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Geophysical, Geotechnical and Groundwater Quality Assessment of a Proposed Sanitary Landfill at Gosa Village, Abuja, Nigeria

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Abstract
Geophysical, geotechnical and water quality investigations of Gosa dumpsite in Abuja were carried out with a view to investigating the feasibility of upgrading it to a modern sanitary landfill. Nineteen Vertical Electrical Soundings (VES) were carried out for geoelectric characterization of the site. Also, eight soil samples (two undisturbed samples and six disturbed samples) were obtained for geotechnical analysis. Inversion of the VES data indicated 3 to 4 geoelectric layers namely; topsoil, laterite, weathered basement and fresh basement. Depth to basement varied from 4.1 m to 27.2 m. Geotechnically, the soil samples from the study area were classified as well graded clayey-sand to silty-sand. Plasticity of the clay fraction of the samples varied from low to intermediate. Maximum activity of clay (Ac) of 0.6 showed presence of inactive clay. Permeability test showed that the permeability of the sample ranges between 5.1×10^{-7} m/s-1.1×10^{-6} m/s which makes the groundwater prone to leachate pollution.

Keywords: *Geophysical Geotechnical, Groundwater, Landfill, Nigeria.*

Introduction

Human population is increasing on daily basis, so is the corresponding quantity of wastes contending for space with man and its effect impairing the quality of the environment (Ige and Ogunsanwo, 2009).Open dumping is a common practice in many cities and towns in Nigeria. The open dumps provide harbourage for diseases causing organisms, bacteria, insects, and rodents (Ogwueleka, 2009). Preferred options of solid waste management are waste reduction at source and reuse (Kontos et al., 2005). However, disposal of solid wastes in sanitary landfills is now increasingly gaining acceptance in many nations of the world (Ige, 2013)(Fig. 1). This can be attributed to the fact that landfills serve as a final repository even for waste managed with other waste disposal techniques. Therefore, in order to achieve safer disposal of municipal solid waste in Abuja, the Abuja Environmental Protection Board (AEPB) propose to upgrade the Gosa dumpsite to a modern sanitary landfill.

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 (Puri and Soni, 2013). In modern landfills, the waste is contained by a liner system (Hughes et al., 2005). The primary purpose of the liner system is to isolate thelandfill contents and the leachate from the environment and, therefore, to protect the soil and ground water from pollutants originating from the landfill. Pursuant to the above, this research work investigates the feasibility of upgrade of Gosa dumpsite to a modern sanitary landfill using integrated geotechnical, geophysical and groundwater quality assessment.

Location of Study Area

Gosa dumpsite is located in Gosa village, Abuja, Nigeria, at about 11 km off Umaru-Y'radua road (Fig. 2). Its geographical coordinates lie between latitudes $8^0$53'N and $9^0$13'N and longitudes $7^0$00'N and $7^0$30'N (Fig. 2). It covers an area of about 1 km^2. Although the presence of highways and major roads makes accessibility in Abuja quite easy as the time of carrying out this research work, the road to the Gosa dumpsite is untarred and therefore accessibility to the study area is difficult especially during the raining season.

Description of the Project Environment

Geology

Abuja is underlain by crystalline basement rocks and the rocks include different textures of granites, coarse to fine, consisting essentially of biotite, feldspars and quartz (Eduvie, 2003). The rocks in the study area comprises of migmatite gneiss, granodiorite, porhyroblastic gneiss, Pan African granite, granite gneiss and amphibolites (Fig. 3).Generally the North North East (NNE) and South South West (SSW) parts of the FCT are made of gneiss, migmatites and granites which characterize the Northern Nigeria (Dikedi, 2012). All these rocks have been affected and deformed by the

