and horizontal leakage into surface and groundwater systems. The merit of the sanitary landfill over other types of waste disposal methods is that handling and management of waste is kept to a minimum level (Ige, 2013; Amadi *et al.*, 2012b). The local geology, hydrogeology and geotechnical characteristics of a site are key determinants of the suitability of a site for use as sanitary landfill, hence the need for this study. Daniel (1993), Kabir and Taha (2006), Rowe *et al*, (1995), Edelman (1999), Ige and Ogunsawo (2009), Oyediran and Adeyemi (2011) in their various investigations have proposed certain recommendations that must be attain for a soil to be considered for use as barrier soil for sanitary landfill. Four major open dump-sites apart from some minor ones scattered all over the metropolis are currently in use in Minna. They constitutes public nuisance by the smell and smoke generated in the course of their decomposition and burning respectively.

Groundwater is an essential natural resource that needs to be protected at all cost, because once it is contaminated it is difficult and expensive to clean up (Amadi *et al.*, 2014). A study targeted at assessing the suitability of a site for use as a landfill in order to ensure protection to the soil and water system and avoid the occurrence of water-borne diseases should be encouraged by all. The choice of site for sanitary landfill construction is critical as the consequences of a wrong choice leads to soil and groundwater pollution, environmental degradation and various health impact (Rowe, 2011). No effort should be spared in making accurate decisions that would lead to the choice of suitable sites for locating a solid waste sanitary landfill system.

1.1. Study Area

The investigated sites (A, B and C) are located within Minna metropolis and lie between longitudes 6°24'E to 7°00'E of the Greenwich Meridian and latitudes 9°30'N to 10°00'N of the Equator and are accessible through major roads (Figure 1). The River Chanchaga catchment basin forms the drainage system for th area and the tributaries are ephemeral. The area has two seasons: the rainy and dry seasons. The average annual rainfall of about 1100mm while the temperature is about 29°C. The vegetation of the study area belongs to the savannah type. The major rock type in the area is granite, granite-gneiss and schist with relics of quartz-veins and pegmatites as minor intrusions.

2. MATERIALS AND METHODOLOGY

Geological mapping was carried out in the area to know the rock types in the area. Fresh rock samples were collected and subjected to both micro-photographic and mineralogical analyses to understand the mineralogical composition and mode of occurrence. The petrographic thin section analysis was carried out at the Geological Laboratory, Federal University of Technology, Minna while the mineralogical analysis was carried out the Nigerian Geological Survey Agency, Kaduna. Geophysical investigation employing the 1-D and 2-D resistivity subsurface imaging were undertaking in the study area to obtain lateral and vertical subsurface information. Hydrogeological mapping was undertaking to establish the aquifer types and groundwater flow direction. Static water level values were collected from 45 hand-dug wells within the vicinity of the investigated sites. Soil samples were collected from trial pits across the sites. A total of five trial pits were excavated at each site. The samples were transported to the Civil Engineering Laboratory at Federal University of Technology, Minna, and Federal Polytechnic, Bida in polythene bags, for relevant geotechnical analysis. The analyses were carried out in accordance with BS 1377 standard.

3. RESULTS AND DISCUSSIONS

3.1. Geological Mapping

Information obtained from the geological mapping shows that the area is underlain by three rock types namely granites, granite-gneiss and schist. The schist is dipping toward the east, with dip ranging from 12° to 64° east. The predominantly joint direction is NE-SW. The petrographic thin section identified biotite, microcline, quartz and plagioclase as the major constituents of the rock from the study area (Plates 1a and 1b).

