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Assessing the physical and geotechnical properties of subsoils within an active municipal solid waste dumpsite for secured future urban growth

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Abstract

This study attempts to investigate the geotechnical properties of subsoils in an active Dumpsite (DS) within the basement complex area of Abeokuta, Nigeria with a view to assess its suitability as a foundation/filling material. Sixteen (16) composite soil samples were collected from four different parts of the DS at varied depths of 0.0 - 0.5, 0.5 - 1.0, 1.0 - 1.5, and 1.5 - 2.0 m. The soil properties considered are particle size distribution, Specific Gravity (SG), permeability, Shear Strength (SS), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Natural Moisture Content (NMC) and Atterberg limit (AL) indices. Results show that the assessed soil samples are sandy soils with less than 30% clay content. The ALs test revealed that analysed samples had low Plasticity index (PI) (0.20 - 11.96%), low values of Plastic Limit (PL) and Liquid Limit (LL) of (14.19 - 18.83% and 17.52 - 26.15%, respectively). The MDD values ranged from 1.07 to 1.76 g/cm^3 while the NMC and OMC were <25% and <18%, respectively. The permeability coefficients ranged from 1.53×10^{-4} to 8.49×10^{-3} cm/s, indicating moderately permeable soil while the SS results (ranging from 3.4 to 12.5 KPa) indicate low cohesive capacity soils. The tested soils are mildly suitable for foundation/filling materials. Further study is needed to study the trend of alteration of soil properties with depth on dumpsite soil located on other geological formations.

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1. Introduction

Human beings engage in many activities that result in the generation of unused garbage every day. municipal solid waste (MSW) comprises heterogeneous collection of different unused materials that vary in size, strength, density and degradation potential [1, 2]. Some of the MSW components are non-biodegradable while others degrade at different rates as a result of biological and chemical processes during waste deposition interaction with soil materials [2]. Limited availability of land for disposal purpose encourages unrestrained dumping of wastes on the outskirts of city and main road channels, causing serious environment and public health hazards [3]. There has been a significant rise in the generation of MSWs in Nigeria in the last decades. Among the reasons for the

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increase in MSW generation are increase in population growth, rural-urban migration and inadequate provision of suitable waste disposal system by relevant environmental agencies [3, 4]. While the degraded MSW components can pollute soil and nearby shallow aquifers, soils that retain heavy metals (undegraded components) tend to have weak vulnerable foundation properties [3, 5–7]. Therefore, a study of the geotechnical properties of the MSW soils within an active dumpsite is vital for the slope stability management of the dumpsite and also provide useful baseline data during the reclamation process of the site thereby preventing any likely structural failures [8, 9]. For instance, determination of the shear strength of MSW soil helps to ascertain the slope stability of the dumpsite/land fill [1, 8]. Many authors have investigated the geotechnical characteristics of MSW soils [1–3, 8, 10, 11]. There are also published research reports on physical and mechanical properties of fresh and aged MSW residues as well as physico-chemical properties of soil and groundwater adjoining dumpsite [7, 12–14] and those that also chronicle the geotechnical features of soils reinforced with waste materials. For instance, Blayi *et al*. [15] studied the potential of waste glass powder (WGP) as a strength improvement catalyst for expansive soils; Yerima *et al*. [16] evaluated the phytoremediation and bioconcentration of heavy metals and mineral oils in *Zea mays* interplanted with *Striga hermonthica* in mechanic village soils while Kishore and Manickavasagam [17] evaluated the geotechnical properties of black cotton soil modified with powdered selected medical wastes at varied proportion of mixing. Furthermore, the geotechnical characteristics of soils reinforced with polythene/polypropylene waste materials was also well reported [18–22].

The ability of a particular soil in a certain geological setting to bear load depends on the soil type [23]. For example, fine grained soil have higher degree of compressibility than coarse grained soil as the former have a relatively smaller capacity in bearing loads [24]. The stability of engineering structures depends on factors such as foundation design, nature of building materials, geotechnical behaviours of receiving sub-soil amongst others [25, 26]. Soil provides the needed support for engineering structure placed on it, thus the need to check the suitability of near surface soils that are used for foundation, landfill liner or as a construction materials [27–30]. In addition, the durability and strength of building materials is a function of its efficiency in response to the load placed on the near- surface soil, thus a detailed understanding of the soil properties with depths will provide needed information to avert likely engineering and environmental problems [23, 29]. For instance, Alabi [26] evaluated the geotechnical properties of residual soil to assess its suitability to bear the load of engineering structure within a residential community while Fatoyinbo *et al.* [29] assessed residual soils within Akure metropolis in order to select those with excellent geotechnical properties for landfill liners.

Many scientists have investigated the physico-chemical levels of soil and /or water samples within and around Saje dumpsite [4, 31–33]; radiological impact assessment of Saje dumpsite soils [34] while Popoola and Adenuga [35] investigated the leachate curtailment ability of Saje dumpsite using integrated geophysical methods. There is still dearth of reported studies on geotechnical characterization of subsurface soils in Saje municipal waste disposal site located in basement complex formation.

To the best of our knowledge, this study is the maiden attempt to characterize the soil of Saje active dumpsite using selected physical and geotechnical properties of subgrade layers. The present study is focused on the assessment of selected physical and geotechnical properties at foundation depths of near surface soils under the MSW deposition within an active dumpsite in Basement Complex formation setting. This will provide information about the suitability of the dumpsite soil for engineering purposes in the nearest future and serve as baseline data on geotechnical status of the soils in the DS. This aim is achievable with the following precise objectives: (i) evaluate the levels of selected soil engineering properties at various sampling depths, (ii) assess the variation of studied soil properties with respect to sampling cardinal directions and (iii) apply the statistical analyses to study the interrelationship among the investigated soil parameters and extent of variations of measured parameters with sampling depths.