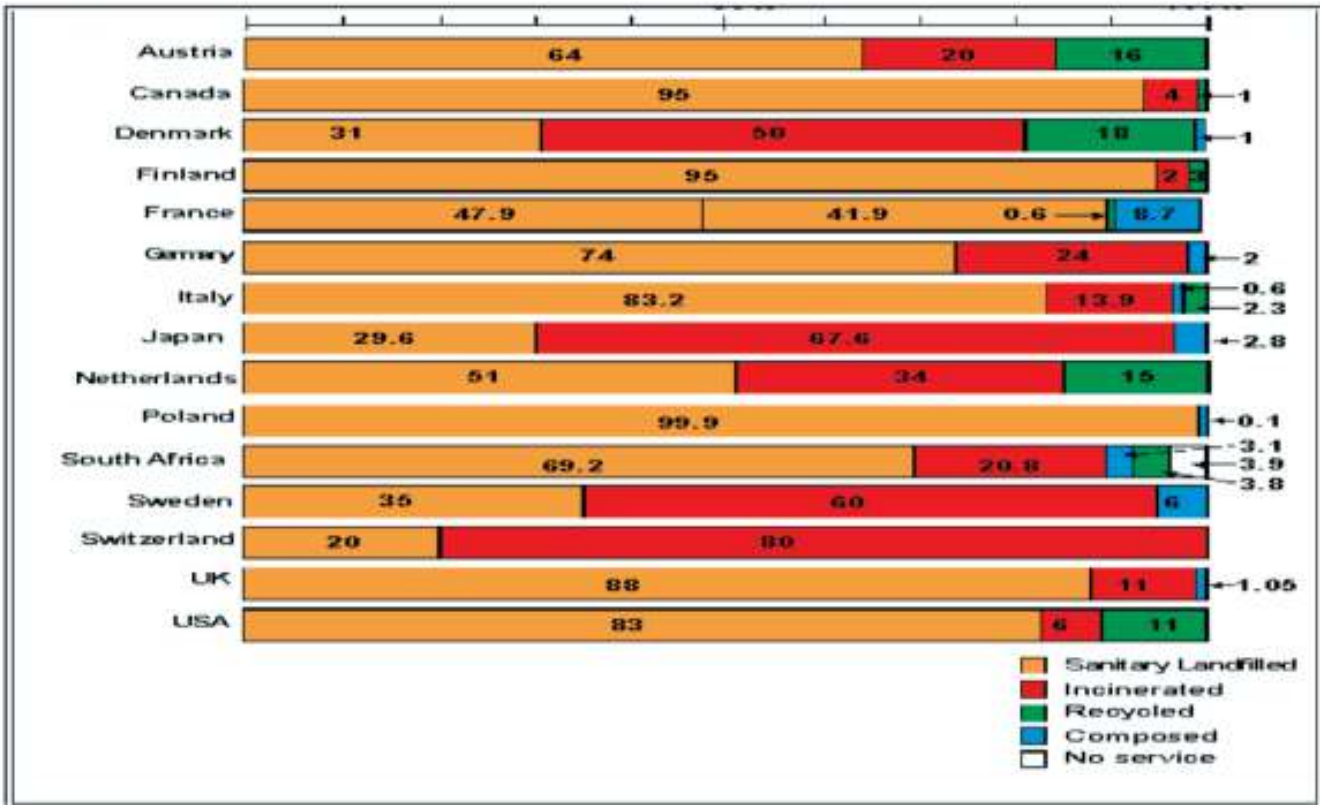


Fig. 1: Proportion of Municipal Solid Waste Managed with Various Disposal Method in Selected Countries (Lumsden, 2002).

Pan-African thermotectonic event (Omeje et al., 2013). The rocks are highly fractured and jointed showing essentially two fracture patterns, NE-SW and NW-SE (Abam and Ngah, 2013) which dictate the drainage pattern of the study area. Minor Cretaceous deposits of Nupe Sandstones occur in the southern part of FCT between Kwali and Abaji, extending to Rubochi and the border with Nassarawa State (Abam and Ngah, 2013). The rocks have reddish micaceous sandy clay to clay materials, often capped by laterite.

Climate

Climatic condition within the study area is essentially a tropical continental climate characterized by two distinct seasons; the wet and dry seasons. The rainy season spans March/April to September/October, while the dry season extends from October to March. The mean annual rainfall is 1630 mm, while temperatures vary from 22°C around December/January to 35°C in March/April (Abam and Ngah, 2013).

Vegetation

The vegetation of the study area is characterized by shrubs, tall grasses and sparsely distributed trees. The vegetation cover consists of shrubs and trees typical of the savannah belt region of north central Nigeria (Omada and Obayomi, 2012). Vegetation is characterized by thorn bushes and trees, herbs, shrubs, and mango trees, the area being in Guinea Savanna Vegetation zone of Nigeria (Abam and Ngah, 2013).

Topography

The topography of the study area characterized by a low-lying outcrop which occur as a hill in the eastern part of the study area. The elevation decreases westward from 404 m -396 m. Hence, the slope is in gently undulating.

Drainage

A seasonal stream flows north-south within the study area and drain into river Wupa which flows southwesternly at about 1.5 km southeast of the study area. Generally, the drainage pattern is dendritic.

Materials and Method

Allied Omega Resistivity Meter was used for the acquisition. Vertical Electrical Sounding (VES) survey