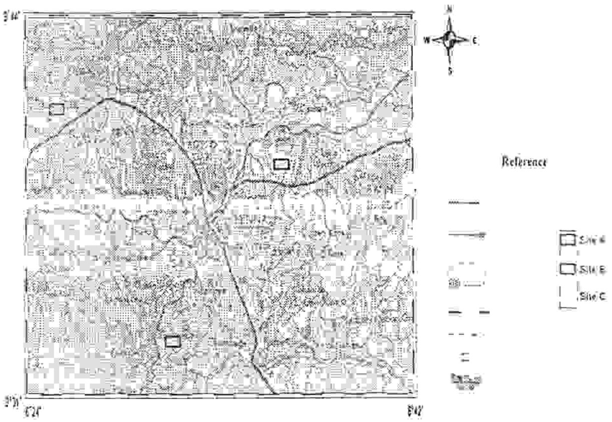

Figure 1: Topo map of Minna, showing the three sites

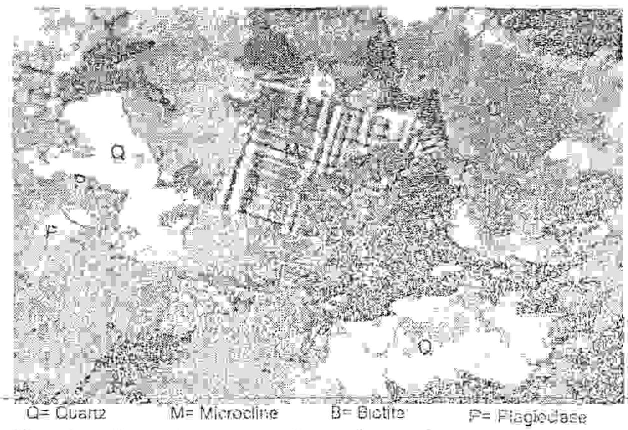

Plate 1a: Photomicrograph of granite-gneiss

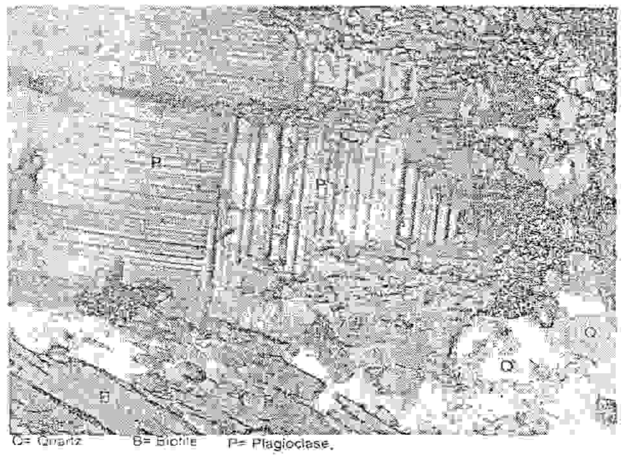

Plate 1b: Under cross polarize light (Magnification X40)

3.2. Geophysical Investigation

The 1-D model sounding curves show three layers indicating four lithological units in the subsurface formations across the study area. Lateritic soil, mottled zone, clayey soil and weathered/fresh basement rocks were the different layers delineated from the VES curves and geoelectric sections. The mottled zone is a transitional layer that exists between the lateritic soil and clay soil. The dominant curve type in the area is HA (Figure 2).

Table 1: Geoelectric parameters indicating Curve Types for profile B

	RESISTIVITY ρ (Ωm)/ Thickness h(m)								
	Profile 1B			Profile 2B			Profile 3B		
LAYER	VES 1B	VES 2B	VES 3B	VES 4B	VES 5B	VES 6B	VES 7B	VES 8B	VES 9B
Layer1 ρ1/h1	141/0.9	93/1.4	380/0.7	64/0.8	130/1.0	100/1.1	89/1.5	118/1.3	99/1.3
Layer 2 ρ2/h2	71/7.2	113/7.4	112/6.0	22/4.4	68/5.7	60/7.3	86/5.2	83/6.3	72/8.0
Layer 3 ρ3/h3	300/∞	290/∞	863/∞	231/∞	245/∞	274/∞	504/∞	303/∞	265/∞
CURVE TYPE →	HA	A	HA	HA	HA	HA	A	HA	HA