2. Materials and methodology

2.1. Site description and its geological setting

The study area is an active dumpsite (Saje dumpsite) located in the northern part of Abeokuta within latitudes 7°10′ and 7°15′ and longitudes 3°17′and 3°26′E [36] in southwest Nigeria. Saje dumpsite is located within Abeokuta South local government with an approximate area of about 40.6 km^2 [4, 33]. It lies between latitude 7°11′116″ to 7°11′ 365″N and longitudes 3°21′ 755" to 3°26′ 992″E [35]. Saje dumpsite caters for the needs of peoples within the core parts of Abeokuta, receiving approximately 150 tons of wastes daily [35].

Abeokuta experiences two local climates (rainy and dry seasons). The rainy season is from March to October, while the dry season is from November to February under the influence of north-easterly winds from Sahara desert [36]. Annual rainfall in Abeokuta and its environs ranges between 1400 and 1500 mm with a mean of 1238 mm [37, 38], while the temperatures are highest on average in March at around 29.1°C on average and lowest on average in August at 25.1°C on average [39]. Abeokuta is characterized by undulating topography with elevation values ranging from 100 to 400 m above sea level [36, 40].

The study area falls within the basement complex formation of southwest Nigeria. The basement rock comprises of folded gneiss, schist quartzite, older granites and amphibolites [41]. Abeokuta belongs to the stable plate which was not subjected to intense tectonics in the past [42]. The Saje dumpsite located within the northern part of Abeokuta is characterized by pegmatite underlain by granite while the southern part enters into the transition zone with the sedimentary formation of the eastern Dahomey Basin [36]. The dominant rock type in the study area is coarse porphyritic biotite / biotite –muscovite granite. Figure 1 is the geological map of Abeokuta and its environs showing the study area and soil sampling points.

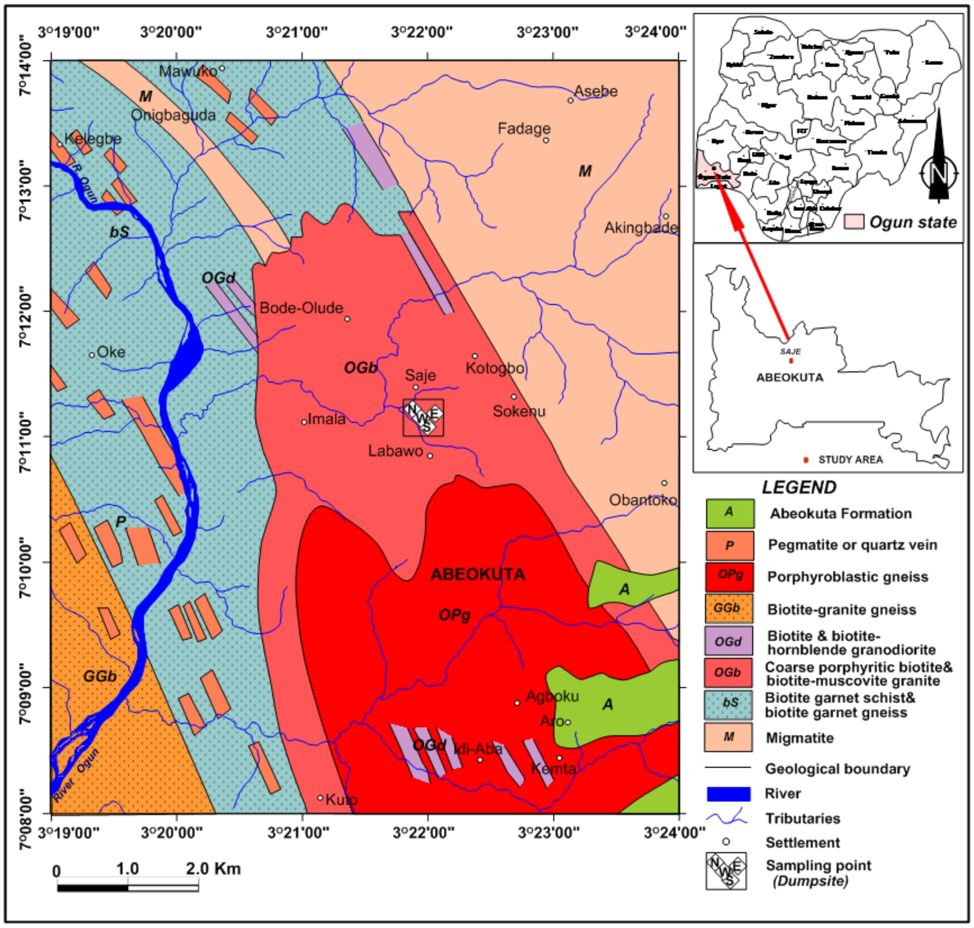

Figure 1: Geological map of Abeokuta showing the study area and soil sampling points.

2.2. *Soil samples collection and laboratory analysis*

The selection of sampling points was chosen on the basis of the four (4) cardinal directions within the dumpsite. Four soil samples were collected at each sampling direction at sampling depths of 0 - 0.5 m (A), 0.5 - 1.0 m (B), 1.0 - 1.5 m (C), and 1.5 - 2.0 m (D) making a total of 16 samples within the dumpsite. At each sampling direction, a grid of 100 m by 50 m was identified with the use of a tape measure. This was divided into five sampling points where soil samples were collected at each sampling depth. Such samples of soil at each sampling depth at all sampling points within a grid were mixed thoroughly together in order to form a composite sample that was later used in geotechnical analysis. The samples were collected with the use of soil auger, packed in carefully labelled polythene bags and conveyed to the laboratory for analysis. The soil samples were labelled with respect to the cardinal directions and sampling depths as NIA-NID, S2A-S2D; W3A-W3D; and E4A-E4D.