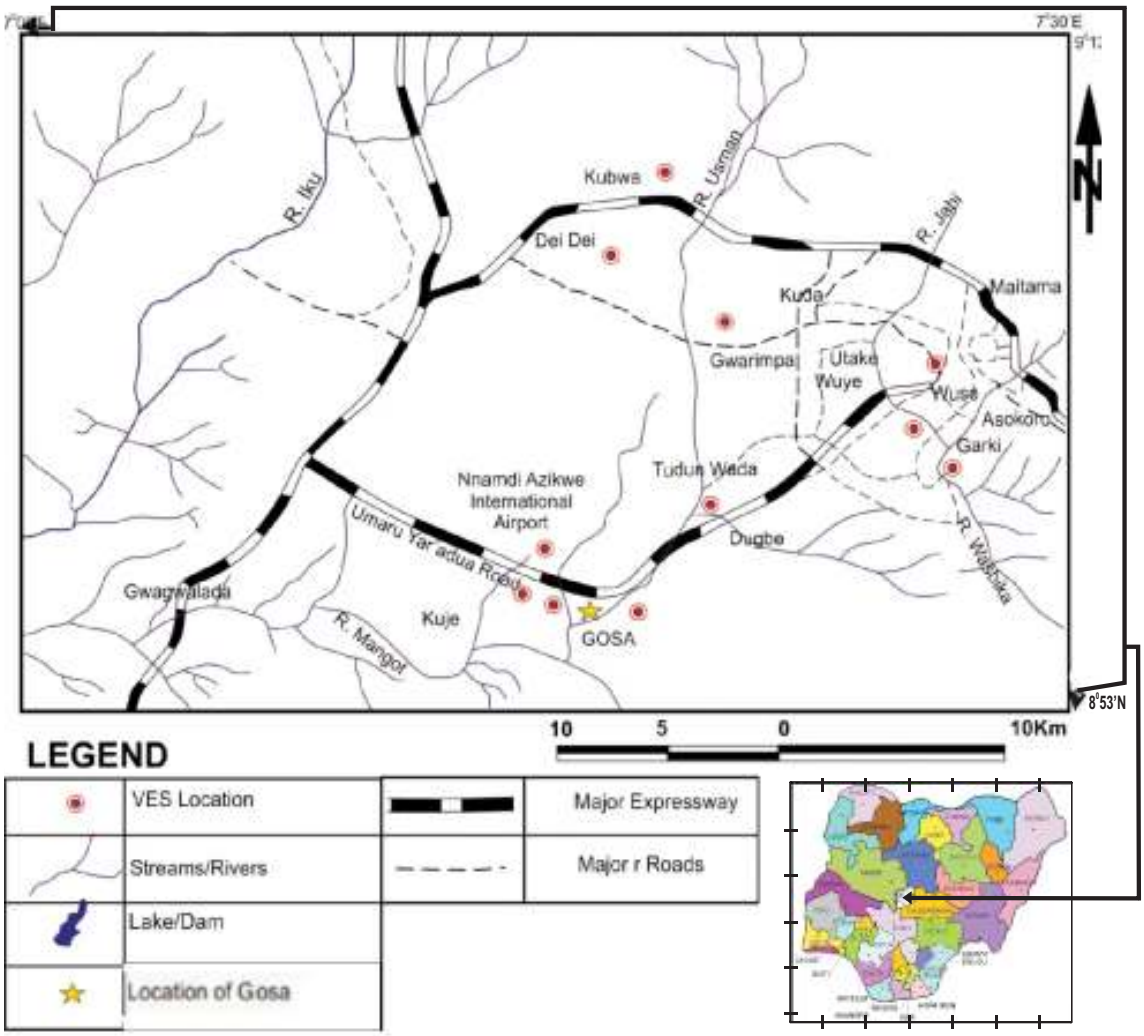


Fig. 1: Proportion of Municipal Solid Waste Managed with Various Disposal Method in Selected Countries (Lumsden, 2002).

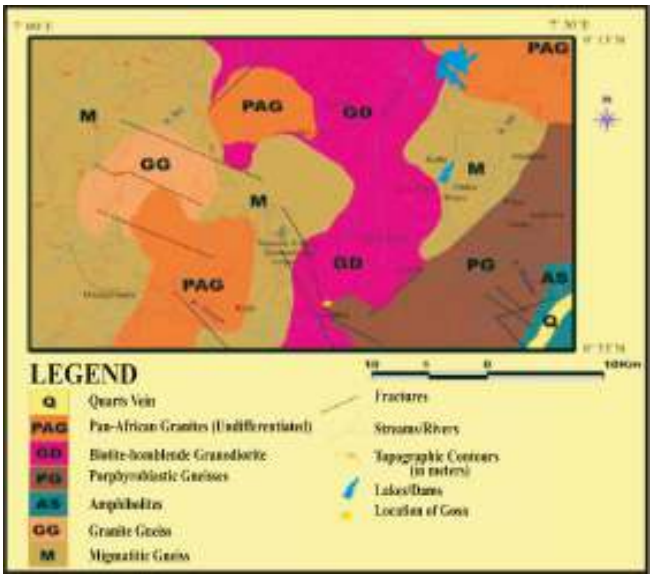


Fig. 3: A Geological Map of the Study Area (Omejeet al, 2013).

using Schlumberger array was carried out on along five (5) traverses (T1-T5)(Fig 4). The orientation of the traverses is NE-SW. Nineteen (19) VES stations were occupied. VES 5, VES 16 and VES 19 were taken outside the boundary of the study area to extend investigation beyond the dumpsite.The VES data were processed using the software IP2Win developed by Alexey Bobachev, Moscow State University, Russia. Also, two (2) undisturbed samples and six (6) disturbed samples were recovered from the study area for geotechnical analysis. The two undisturbed samples were recovered from two boreholes drilled during Standard Penetrometer Test (SPT) while the six disturbed samples were recovered from six Trial/Test pit dug manually.The soil samples recovered from the two boreholes (BH1 and BH2) and the six test pits (T1-T6) were analysed to obtain required geotechnical parameters in the landfill characterization.

Geotechnical parameters obtained include: grain size, Atterberg consistency limits, specific gravity, bulk density and dry density, moisture content, permeability, compaction, consolidation and shear strength.

Results and Discussion

Geophysical Assessment

The summary of results inversion of VES data are presented in Table 1. The geoelectric parameter obtained at VES 1 and VES 2 are presented in Figures 5 (a and b). The 2D geoelectric sections generated from interpretation of results VES data along traverses 1-5 are presented in Figure 6 (a and b).Four geologic layers were delineated beneath VES 1-VES 9 and VES 13. These layers correspond to topsoil, laterite, weathered basement, and fresh basement. Also, three geologic layers were delineated at VES 10-VES 12 and VES 14-VES 19.