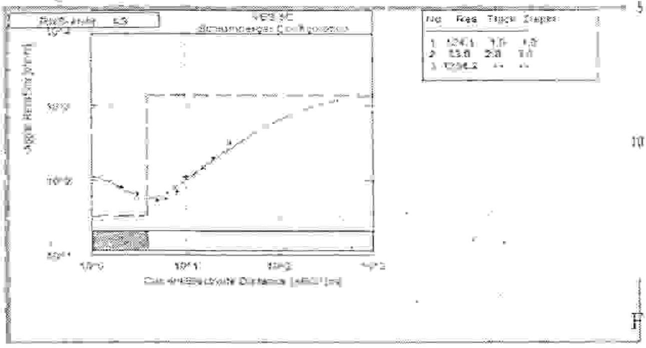

Figure 2: Sounding Curve Type for HA

The geoelectric section as constructed from the geoelectric parameters obtained from VES contained in Table 1 indicates different layers. The resistivity of the mottled zone ranged between 74 Ωm to 96 Ωm to the depth of about 1.0m to 1.4m while that of laterite ranged between 100 Ωm to 174 Ωm to the depth of about 0.9m to 1.3m. The top layer is underlain by clayey soil characterized with low resistance which ranged between 18 Ωm to 86 Ωm with a thickness range of 2.8m to 8.0m to the depth of 3.8m to 9.3m. The last layer is the crystalline basement rock unit with varying degree of weathering which has resistivity values range between 231 Ωm to 366 Ωm to a fairly infinite depth. From the geoelectric sections (Figures 3a and 3b) the clay soil, show low resistivity values due to their charged surfaces and associated boundary layers of attracted ions.

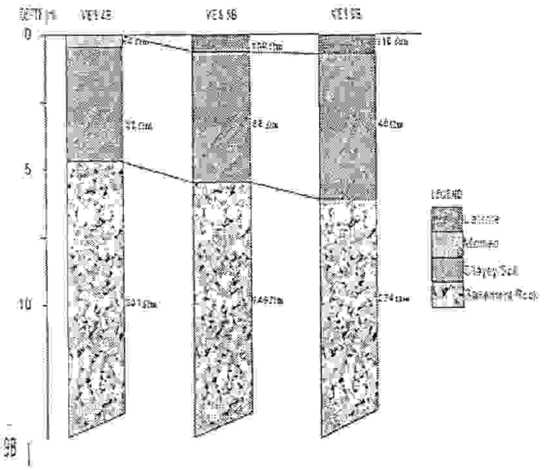

Fig. 3a. Geoelectric Section 2B for site B

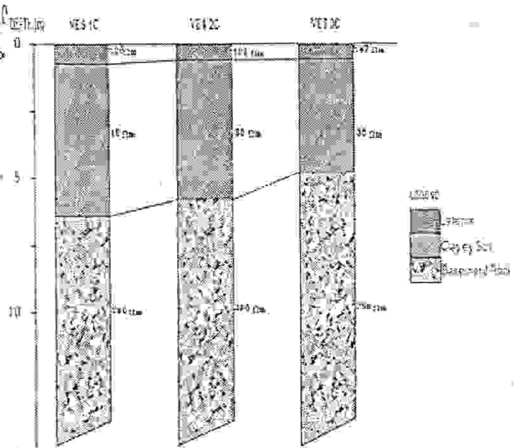

Fig. 3b. Geoelectric Section 1C for site C

The 2-D subsurface images identified different lithologic layers which are distinguishable based on the response to electrical current. The resistivity increases away from the blue colour to the red and pink colours as indicated on the inverses model resistivity sections (Figures 4a and 4b). The inverse model shows a highly conductive clay layer as the top layer with resistivity values less than 100 Ωm and depth extend of about 12m. Underlying the clay layer is the weathered basement rock unit with resistivity value range of 110 Ωm to 500 Ωm. The last layer is the highly resistive bed rock with resistivity values range of 558 Ωm to greater than 1433 Ωm extending to a fairly infinite depth.

3.3. Hydrogeological Mapping

The study area is made up of two aquifer units which are; the regolith aquifer and the fractured aquifer.