Preservation of soil samples and geotechnical tests were carried out using standard ASTM guidelines. The physical and engineering tests considered in this study include particle size distribution (PSD), compaction tests (Natural Moisture Content (NMC); Optimum Moisture Content (OMC) and Maximum Dry Density (MDD)); Permeability, Specific Gravity (SG), Shear Strength (SS) and Atterberg Limits (AL), Plastic limit (PL), Liquid Limit (LL), and Plasticity Index (PI)).

The PSD was done according to procedures drawn by Gee and Or [43] with the use of modified Bouyoucos hydrometer method. The textural classification was done using the United States Department of Agriculture (USDA) textural soil classification system. The NMC was determined according to the ASTM D2216 standard [44] while the permeability test was performed with flexible wall parameter based on ASTM D5084 standard [45]. The MDD and OMC values were determined according to ASTM D698-00 standard [46] while the SS was determined in accordance to ASTM D6528-17 standard [47]. The Atterberg limits test was determined according to the ASTM D4318 standard [48] while the SG was measured by water pycnometer in accordance with ASTM D854-00 standard [49].

2.3. *Statistical analysis of soil data*

Descriptive statistics, Pearson correlative matrix and Analysis of variance (ANOVA) were performed on the soil data. The descriptive statistics considered include mean, standard deviation and coefficient of variation. The Pearson's correlation matrix and

Table 1: Mean values of analyzed physical and geotechnical parameters in soil samples.

Description	Sand	Clay	Silt	Textural class	Max. dry density	Natural MC	Optimum MC	Permeability	Specific gravity	Shear strength	Atterberg Limit indices		
											LL	PL	PI
		%			g cm^{-3}	%	%	cm hr^{-1}		kPa		%	
W 3A	78.3	6.3	15.4	LS	1.61	9.5	9.34	8.55	1.76	6.4	19.33	17.72	1.61
W 3B	74.3	10.3	15.4	SL	1.60	9.1	8.42	5.60	1.74	6.4	20.21	17.65	2.56
W 3C	72.3	13.3	14.4	SL	1.56	8.4	8.31	2.53	1.69	4.4	22.14	16.21	5.93
W 3D	64.3	25.3	10.4	SCL	1.51	7.8	8.11	1.03	1.63	4.2	25.35	15.15	10.20
N 1A	76.3	10.5	13.2	SL	1.07	20.5	16.42	30.55	1.24	8.7	18.53	18.04	0.49
N 1B	72.3	15.5	12.2	SL	1.29	14.5	10.33	8.01	1.42	9.8	20.13	18.83	1.30
N 1C	65.3	22.5	12.2	SCL	1.33	11.8	9.42	4.42	1.46	10.6	24.37	15.03	9.34
N 1D	62.3	27.5	10.2	SCL	1.40	10.4	8.21	2.08	1.51	12.5	26.15	14.19	11.96
E 2A	81.1	5.5	13.4	LS	1.61	11.3	8.21	8.69	1.74	6.3	17.52	17.32	0.20
E 2B	78.1	9.5	12.4	SL	1.53	12.4	8.41	6.35	1.66	4.5	19.12	17.52	1.60
E 2C	75.1	14.5	10.4	SL	1.54	8.3	7.42	5.25	1.65	3.4	21.20	17.22	3.98
E 2D	75.1	15.5	9.4	SL	1.76	7.3	5.23	5.54	1.85	7.5	21.32	17.17	4.15
S 2A	76.1	10.1	13.8	SL	1.38	15.1	10.32	5.66	1.52	9.9	18.12	17.63	0.49
S 2B	75.1	13.1	11.8	SL	1.41	14.6	9.91	3.63	1.55	10.5	18.19	17.25	0.94
S 2C	72.1	16.1	11.8	SL	1.44	13.4	9.42	1.19	1.56	10.5	21.75	17.42	4.33
S 2D	66.1	23.1	10.8	SCL	1.32	13.0	8.61	0.55	1.44	7.9	25.46	15.15	10.31

LS = loamy sand; SL = sandy loam; SCL = sandy clay loam; MC = moisture content; LL = Liquid limit; PL = Plastic limit and PI = Plastic index

ANOVA were performed in order to determine the interrelation between measured parameters and trend of variation of assessed soil variables with sampling depths among the four sampling points within the dumpsite. Pearson correlation analysis is generally utilized to measure and establish the association between two continuous variables. It is a basic statistical tool usually employed to display the extent of dependence of one specific variable to the other via the computation of correlation coefficient. The sign of the correlation coefficient value designates the inverse or direct of the relationship while its absolute value discloses the strength of the linear connection. Parameters with correlation coefficients (r) > 0.70, 0.70 > r > 0.50, and r < 0.50 were considered as strong, moderate, and weak, respectively [50, 51]. The ANOVA data were presented as mean ± standard deviation, and the means were separated at the p≤ 0.05 level of significance.

3. Results and discussions

3.1. Physical and geotechnical properties

The results of analyzed soil properties are presented in Table 1. The amount of sand particles at each sampling direction within the DS decreases with sampling depths. The highest sand fractions (81.1%) occurs at depth 0 - 0.5 m at the eastern part of the DS while the least % sand (62.3%) occurred at 1.5 - 2.0 m depth at the northern side of the DS (Figure 2). The % clay content increases with depths at each sampling point (Table 1). Generally, the % clay for each sampling depth at all the sampling points was < 35%, thus the subgrade samples can be used for road construction (Figure 3), foundation and filling materials [52]. However, according to Handy [53] and Abd El Aal and Rouaiguia [28], soils with clay content <32% are likely to collapse, thus the use of deep foundation such as piers, piles as well as continuous strip footings as shallow foundation may be required in the study area since clay particles at each sampling depth at all the sampling locations was less than 32%. The activity values for all soil samples were <0.75, an indication of inactive clay of low moisture affinity [29, 54]. The % silt ranged from 9.4 to 13.4% and did not follow clear trend with sampling depths. Furthermore, it was observed that relatively highest value of % silt at each sampling point was recorded at 0 - 0.5 m depth (Figure 4). The range of % silt obtained in this study was lower than that reported by Oluwagbemi *et al.* [7], where particle size distribution ranged from 8.8 to 27.7% silt. The textural class of collected soils at all sampling depths varied from loamy soil, sandy loam (SL) to sandy clay loam (SCL) (Table 1). Samples at depth 1.5- 2.0 m at northern, southern, and western parts of the DS belong to SCL in contrast to SL texture of samples at eastern part of the DS (Table 1).