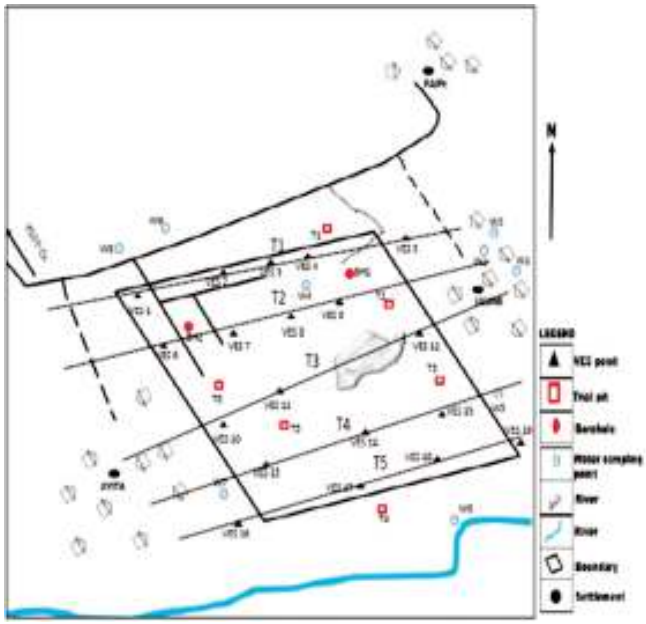


Fig. 4: VES, Borehole and Trial Pits Location.

Table 1: Summary of the Geophysical Characteristic over the Studied Area

VES STATION	No. of Layers	Apparent Resistivity (Ωm)	Thickness (m)	Depth to Basement (m)	Notes
1	4	796/1883/903/4455	1.45/8.38/17.4/...	27.2	
2	4	120/522/685/1000	1.18/6.57/16.6/...	24.4	
3	4	74.2/415/755/2663	1.19/4.92/15.9/...	22.0	
4	4	742/1474/590/3026	1.28/5.17/13.4/...	19.8	
5	4	916/3871/1579/4780	1.47/11.8/8.38/...	21.6	
6	4	613/3190/1018/4249	1.0/6.99/15.7/...	23.7	
7	4	461/850/554/5652	1.88/7.72/11.7/...	21.3	
8	4	231/1503/554/4080	1.13/8.09/12.0/...	21.2	
9	4	490/1699/922/6790	1.13/2.79/15.3/...	19.2	
10	3	5426/2040/8849	2.31/15.2/...	17.5	
11	3	356/478/1000	0.5/6.05/...	6.6	
12	3	686/416/1570	2.17/4.76/...	6.9	
13	4	2945/408/1818/4455	1.08/4.92/8.72	14.7	
14	3	1519/3334/7682	2.1/3.49/...	5.6	
15	3	2659/1279/7483	1.02/3.51/...	4.5	
16	3	752/2353/5599	2.17/3.94	6.1	
17	3	3799/1264/6453	0.79/6.58	7.4	
18	3	1000/2259/5427	1.18/4.08	5.3	
19	3	110/736/5934	0.13/7.0/...	7.1	

These layers correspond to top soil, weathered basement, and fresh basement. The resistivity of the top soil varies from 110 Ωm at VES 19 to 5426 Ωm at VES 10 while its thickness varies from 0.5 m -2.31 m at VES 11 and VES 10 respectively. The second layer has resistivity ranging from 408 Ωm at VES 13 to 3871 Ωm at VES 5. Also, the thickness of the second layer varies from 2.79 m at VES 9 to 15.2 m at VES 10. This layer is clayey and therefore more significant in providing material barrier/seal in the proposed sanitary landfill. The 2D geoelectric sections (Fig. 6 a-e) show that this layer thinned out towards the south of the study area.

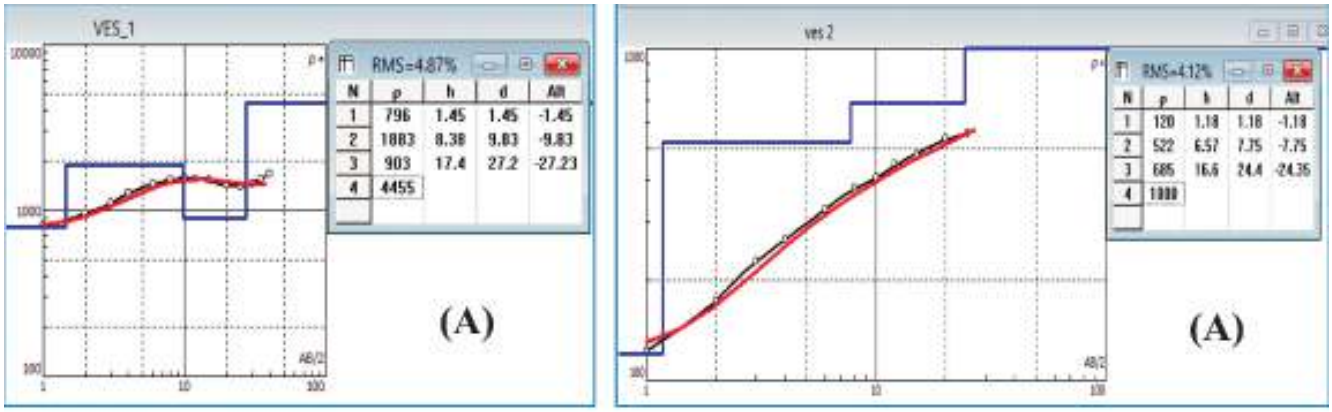


Fig. 5: Results of the 1D Inversion of the Apparent Resistivity Data at: (a) VES 1 and (b) VES 2