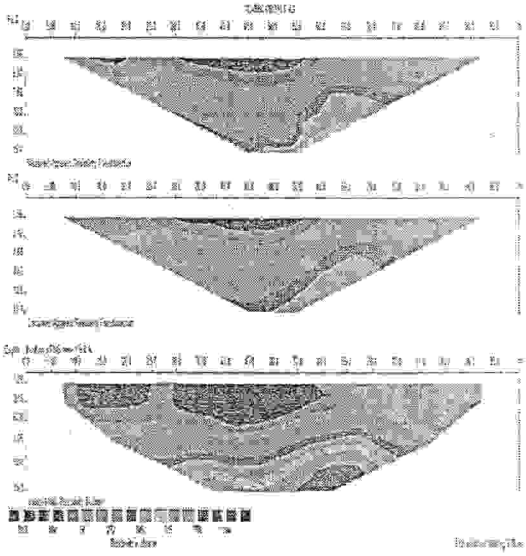

Fig.4a. Inverse Model resistivity section for profile B3

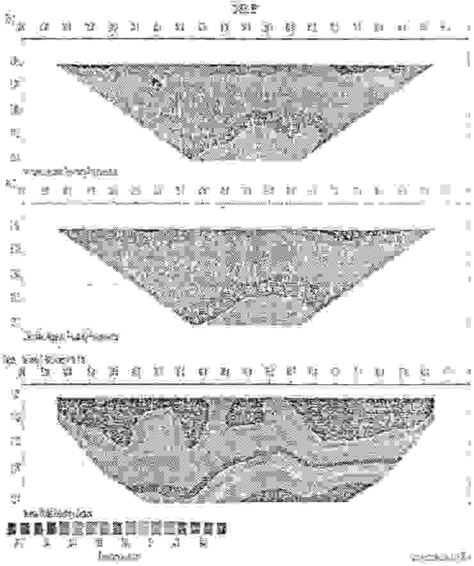

Fig.4b: Inverse Model resistivity section for profile C3

From the data (Table 2), the average depth to static water level in the study area is about 4m. The depth of the wells ranged from 2.6m to 10m depending on the thickness of the overburden material. The groundwater flow direction map generated from the water level data (Figure 5) indicates a NE-SW flow direction is mainly toward the southern portion of the mapped area. This finding is in line with the result of the principle joint direction. This implies that the groundwater in the area is structurally controlled.

Table 2: Representative Hydrogeological Well Data.

S/N	Co-ordinates		Altitude (m)	SWL (m)	Depth of well (m)	Hydraulic Head
	N (°)	E (°)				
1	9.63275	6.57119	286	6.9	7.2	279.1
2	9.63328	6.57150	278	4.6	6.3	273.4
3	9.63103	6.57386	299	7.6	8.3	291.4
4	9.63008	6.57583	288	3.5	5.2	284.5
5	9.62992	6.57553	273	6.0	6.2	267.0
6	9.62950	6.57583	276	5.0	5.4	271.0
7	9.62936	6.57578	269	3.7	3.8	265.3
8	9.62900	6.57611	295	3.6	3.9	291.4
9	9.62925	6.57606	289	3.7	5.0	285.3
10	9.62919	6.57542	296	3.5	4.6	292.5
11	9.62853	6.57619	284	4.8	5.0	279.2
12	9.62869	6.57603	284	3.4	4.3	280.6
13	9.62817	6.57619	298	3.9	4.0	294.1
14	9.62761	6.57772	280	3.6	4.6	276.4
15	9.62761	6.57789	234	0.9	4.6	233.1
16	9.62742	6.57811	203	1.2	5.3	201.8
17	9.62794	6.57825	284	1.0	3.8	283.0
18	9.62828	6.57861	285	2.0	4.0	283.0
19	9.62842	6.57958	293	3.0	5.4	290.0
20	9.62844	6.58017	294	6.7	7.1	287.3