The MDD values ranged from 1.51 to 1.61 in the west, 1.07 to 1.40 g/cm^3 in the east and from 1.32 to 1.44 g/cm^3 in the southern part of the DS (Figure 5). The MDD of soils decreases with depth at western side. However, the variation of MDD with depth did not follow clear trend at the northern and southern parts of the DS. Highest MDD value (1.76 g/cm^3) was obtained for samples collected from 1.5 - 2.0 m depth in the eastern part of the DS with sandy loam texture and lowest OMC and NMC values (5.23 and 7.30%,

Table 2: ANOVA results for analysed parameters based on sampling depth.

Parameters	0.0 - 0.5 m	0.5 - 1.0 m	1.0 - 1.5 m	1.5 - 2.0 m
Sand*	77.95 ± 2.3231^{a}	74.95 ± 2.4076^{ab}	71.20 ± 4.1649^{bc}	66.95 ± 5.6507^{c}
Clay*	8.10 ± 2.5665^{a}	12.10 ± 2.7423^{ab}	16.60 ± 4.0972^{b}	22.85 ± 5.2189^{c}
Silt*	13.95 ± 0.9983^{a}	12.95 ± 1.6523^{a}	12.20 ± 1.6573^{ab}	10.20 ± 0.5888^{b}
Max dry density	1.42 ± 0.2558^{a}	1.46 ± 0.1365^{a}	1.47 ± 0.1056^{a}	1.50 ± 0.1916^{a}
Nat MC	14.10 ± 4.8635^{a}	12.65 ± 2.5749^{a}	10.48 ± 2.5395^{a}	9.63 ± 2.6285^{a}
Opt MC	11.07 ± 3.6678^{a}	9.27 ± 0.9992^{a}	8.64 ± 0.9685^{a}	7.54 ± 1.5551^{a}
Permeability	13.36 ± 11.5431^{a}	5.90 ± 1.8164^{a}	3.35 ± 1.8342^{a}	2.30 ± 2.2525^{a}
SG	1.57 ± 0.2424^{a}	1.59 ± 0.1389^{a}	1.59 ± 0.1023^{a}	1.61 ± 0.1797^{a}
Shear Strength	7.83 ± 1.7727^{a}	7.80 ± 2.8367^{a}	7.23 ± 3.8612^{a}	8.03 ± 3.4131^{a}
LL*	18.38 ± 0.7598^{a}	19.41 ± 0.9541^{a}	22.37 ± 1.3912^{b}	24.57 ± 2.1954^{b}
PL*	17.68 ± 0.2962^{a}	17.81 ± 0.6985^{a}	16.47 ± 1.0964^{ab}	15.42 ± 1.2545^{b}
PI*	0.70 ± 0.6235^{a}	1.60 ± 0.6946^{a}	5.90 ± 2.4485^{b}	9.16 ± 3.4324^{b}

Values represent Mean ± S.D. Values along the same row with different superscripts are significantly different at 5% ($p<0.05$) level.

Table 3: Correlation coefficients of analyzed parameters.

	Sand	Clay	Silt	Max dry Density	Nat MC	Opt MC	Permeability	SG	Shear Strength	LL	PL	PI
Sand	1											
Clay	-.970**	1										
Silt	.499*	-.693**	1									
Max dry Density	.290	-.247	.021	1								
Nat MC	.180	-.195	.163	-.849**	1							
Opt MC	.138	-.213	.354	-.840**	.881**	1						
Permeability	.434	-.442	.290	-.491	.640**	.797**	1					
SG	.349	-.321	.109	.995**	-.820**	-.789**	-.442	1				
Shear Strength	-.333	.317	-.143	-.516*	.514*	.318	.027	-.537*	1			
LL	-.940**	.932**	-.540*	-.068	-.396	-.334	-.500*	-.133	.112	1		
PL	.831**	-.815**	.444	.024	.358	.319	.480	.073	-.133	-.869**	1	
PI	-.932**	.921**	-.525*	-.056	-.396	-.339	-.509*	-.118	.122	.987**	-.937**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

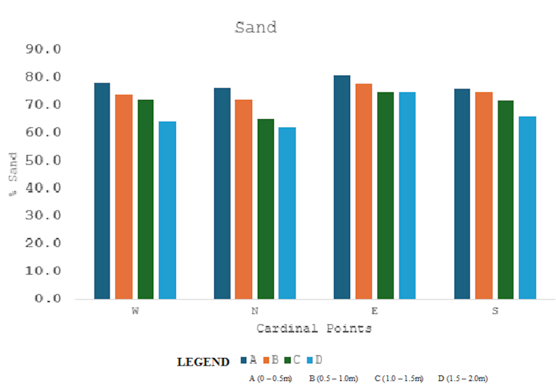

Figure 2: Variation of sand particles with sampling depths.