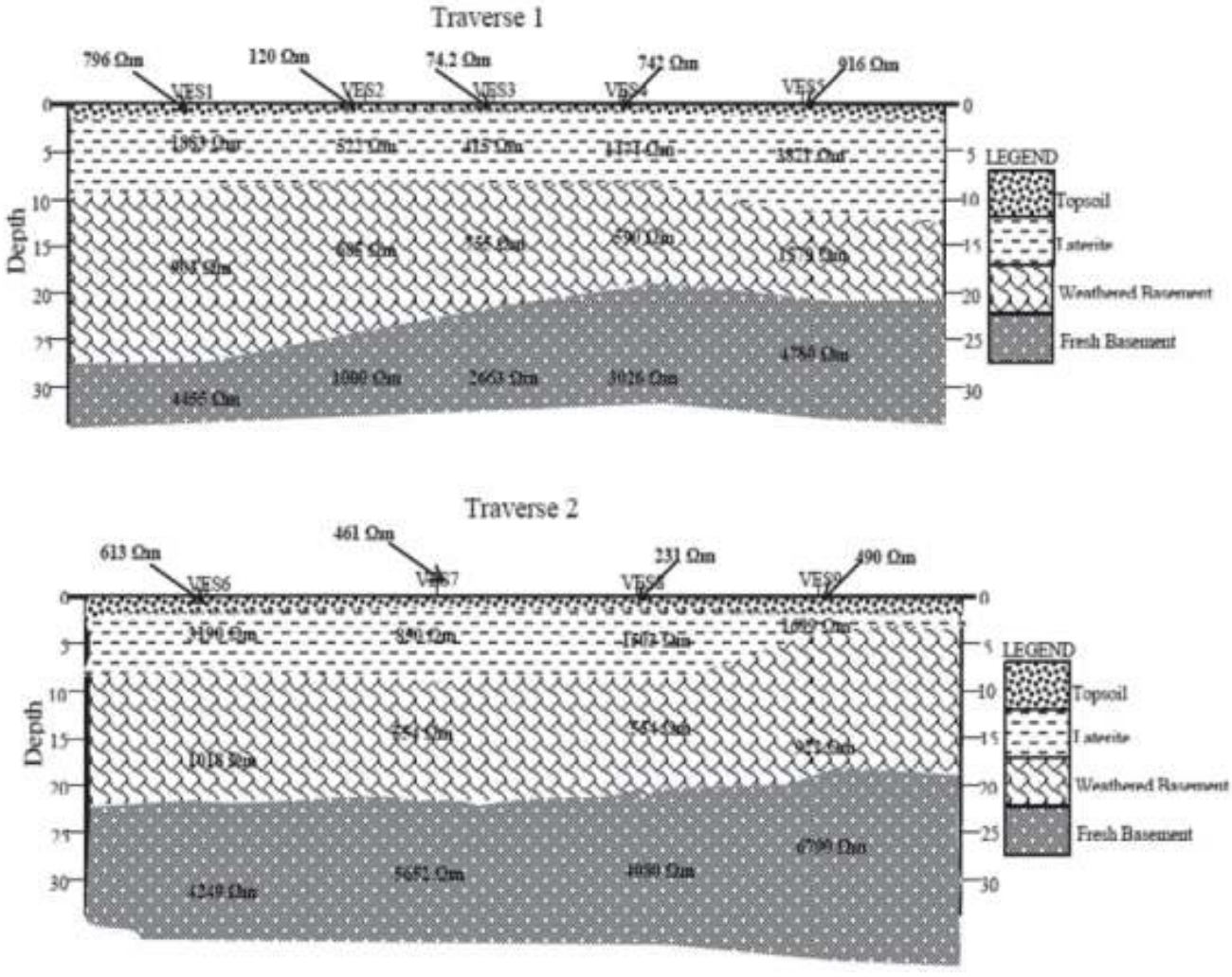


Fig. 6a: The 2D Geoelectric Sections Generated from Interpretation of Results VES Data along Traverse 1 and Traverse 2.

Furthermore, depth to basement also reduce southerly from a maximum of 27.2 at VES 1 to a minimum of 4.5 m at VES 15. Therefore, the clay/clayey material required as landfill liner is more abundant in the Northern part of the study area. The third layer is the weathered basement which immediately overly the