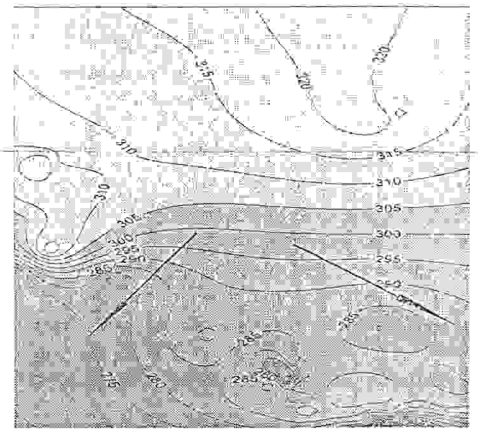

Figure 5: Groundwater flow direction of the study area

3.4 Grain size distributions

The result of the grain size distribution and a representative grading curve are presented in Table 3. Particle size distribution is one of the key factors that influence the hydraulic characteristic of soil. Daniel, (1993), Rowe *et al*, (1995), Ige, (20013), Oyediran and Adeyemi, (2011) suggested the minimum of 30% fines and less than 30% gravel size particles for soil to be used as mineral seals in sanitary landfill. Declan and Paul, (2003) suggested 10% clay content as requirement for soil to qualify for use in sanitary landfill as mineral seal.

From the grain size analysis the soil retained on the BS sieve No.4 ranged from 0.0% to 10%. The sand size fraction ranges from 8.2% to 42.1% while the amount of fine particles passing the BS sieve No.200 ranged from 50% to 91.8%. The results of the grain size distribution are within the limits suggested by previous authors. The high percentage of the fine particles predominantly clay fractions will influence the low permeability of the soils. Ogunsawo, (1996) observed that soils containing adequate amount of sand particle could prevent the soil from volumetric shrinkage when used as mineral seal.

Table 3: Summary of particle size distribution of soils in percentage

Site	Samples	Gravel %	Sand%	Fines%
A	A	0.9	36.5	62.6
	B	1.8	42.1	56.1
	C	0.2	28.2	69.6
	D	1.5	28.9	69.6
B	E	0.0	25.5	74.5
	F	1.1	24.4	74.5
	G	1.0	21.9	77.1
	H	0.2	25.8	74.0
C	I	0.0	8.2	91.8
	J	0.2	25.8	74.0
	K	10.0	40.0	50.0
	L	0.1	24.0	75.9
Minimum		0.0	8.2	50.0
Maximum		10	42.1	91.8
Mean		1.4	30.0	71.6

3.5. Atterberg Consistency Limits

The result of the Atterberg consistency limits are presented on Table 4. The consistency limit tests indicate that the liquid limit of the soils ranged from 24.5% to 51.5% while the plastic limit varied from 13.2% to 26.8%. The plasticity index ranged from 11.3% to 24.7% (Table 4). The plasticity index indicates the fines portion soil and their ability to change shape without a change in volume. Declan and Paul (2003) and Benson et al. (1994) suggested a minimum liquid limit of 90% and 20% respectively for soil to be used as mineral seal in sanitary landfill. This implies that the soils have the potential to exhibit low hydraulic conductivity.

Daniel (1993), Rowe et al. (1995) and Ige, (2007). suggested that plasticity index for soil to be used as mineral seal must be greater than 7%. The analysed soils possess liquid limits greater than 20% but less than 90% and plasticity index greater than 7%. This indicates that the soils have the potential to exhibit low hydraulic conductivity, display minimal expansion rate when in contact with fluid and have low potential for developing secondary leachate pathways (Benson *et al* 1994). This finding is in agreement with the recommendation of Benson *et al* (1994) for soil to be used as mineral seal in sanitary landfill.

Table 4: Summary of Atterberg limits results in percentage

Sites	Label	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index
A	A	33.5	17.1	16.4
	B	39.9	21.5	18.4
	C	34.9	18.5	16.4
	D	35.0	18.5	16.4
B	E	42.0	24.1	17.9
	F	40.0	20.0	20.0
	G	36.0	18.1	17.9
	H	34.0	19.1	14.9
C	I	51.5	26.8	24.7
	J	47.5	23.6	23.6
	K	44.0	22.2	21.8
	L	24.5	13.2	11.3
	Minimum	24.5	13.2	11.3
	Maximum	51.5	26.80	24.70
	Mean	38.6	20.23	18.21