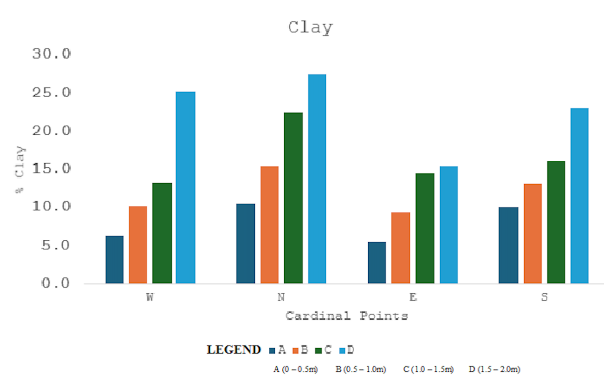

Figure 3: Variation of clay particles with sampling depths.

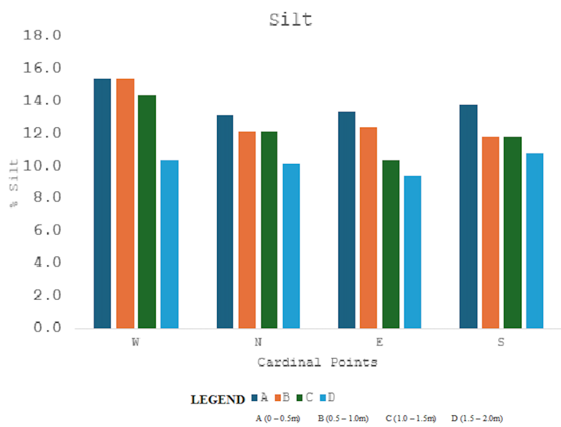

Figure 4: Variation of silt particles with sampling depths.

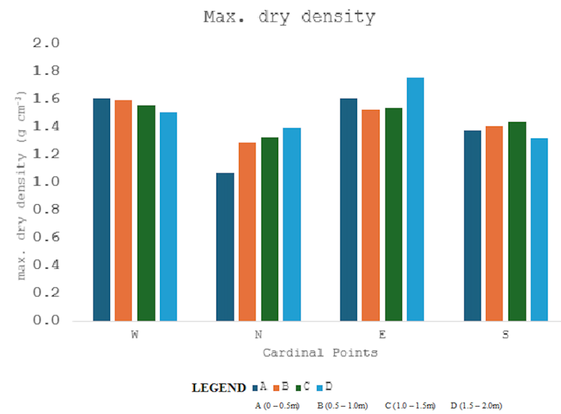

Figure 5: Variation of maximum dry density with sampling depths.

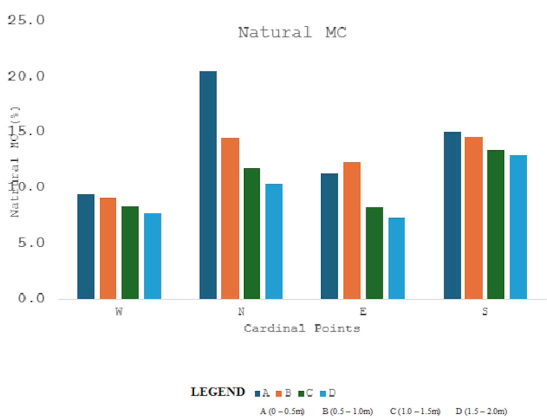

Figure 6: Variation of natural moisture content with sampling depths.

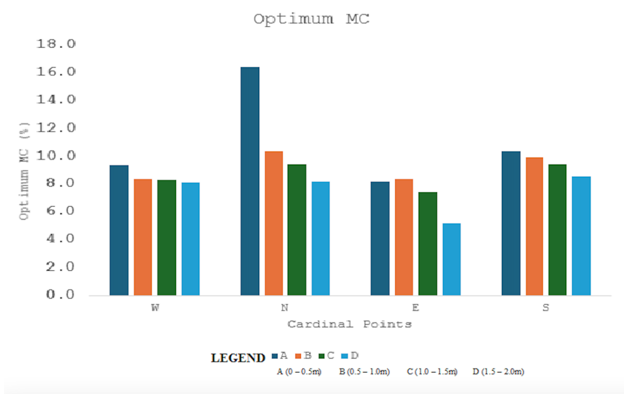

Figure 7: Variation of optimum moisture content with sampling depths.

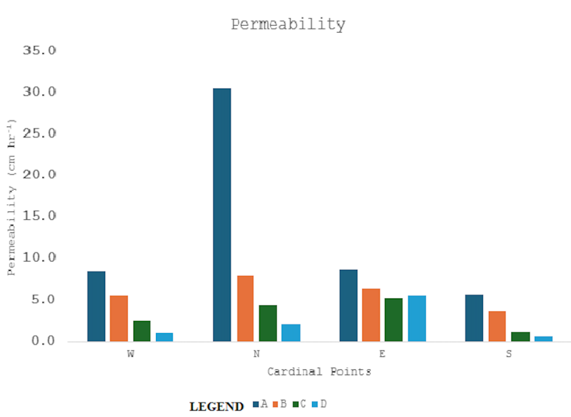

Figure 8: Variation of permeability with sampling depths.

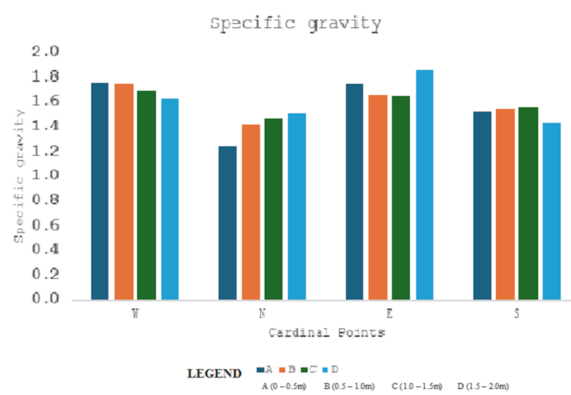

Figure 9: Variation of specific gravity with sampling depths.

respectively). This concurs with earlier similar result by Alhassan [55]; Abagandura *et al.* [56] and Ganiyu *et al.* [57] that reported highest MDD at lowest moisture content. Furthermore, Table 1 shows that lowest MDD (1.07 g/cm^3) observed at 0 - 0.5 m depth in the northern part of the DS corresponds to sample with highest mean values of NMC and OMC but lowest SG. The lowest MDD obtained for soil samples at the northern part relative to other sampling points may be due to low density of waste plastic materials predominant at that part of the DS [21].