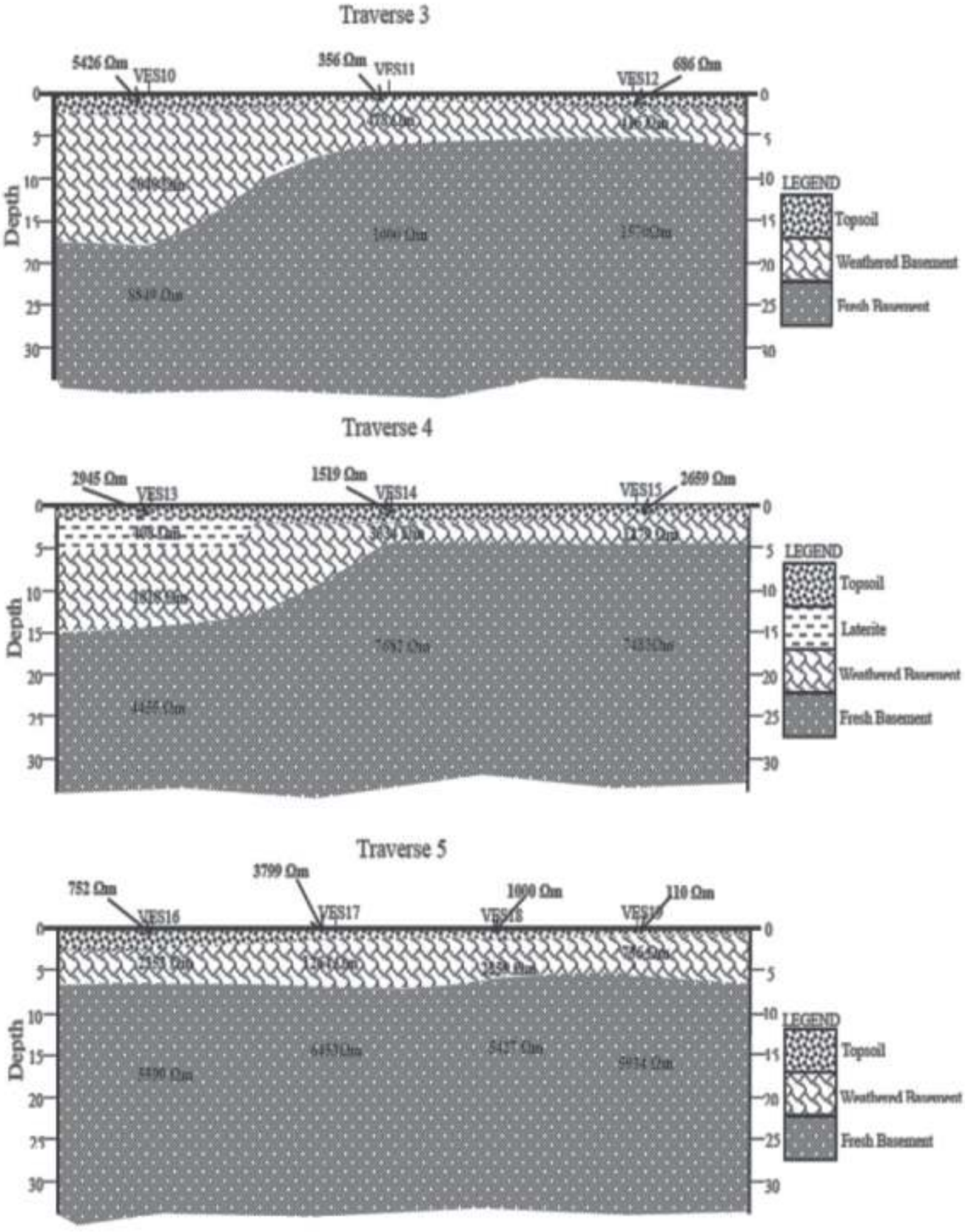


Fig. 6b: The 2D Geoelectric Sections Generated from Interpretation of Results VES Data along Traverse 3, Traverse 4 and Traverse 5.

fresh basement. Its resistivity varies from 416 Ωm at VES 12 to 3334 Ωm at VES 14 while its thickness varies from 3.49 m at VES 14 to 17.4 m at VES 1. The last layer corresponds to the basement and its resistivity varies from 1000 Ωm at VES 2 and VES 11 to 8849 Ωm at VES 10. The relatively high resistivity values measured in the study area possibly due to compaction of the soil surface by heavy duty equipment used for wastes-burying operations on the site.

Geotechnical Assessment

The geotechnical requirements of soil to be used as landfill liners based on the recommendation of Ige et al (2011) are presented in Table 2. The results of specific gravity indicate values ranging from 2.50 to 2.69. This imply the soil samples are composed of sand, silt and clay base on classification of Bowles (1990). Also, the dominants mineral in soil sample is Kaolinite and quartz based on specific gravity of common minerals given by Das (1998). Kaolinite is non-expansive clay and it is generally good for liner materials in dams and landfills. Grain size analysis of soil samples T1, T2, T3, T4 and T6 shows that the abundance of gravel, sand, silt and are as follows: T1(0%Gravel, 50% sand, 30% silt, 20% clay); T2(25%Gravel, 45% sand, 23% silt, 7% clay); T3(10%Gravel, 90% sand, 0% silt, 0% clay); T4(10%Gravel, 60% sand, 19% silt, 11% clay); T5(25%Gravel, 57% sand, 13% silt, 5% clay); and T6(1.2%Gravel, 48.8% sand, 36% silt, 14% clay).

The grain size analysis shows that the samples are composed predominantly of sand size particles with some amount of silt and clay. The only exception is sample T3 which is composed almost entirely (90%) of sand size particles had no silt or sand portion. All the soil samples (except sample T3) are classified as clayey-sand to silty sand (SC/SM) based on Unified soil classification. Sample T3 is classified as poorly graded sand (SP) which implies that all the grain sizes are not well represented. The percentage of sand predominates, follow by silt and sand respectively. The bored samples (BH1and BH2) can be classified as clayey-sand lateritic soil with dominant percentage of clay (14-30%).The largest grain size in soil samples is 16 mm and thus satisfies the grain size requirement of ≤ 63mm suggested by ONORM S 2074, (1990) and the values of between 30 mm and 50 mm suggested by Daniel, (1993). The percentages of fines contained in the soils are: T1 = 50%, T2 = 30%, T3 = 0%, T4 = 30%, T5 = 18 %, T6 = 50%, BH1 = 29-30%, BH2= 30%. The values of the percentage of fines also satisfy the required ≥ 15%. This shows that the soil samples (except T3) are

Table 2: Required geotechnical criteria, recommendations (Ige et al, 2011) and Research Results.