4.6. Compaction Test

This test method was used to determine the relationship between Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the soil samples. The amount of mechanical energy applied to soil mass is known as the compaction energy. The standard and modified Proctor compaction energies were employed in this work. The results of the MDD and the OMC and a representative plot of dry density versus moisture content are contained in Table 5. The peak of the curves indicates the MDD and the corresponding OMC (Fig. 9). The result of the MDD and OMC of the standard Proctor energy ranged from 1.58 KN/m3 to 1.82KN/m3 and 16.5% to 25.9% respectively while for the modified proctor energy, the soils MDD and OMC ranged from 1.74KN/m3 to 2.10KN/m3 and 11.0% to 18.9% respectively. Kabir and Taha (2004) stated that for a soil to use as mineral seal it should possess MDD not less than 1.45g/cm^3 for standard Proctor and 1.64g/cm^3 for modified Proctor. The analyzed soils have values that compete favourably with the recommendations of Kabir and Taha (2004). Ige and Ogunsawo (2009) stated that MDD increases and OMC decreases with an increase in compactive efforts. This may be due to the fact that more parallel orientation of the phyllosilicate mineral particles occurs at higher compaction energy. A higher unit weight of compaction occurs as the clay particles become closer on higher compactive effort. Hence, the modified compaction effort is preferable as it does significantly reduce the hydraulic conductivity of the soil.

Table 5: Summary of the MDD and OMC of the two Compaction Energies

Sample Label	Standard Proctor		Modified Proctor	
	MDD (KN/m^3)	OMC %	MDD (KN/m^3)	OMC %
A	1.70	19.0	1.94	14.0
B	1.76	17.6	2.00	12.0
C	1.71	20.1	1.89	14.0
D	1.74	18.1		
E	1.59	24.0	1.88	13.5
F	1.64	18.5		
G	1.49	19.1	1.74	18.9
H	1.58	25.9	1.80	16.5
I	1.68	19.9		
J	1.70	19.7		
K	1.82	17.9	2.10	11.0
L	1.68	16.5	1.87	15.5
Minimum	1.49	17.9	1.74	11.0
Maximum	1.82	25.9	2.10	18.9
Mean	1.67	19.96	1.88	15.08

3.7. Coefficient of Permeability

The results of the permeability coefficient are presented i Table 6. Coefficient of permeability is one of the critica factors in the choice of soil or site for sanitary landfill. It i the function of the structure and grain size of the soil. Th coefficient of permeability of all the analysed soils range from 3.4 x 10^{-6} cm/s to 5.68 x 10^{-8} cm/s. USEPA (1973 suggest a permeability of 1x10^{-4}cm/s as the boundar between permeable and impermeable linears. Allen (2000 suggested that natural geological materials considered for attenuation of leachate in landfill should possess an optimum coefficient permeability range of 10^{-6}cm/s to 10^{-8}cm/s. For a soil to be used as mineral seal for the attenuation of leachate it should have a maximum permeability coefficient of 1x10^{-7}cm/s (Rowe *et al*, 1995, Ige and Ogunsawo, 2011, Oyediran and Iroegbuchu, 2013). All the analysed soil samples are in line with the findings of Allen (200); Rowe et al (1995) and Ige and Ogunsawo (2011). The soils have the potential to exhibit low to practically impermeable permeability characteristics which will enhance grater attenuation of leachate contaminant in sanitary landfill system.

Table 6: Coefficient of Permeability of the Soil Samples

Soil	A	B	C
k (cm/s)	5.53 x 10^{-6}	4.58 x 10^{-6}	4.73 x 10^{-6}
Soil	D	E	F
k (cm/s)	3.56 x 10^{-6}	4.81 x 10^{-7}	3.85 x 10^{-7}
Soil	G	H	I
k (cm/s)	1.88 x 10^{-7}	4.73 x 10^{-6}	4.65 x 10^{-8}
Soil	J	K	L
k (cm/s)	5.68 x 10^{-8}	3.40 x 10^{-6}	6.42 x 10^{-7}

3.8. Clay Mineralogy

Chemical weathering of rock results in the formation of clay at or near the earth's surface. The formation of clay as a result of weathering activities is dependent on four major factors which include; mineralogical and textural composition of the parent rock, porosity and permeability of the parent rock, composition of the aqueous solution and the morphology (position of the weathered parent rock) (Thair and Olli, 2008).