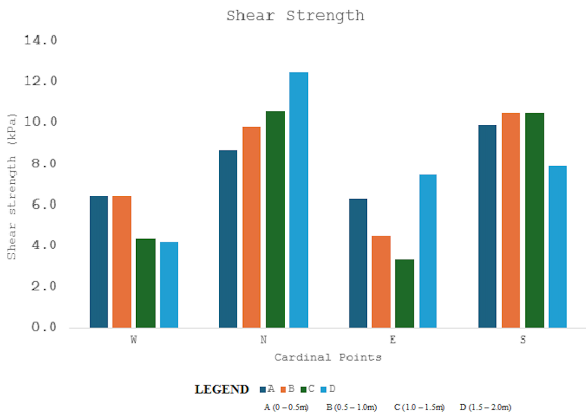

Figure 10: Variation of shear strength with sampling depths.

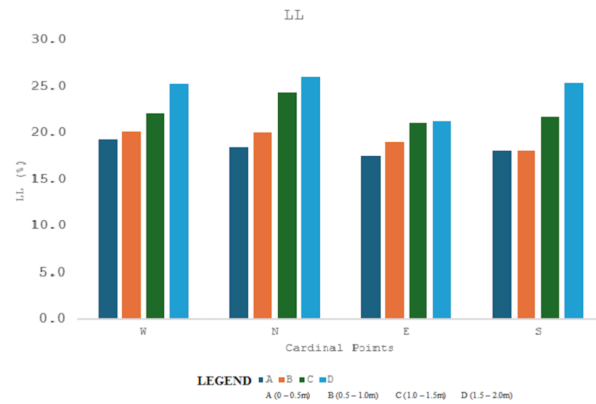

Figure 11: Variation of liquid limit with sampling depths.

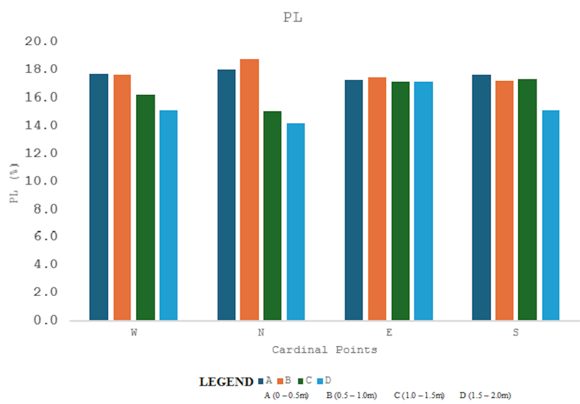

Figure 12: Variation of plasticity index with sampling depths.

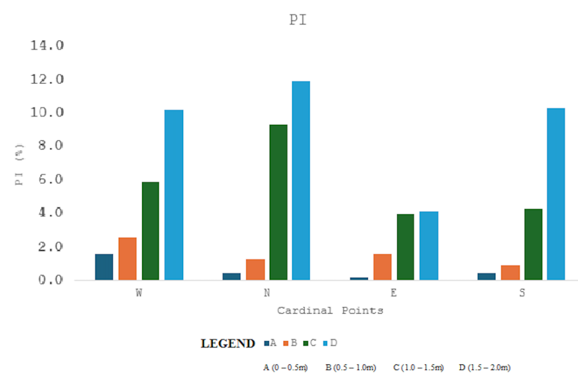

Figure 13: Variation of plastic limit with sampling depths.

The NMC (in %) ranged from 7.8 to 9.5; 10.4 to 20.3; 7.3 to 12.4 and 13.0 to 15.1 at the west, north, east and southern parts of the DS, respectively (Figure 6). The NMC value decreases with sampling depth in the west, north and south of the DS. However, at the eastern part, the NMC increases slightly with depth (from 0.5 to 1.0 m) but decreases with depth afterwards (from 1.0 to 2.0 m depth). The values of NMC at all sampling depths in the north and south parts of the DS were >10% while NMC <10% at each sampling depth characterized near surface soils at the western part of the DS (Figure 6). However, at the eastern part, the NMC >10% were found within the depth range 0.0 - 1.0 m while NMC values <10% were obtained within the depth range 1.0 - 2.0 m. Generally, the NMC values at all sampling depths for soils at the western, eastern and southern parts of the DS are of moderate moisture content, thus good for engineering purpose [26]. The values of OMC ranged from 8.11 to 9.34% in the west, from 8.21 to 16.42% in the north; 8.23 to 8.41% in the east and 8.61 to 10.32% at the southern part of the DS (Figure 7). It was discovered that the OMC value reduces with sampling depths at the western, northern and southern parts but follows no clear trend in the eastern part of the DS. According to FMW&H [54] specification that the MDD and OMC for suitable soil for foundation purpose should be > 1680 kg/m^3 and < 18%, respectively, only soil samples at 1.5 - 2.0m depth at the eastern part of the DS pass the specification guidelines for foundation materials. However, it must be noticed that all collected samples had OMC value <18% and thus lie within the specified OMC [27, 58].