Parameters	Author(S)	Recommendations	Research Results
Grain Size	Oelzschner (1992) Bagchi (1994) ONORMS 2074 (1990) ONORMS 2074 (1990) Daniel (1993b), Rowe *et al,* (1995)	Clay fraction <20% Largest grain size=63mm Silt/clay fraction=15% Largest grain size <25mm, %Gravel < 30, % fine= 30%	Clay = 5-30% Largest grain size= 16mm 20-50% fines =10% gravel
Atterberg Consistency Limits	Daniel (1993b); Rowe *et al,* (1995) Seymour and Peacock (1992) Oelzschner (1992)	LL=30%, IP= 15% LL=30%, IP=10% LL=30%, IP=15% LL=25%, IP=15% LL=30%, IP=15% Inorganic clay of low-medium plasticity (CL-CI) and Ac of <1.25	LL= 22-39%, IP= 5.4-18.4% Ac=0.2-0.6
Moisture Content-Density Relationship	ONORMS 2074 (1990) Taha and Kabir (2006)	MDD=1.71t/m^3 MDD=1.71t/m^3	SP=1.7-1.80g/cm^3 MP=1.7683g/cm^3
Permeability	Murphy and Garwell (1998) Mark (2002) Joyce (2003) Fred and Anne (2005)	= 1 x 10^{-9} m/s = 1 x 10^{-9} m/s = 1 x 10^{-9} m/s = 1 x 10^{-8} m/s = 1 x 10^{-9} m/s	5.1 x 10^{-7} m/s-1.1 x 10^{-6} m/s

SP=standard proctor, LL=Liquid Limit, MP=Modified proctor, IP=Index of plasticity, Ac=Activity of clay.

cohesive soil with very little porosity which is desirable for liner materials.

Compaction test was carried out to determine the response of the soil samples to compaction effort. It evaluates the ease with which the soil samples from the study area can be improved by compaction. Improvement by compaction is necessary to obtain low hydraulic conductivity which is desirable in landfill barrier. The soil samples were compacted using both standard proctor and modified proctor methods. The compaction curves for samples T1 and T2 are presented

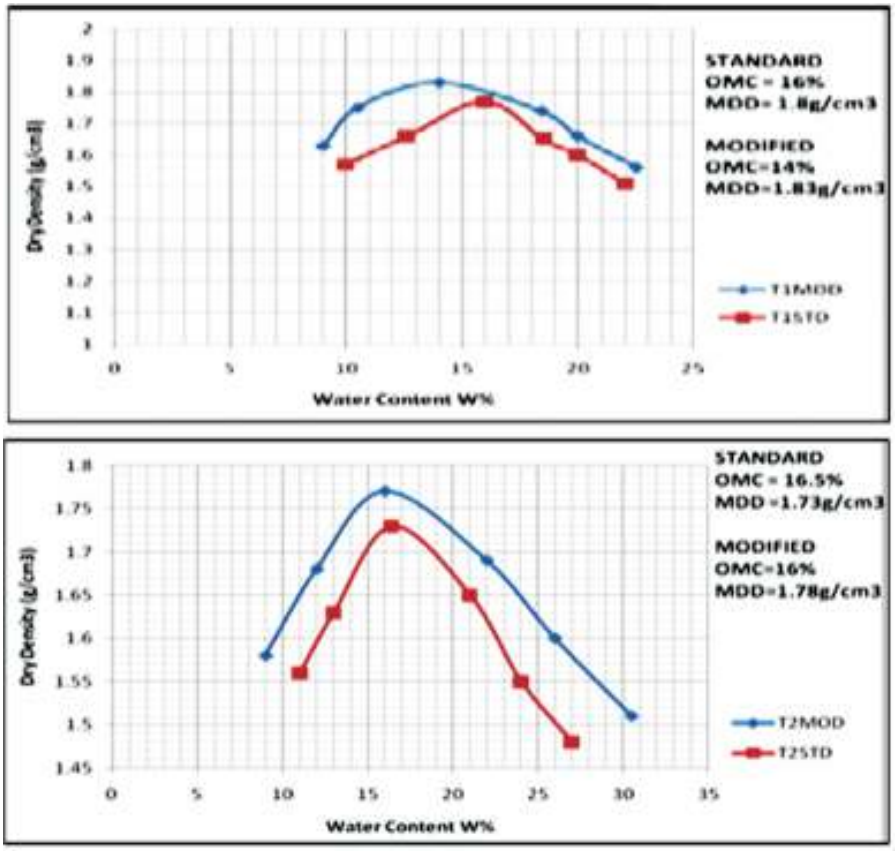


Fig. 7: Compaction Curves for Standard and Modified Proctor Tests for (a) sample T1 and (b) sample T2.

Table 3: Summary of Results of Compaction Test.

Pit No.	Sample Symbol	Sample Depth(m)	Standard Proctor		Modified proctor	
			OMC (%)	MDD (g/cm^3)	OMC (%)	MDD (g/cm^3)
1.	T1	1	16.0	1.80	14.0	1.83
2.	T2	1	16.5	1.73	16.0	1.78
3.	T3	1	10.0	1.80	9.0	1.83
4.	T4	1	15.5	1.80	14.5	1.85
5.	T5	1	12.0	1.79	11.0	1.82
6.	T6	1	16.0	1.70	14.0	1.76

in Figure 7. The summary of the results of compaction test of the soil samples are presented in Table 3.