Table 7: Facial mineralogical composition of some clay samples

Clay Soil	Mineralogy (Decreasing order)					
		Quartz	Kaolinite	Muscovite	Goethite	Hematite
	Compound name	Silicon Oxide	Aluminum Silicate Hydroxide	Potassium Aluminum Silicate Hydroxide	Iron Oxide Hydroxide	Iron Oxide
	Chemical formula	SiO_2	$Al_2Si_2O_5(OH)_4$	$KAl_2(Si_3Al)O_{10}(OH)_2$	$Fe_2O(OH)$	Fe_2O_3
	Crystal system	Hexagonal	Anorthic	Monoclinic	Orthorhombic	Orthorhombic
Sample B		✓	✓	✓		
Sample F		✓	✓			
Sample I		✓	✓		✓	
Sample J		✓	✓	✓		✓

From the mineralogical composition of the representative clay soil, kaolinite is the most dominant clay mineral in all the soil analysed (Table 7). From the oxide composition of the rock and clay samples as determined by XRF (Table 8), the major oxides found are SiO_2, Al_2O_3 and K_2O. These oxides form the composition of potassium feldspar and kaolin, and it is the transformation of potassium feldspar into kaolin that forms clay as justified from the equation: $2\ KAlSi_3O_8 + 3\ H_2O\ Al_2Si_2O_5\ (OH)_4 + 4\ SiO_2 + 2\ K\ (OH)$ (Thair and Olli, 2008). This therefore implies that the clays are non-expendable with low cations exchange capacity (CEC). The clays will exhibit less effective surface area of about 10-30m^2/g (Thair and Olli, 2008). With the effective surface area been small, the clays will exhibit low to moderate expansion on wetting and low to moderate expansion on drying. The high occurrence of quartz as indicated in the diffractograms (Figure 6) may be responsible for the significant percentage of sand size particles in the grain size distribution.

3.9. Soil Classification

Soils for engineering purposes are classified in accordance to the Unified Soil Classification (USCS) and American

Association of State Highway Transport Officials (AASHTO) Classification systems.

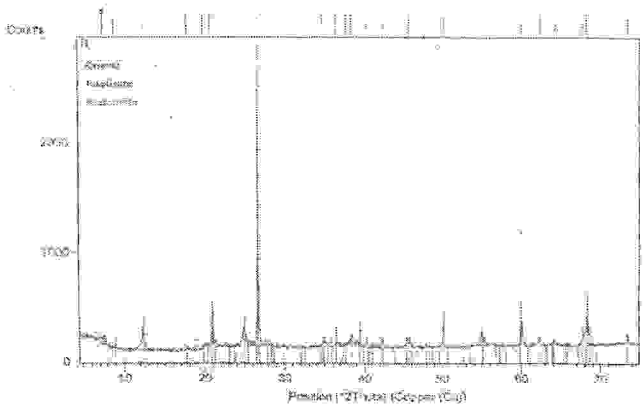

Figure 6: X-Ray Diffractogram for a sample

Table 8: Major Oxide Composition of Rock and Soil Samples

Oxide	Rock Samples			Clay soil Samples			
	MK1	MA1	DB1	B	F	I	J
SiO_2	74.3	75.10	66.80	56.2	50.80	44.10	46.20
TiO_2	0.30	0.21	0.81	0.94	1.20	1.21	1.94
Al_2O_3	14.70	14.90	16.50	23.30	27:20	27.50	26.80
Fe_2O_3	4.16	3.75	6.23	4.58	4.44	8.84	5.70
MnO	0.10	0.11	0.29	0.03	0.04	0.05	0.04
MgO	0.36	0.81	1.03	1.96	0.96	2.50	2.43
CaO	2.43	2.07	3.26	0.45	0.48	0.29	0.60
Na_2O	1.62	1.17	2.04	2.01	2.24	2.41	2.09
K_2O	1.03	0.78	1.78	0.82	0.84	0.88	1.17
P_2O_5	0.15	0.13	0.19	0.01	0.006	0.02	0.008
BaO	0.11	0.05	0.24	0.006	0.11	0.04	0.001
LOI	0.74	0.92	0.83	9.64	11.68	12.16	12.42
Total	100	100	100	99.946	99.996	100	99.399