The permeability (in cm/hr) for analysed soil samples ranged from 1.03 to 8.55; 2.08 to 30.55; 5.25 to 8.69 and 0.53 to 5.66 in the west, north, east and south parts of the DS, respectively (Table 1). The maximum value of permeability (30.55 cm/hr) was recorded for samples collected at 0 - 0.5 m depth at the northern part, while the least permeability value (0.55 cm/hr) was observed at 1.5 - 2.0 m depth at the southern part of the DS (Figure 8). The highest mean permeability (30.55 cm/hr) corresponds to samples with lowest mean SG at the northern part of the DS. This could be due to interfacial zone between the soil matrix and the plastic aggregates that can enhance water transport [21]. On the basis of variation with depth, the permeability value decreases with sampling depths at western, northern and southern parts of the DS (Figure 8). The reduction of permeability with depth at the west, north and south part of the DS may be due to clogging of the inter-connected pores by coarse suspended solids and micro-organisms in the dumpsite

[11, 59]. However, permeability value reduces with depth from 0.5 to 1.5 m but increases slightly at 1.5 - 2.0 m depth at the eastern part of the DS. The sudden slight increase in permeability value at depth 1.5 - 2.0m could be due to acidic leachate dissolving soil materials leading to increase in effective pore space [11]. Generally the permeability values ranged from 1.5310^{-4} to 8.4910^{-3}cm/s, an indication of pervious soil within the DS [60, 61]. The range of permeability values obtained in this study agrees with that of Xiangrong *et al*. [62] reported for soil samples from MSW landfill site.

The specific gravity (SG) values of soil samples at all the four sampling points within the DS varied from 1.24 to 1.85 (i.e. < 2.65 for normal soil) (Figure 9). Similar low values of SG in comparison to that of normal soil were also reported by Alhassan [55], Sharma *et al*. [63] and Mir [64]. The range of SG obtained in this study falls within the range of 1.4 to 2.1 reported by Campbell *et al*. [65] but lesser than the range of 2.44-2.58 reported by Song *et al*. [66] for dumpsite soils as well as mean SG of 2.22 reported by Pandey and Tiwari [2]. The lowest range of SG values (1.24- 1.51) of soil samples in the Northern part could be attributed to low SG of polypropylene and polyethylene materials that constitute wastes deposited at this part of the DS [22, 67].

he SG value reduces with depth at the west but increases with sampling depth at the Northern part of the DS. However, at the southern part, SG value increases slightly from 0.5 -1.5 m depth but later decreases at 1.5 - 0.2 m depth. The reverse is the case for soil samples at the eastern side of the DS. Generally, the SG values obtained for analysed soil samples fall below 2.5 stipulated by FMW&H [52] for construction purpose.

The shear strength (SS) ranged from 3.4 to12.5 kPa at all the four sampling directions within the DS (Figure 10). This is an indication that the obtained SS values were less than that of natural soil (65.5 kPa) [21]. The obtained range of SS values indicates that studied soils are weak to withstand shearing forces, thus unsuitable for lighter or heavy engineering structures unless suitable foundation type and specialized soil treatment are carried out [63]. The low cohesion of analysed soils may be due to their low day contents relative to sand contents [68]. Furthermore, the low cohesion of sandy soil may also be due to roundness and smaller number of particles in the soil [69]. The range of obtained SS values on all analysed soil samples fall within the cohesion range of 0.5-71 kPa for MSWs shear strength reported by Reddy *et al*. [7] and Hossian and Haque [70].

The variation of SS with depth reveals that SS value <10 kPa was recorded at each sampling depth in the west and east sides of the DS. Furthermore, there is a clear trend of slight increase in SS value with depths at the northern part but no clear trend of variation of SS with depth in the eastern and southern parts of the DS. The increase in SS value with depth in the northern part of the DS may be due to presence of waste plastic materials that can reinforce the MSW shear strength [70, 71].

From Table 1, the LL values ranged from 19.33 to 25. 35% in the west, 18. 53 to 26. 15% in the north, 17.52 to 21.32% in the east and 18.12 to 25. 46% in the southern part of the DS (Figure 11). The LL values < 30% at all sampling points suggest low to medium swelling potential of soils in the dumpsite [54]. The LL value increases with sampling depth in the west, north, east and southern parts of the DS (Figure 11). The PI values ranged from 1.61 to 10. 20% in the west, 0.49 to 11.96% in the north, 0.20 to 4.15% in the east and from 0.49 to 10.31% in the southern part of the DS (Figure 12).

The mean PI value of assessed samples increases with depth at each of the sampling points within the DS (Table 1). The increase in LL and PI with sampling depths concur with similar trend of variations in LL and PI with depth as reported by Khodary *et al*. [11].

A further scrutiny of the obtained PI values revealed that PI value at each sampling depth from each of the sampling points was < 20% (Table 1). Specifically PI values were< 7% at all sampling depths in the eastern part of the DS, thus belong to low plastic soil [11]. However, the PI values at 1.5 - 2.0 m depth (of SCL texture) in the west, north, and south parts of the DS were > 10%, an evidence of medium plasticity [26]. In addition, the relatively highest values of LL (26.15%) and PI (11.96%) at the northern part of the DS correspond to samples with highest mean % clay and lowest PL (14.19%) [59]. According to Handa [72] classification, all the sampled soils have LL and PI within the range of 12 - 35% and < 12%, respectively, thus belong to low degree of expansion and non-critical in terms of danger of severity [73]. The mean PL value of soil samples at each sampling depth from each of the four sampling points was < 20% (Figure 13). The variation of PL with sampling depths did not follow clear trend in the north, east and southern parts but reduces with depth in the western part of the DS (Figure 13). Generally, the obtained values of LL, PL, and PL for all samples were < 50%, < 30% and < 20%, respectively as stipulated by FMWH [74] and thus suitable for structural foundation materials [74, 75] and pavement construction [54].