Results of Atterberg consistency limits of samples T1, T2, T4, T5, T6 and the bored samples BH1and BH2 indicate liquid limits ranging from 25% to 39%, flow index of 3.7 to 29.1 and toughness index of 0.3 to 0.6. Plot on the plasticity chart shows samples T1, T2, T4, T5, T6 are dominantly of low plasticity (PI: 10-20%) while the bored samples (BH1 and BH2) are of low to intermediate plasticity (PI<10%). Plot on the plasticity chart also confirmed the excavated samples are composed of inorganic clay of medium plasticity while the bored samples are of inorganic clay of low plasticity. The clay activity of soil sample T1, T2, T4, T5 and T6 are: 0.33, 0.28, 0.35, 0.6 and 0.2 respectively. Therefore, the samples are composed of inactive clays (Ac<0.75)(non-swelling clay minerals) such as kaolinite, muscovite. Plots of the soil samples on the Casagrande Plasticity Chart (Fig. 8) shows that BH1 and BH 2 are inorganic clay of low plasticity (CL) while T1-T6 are inorganic clay of intermediate plasticity

(CI).Also, results obtained for clay activityof the soil samples shows that clay activity of the soil ranges between 0.20-0.6 further confirming the dominance of kaolinitic clay type. Therefore, the soil samples are recommended for use as landfill liners.The results of the permeability test of sample T1-T6 shows that the permeability of the sample ranges between 5.1 x 10^{-7} m/s-1.1 x 10^{-6} m/s. The sample needed to be improved by the addition of little amount of clay to meet up to 1 x 10^{-8}recommended by Ige et al., (2011).

The maximum dry density (MDD) for all the samples ranged from 1.7 g/cm^3-1.80 g/cm^3) for samples compacted at both standard and modified proctor. These range satisfy the requirement of 1.7 g/m^3 (Ige et al., 2011) under standard proctor. The MDD values under modified proctor range from 1.76 to 1.83g/cm^3 much better than 1.45g/cm^3 (standard proctor) and 1.64g/cm^3 (modified proctor) stipulated by Taha and Kabir, (2006) for soils produced from basement complex rocks to be usable as liners in landfill.

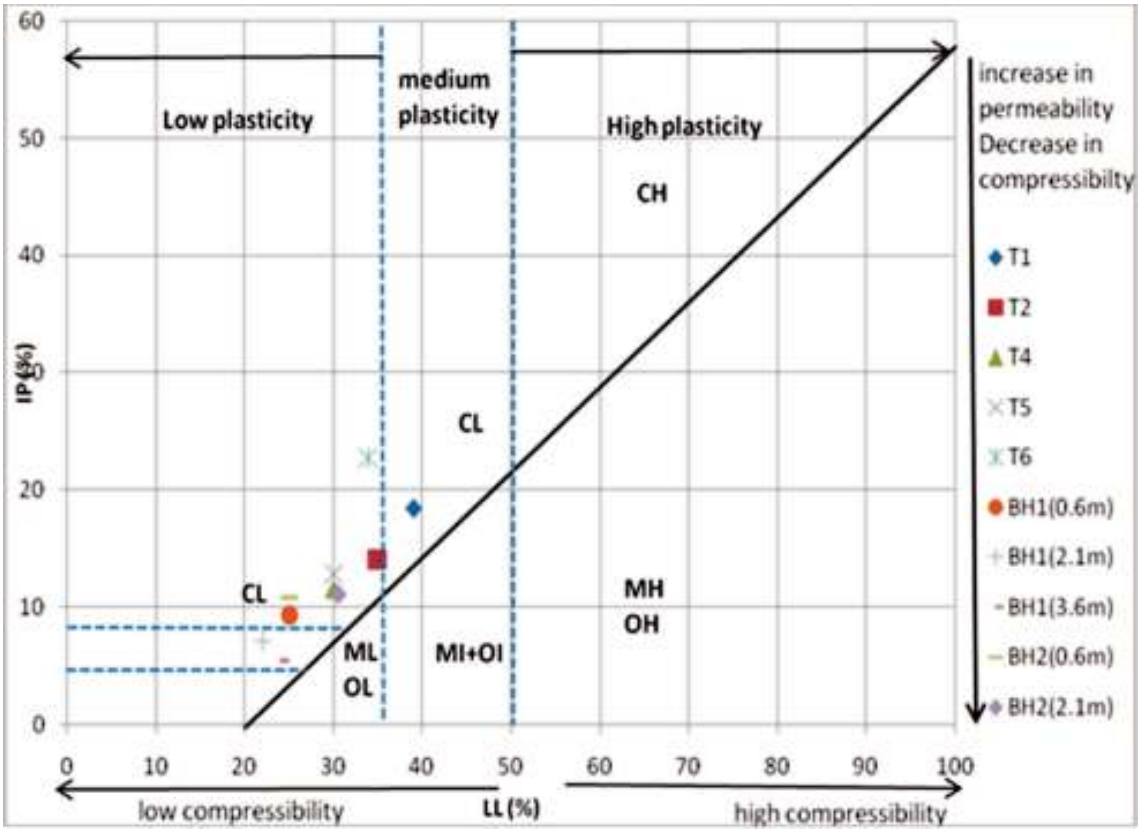


Fig. 5: MDD and OMC variation with QD a). WA level; b). MA level.

Conclusion

The results of the geophysical and geotechnical assessments indicate that the Northern part of the study area is preferable for siting the sanitary landfill. This is due to the presences of thick layer of clay and absence of fractures and shear zones which may increase the risk of groundwater pollution. Furthermore, geotechnical analysis shows that soil samples obtained from the Northern part of the study area are less permeable and could be used as seal in sanitary landfill. Although, the sample needed to be improved by the addition of little amount of clay. Also, plots of the soil samples on the Casagrande Plasticity Chart show that BH1 and BH 2 are inorganic clay of low plasticity (CL) while T1-T6 are inorganic clay of intermediate plasticity (CI).Also, results obtained for clay activityof the soil samples shows that clay activity of the soil ranges between 0.20-0.6 and thus confirm the dominance of kaolinitic clay type.

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