In accordance to the USCS all the soil samples indicate PI greater than 7 and LL less than 50% except for sample I which have LL greater than 50%. Based on the soil classification, all the soil are classified as inorganic clay materials of low to medium plasticity with the exception of sample I which is classified as inorganic clay with high plasticity. According to the AASHTO classification system, the soil samples analysed have more than 35% soil particles passing the No.200 sieve, the PI of the soils is greater than 10% and the LL less than 40%. Hence, the soil samples are clayey soil with the symbol A-7-6.

On the plasticity chart (Figure 7), samples A, B, C, D, E, F, G and H fall within the A-7-6 section which indicate that they are inorganic clay (CL) of low to intermediate plasticity. Soil sample I is classified as inorganic clay of high plasticity (CH) because it has liquid limit greater than 50% and occur above the A line. Soil samples J, K and L fall within the A-6 section of the plasticity chart, which indicate that they are inorganic clays (CL) of low plasticity. Soil which fall under groups A-7-6 and A-6 contain appreciable amounts of fine which makes the soils suitable for use as sanitary landfill liners.

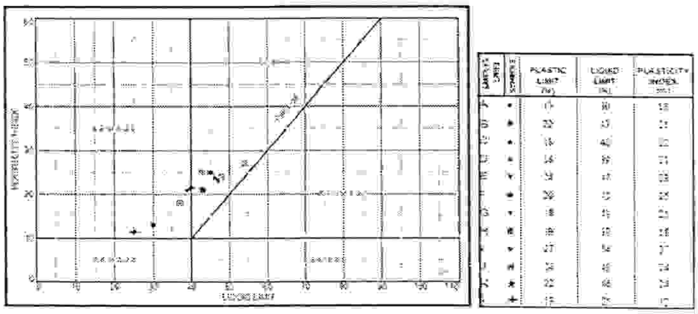

Figure 7: Plasticity chart of the clay soils

4. CONCLUSION

An integrated geoscience approach was used to investigate three sites in Minna, for the purpose of generating a data that will aid the siting (design and construction) of a sanitary landfill. The area was underlain by granite, granite-gneiss and schist. The soil profile of the study areas are in the order of: top humus soil, laterite/mottle zone, clay soil and weathered to fresh basement rock. Inverse model resistivity sections shows a thin to thick highly conductive clayey layer underlain by weathered basement rock which overlays the fresh basement rock. The safe depth of excavation is between 7m to 9m, due to the inhomogeneous nature of the sites. The study area is made up of the regoliths and fractured aquifer units. The groundwater flow direction is NE-SW in accordance with the principle joint direction in the area. Hence care should be taking to protect the groundwater vulnerable area by minimizing leachate infiltration into groundwater system, since the direction of groundwater flow can also serve as conduit for leachate movement.

The soils are generally well graded possessing the required amount of fines, clay minerals and sand size fraction required for a soil to be used as mineral seal. The clays possess low, intermediate to high plasticity with low shrinkage abilities. The coefficients of permeability of the soils indicate very low permeability with the soils falling within the favourable range ($1x10^{-6}$cm/s to $1x10^{-8}$cm/s) of optimum hydraulic conductivity for attenuation. Although the sites indicated favourable geotechnical properties, site A is geological and hydrogeological unsuitable for a sanitary landfill as a result of the high weathering and fracture of the underlying rocks. The fractures can serve as conduits for possible migration of leachates. Site B and C have competent rocks that have not experience significant weathering and fracturing and hence suitable for siting sanitary landfill system. The integrated approach employed in evaluating the sites for sanitary landfill are more rewarding to using any single method to investigate the sites.

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