3.2. Results of statistical analysis

Table 2 shows the ANOVA result based on sampling depths. From Table 2, the differences in MDD, NMC, OMC, permeability, SG and SS in all analyzed samples were not significant based on depth among the four sampling points within the DS at 5% level. However, there were significant differences in values of % sand, % clay, % silt, LL, PL, and PI at 5% level ($p < 0.05$) among the sampling depths at all the sampling points within the DS.

The ANOVA result (Table 2) further shows that the sand content of the soil samples decreases significantly with sampling depth, with the least value 66.95 ± 5.65 at 1.5- 2.0 m depth in the southern part while the highest value of % sand (77.95 ± 2.32) was recorded at 0.0-0.5 m depth at the eastern part of the DS. On the contrary, the clay content of the DS soils increases significantly with sampling depth and varies from 8.10 ± 2.57 to 22.85 ± 5.22. The least value (8.10 ± 2.57) recorded at 0.0 - 0.5m depth in the eastern part and highest value of 22.85 ± 5.22 (for % clay) noticed at 1.5-2.0 m depth in the northern part. The silt content of the analysed DS soils also decreases significantly with sampling depth and ranges from 10.20 ± 0.59 to 13.95 ± 0.99.

The ANOVA result (Table 2) also shows that sampling depths does not have significant effect on MD, NMC, OMC, permeability, SG, and SS. On the other hand, the LL of collected samples increases significantly with sampling depth and ranges from 18.38 ± 0.76 to 24.57 ± 2.19. The PI of soil samples also increases significantly with sampling depth and varies from 0.7 ± 0.62 to 9.16 ± 3.43. However, the PL of the soil samples decreases significantly with soil depth and ranges from 15. 42 ± 1.25 to 17. 81 ± 0.69.

The significance of the observed correlation coefficient results are presented in Table 3. From Table 3, some pair of parameters correlate significantly at 1 % ($p <0.01$) level while some correlate significantly at 5% level ($p < 0.05$). For instance, strong negative correlation exists between % sand and % clay, % sand and LL, and % sand and % clay is in agreement with previous similar results by De Jong *et al*. [57, 69]. Strong negative correlations between % sand and LL, % sand and PI are in arrangement with similar results by Ganiyu *et al*. [57] and Nebeokike *et al*. [68]. The % clay displays strong positive correlation with each of LL and PI at 1% level, but negative correlation with PL (-0.815). Similar positive correlation between % clay and PI/LL was also reported by Moradi and Ebrahimi [76]. Negative correlation between % clay and PL may be due to presence of soft clay content in the assessed soil samples [77]. A strong negative correlation at 1% level exists between MDD and each of NMC and OMC (Table 3). Similar negative correlation between MDD and OMC was also reported for soil in the humid tropics by Udom and Ehilegbu [78], and Al-Obaidi *et al*. [79].

Positive correlation between NMC and OMC (0.881) at 1% level obtained in this study was also reported by Nebeokike *et al*. [68]. A very strong positive correlation exists between SG and MDD. Similar strong direct relation between MDD and SG of soil was also obtained by Worku and Shiferaw [80] and Gomaa and Abdelrahman [81]. The SG exhibits strong negative correlation with each of NMC and OMC (Table 3). Inverse relation between SG and OMC/NMC may be due to the fact that intact soil aggregates with low absorption rate has high specific gravity [82]. A moderate negative correlation exists between SS and SG, as well as SS and MDD (Table 3). Similar inverse relation between SS and MDD was reported by Han *et al.* [83]. This could be due to internal friction angle of soil that decrease with rise in soil water content [83]. Strong positive correlation exists between NMC and OMC while moderate positive correlation at 1% level exists between NMC and permeability (0.640) (Table 3). Direct relationship between NMC and OMC obtained in this study is in agreement with similar positive association between water retention and OMC in Latossolos clay (Oxisols) and Vertisol of Brazil soils by Millan-Romero and Millan-Paramo [84]. Similar positive correlation between NMC and OMC (0.881) at 1% level was also obtained by Nebeokike *et al.* [68]. Table 3 also shows that strong positive relation exists between OMC and permeability (0.797). Highly significant positive relationship between the OMC and permeability was also reported by Udom and Ehilegbu [78].

Strong negative correlations exist between PL and LL (-0.869) as well as PL and PI (-0.937) at 1% level (Table 3). However, there is positive correlation between LL and PI (0.987) at 1% level. Direct correlation between LL and PI agrees with the similar positive relation obtained by Rashed *et al*. [85] and Salih [86] for fine-grained soils.

4. Conclusion

Geotechnical parameters of the near surface soils within active dumpsite were investigated in this study with a view to assess their suitability as foundation/filling materials. The following conclusions can be drawn based on the results of this study.

1. All the tested soils samples are sandy soil with less than 30% clay content. The activity values were <0.75, indicating inactive clay of low moisture affinity.
2. As sampling depth increases, the % sand decreases while the % clay, LL and PI increase at all sampling points.
3. The MDD values ranged from 1.07 to 1.76 g/cm^{3,} with the lowest range of MDD (1.07 – 1.40 g/cm^3) obtained in plastic waste-impacted soils at the northern part of the DS.
4. The SG and MDD values of DS soils are lower than their published values in natural soils.
5. The permeability coefficient values ranged from 1.53×10^{-4} to 8.49×10^{-3}cm/s, suggesting moderately permeable soils. The ALs results revealed assessed soils to be of low plasticity and low degree of clay expansion.
6. The SS values of the DS soils were <20kPa, an indication of very low reaction to shearing forces and thus need improvement before use. The use of helical piers footings could be useful in the study area
7. The results will assist site engineer when designing and constructing suitable foundations for engineering structures should the DS be turned back to urban development use.

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