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Geotechnical characterization and suitability analysis of soil underlying solid waste dumpsite in southwestern Nigeria

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Abstract

Soil servers as natural containment medium that influences leachate migration, contaminants attenuation for the stability of waste disposal system. Soil selection for dumpsite should emphasize adequate clay properties, low hydraulic conductivity, favorable plasticity, geotechnical analysis and chemical properties. This research aimed to determine the geotechnical characteristics of Ilokun dumpsite underlying soil in Ado-Ekiti to access its suitability in preventing the migration of the leachate within the environment. Three (3) Soil samples were randomly selected while samples were collected at 0-0.5 and 0.5-1.0m depth within the dumpsite at different locations using trial pit method, air dried, sieved using 2 mm mesh. Each of the pits were dug by hand excavation and samples were collected from pit of 1.0 X 1.0m, while laboratory tests were conducted on the soil samples. Soil index properties and classification test such as particle size distribution, specific gravity, Atterberg limits and permeability test were performed on the samples. All the tests were conducted according to BS 1377:1990. Particle size distribution results show that; the percentage fines of the underlying soil samples are predominantly below 50 % except 1B. A standard value of fines greater than 50 % (≥ 50 %) was specified for clay liner material as reported by CGRM (2007). The values of the Liquid limit of the underlying soil ranged from 19.57 to 27.80, Plastic limits ranged from 10.13 to 24.25 and the Plastic Index ranged from 2.23 to 12.23 respectively. The analysis revealed that the Liquid limit of the soil samples are below 30% and Plastic Index of the soil samples are below 20%. The underlying soil results is indicative that the soil is predominantly coarse-grained and is unsuitable as a liner material.

Keywords: Dumpsite; Development; Soil Suitability; Geotechnical; Analysis

1. Introduction

The assessment of soil suitability is a fundamental requirement in the designing of dumpsites. Soil serves as a natural containment medium, that influences leachate infiltration, contaminant attenuation, and serves as barrier for structural stability of waste disposal systems. Solid waste disposal remains a major concern in developing countries worldwide. (Adewole, 2009). Increased population growth, urbanization, and poor funding have resulted to inefficient waste management system. **(**Guerrero *et al,* 2013**).** leachate impact on soil and groundwater elevated level of some potentially toxic elements using integrated geo chemical and physicochemical approach in Ilokun dumpsite of Ado-Ekiti. (Olagunju *et al.,* 2018). Identifying appropriate municipal solid waste disposal sites and ensuring their effective management present significant challenges for developing nations such as Nigeria. The widespread practices of open dumping in many parts of Nigeria has contributed to environmental degradation and public health risks, primarily due to non-compliance with established criteria for suitable site selection. (Amasuomo & Baird, 2017). A systematic assessment of its engineering, physicochemical, geotechnical and hydrogeological properties is essential before the establishment. Dumpsite Suitability focuses on determination of whether the soil possesses some vital characteristics that are capable

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of minimizing environmental risks. Urbanization, industrialization and agricultural activities has resulted to generation of huge amounts of solid and liquid waste that degraded the land and the environment.

Soil selection for dumpsite should emphasize adequate clay properties for enhancement of adoption of contaminants, low hydraulic conductivity to resist leachate migration, favorable plasticity for the enhancement of effective compaction, geotechnical analysis and chemical properties. Soil rich in clay are generally preferred due to their fine particles size, low hydraulic conductivity and high cation exchange capacity which prevents their ability to retard the infiltration of contaminants. Akiro and Oni, (2022) evaluate the physical and hydraulic properties of soil underlying the municipal solid waste dumpsite at Ilokun Ado-Ekiti, revealed an indication of soil contaminations in the vicinity. Soil is contaminated when excess amount of chemicals, such as pesticides, ammonia, herbicides, petroleum hydrocarbons, nitrate, lead, mercury are deposited on land through various mechanisms, including direct application, leaching, runoff, and infiltration process from dumped waste. Heavy metal contamination in soils near waste dumpsite in Ado – Ekiti using pollution and geo-accumulation indices revealed that Ilokun dumpsite shows highest contamination levels. (Awoyemi *et al.,*2025). A comprehensive environmental analysis of heavy metals containing ecological risk and health impact in Ilokun area of Ado-Ekiti was conducted by Ogntuase *et al.,* (2024), revealed an evidence of heavy metal contamination in soil and biota near Ilokun with potential ecological and human health risks.

This study aimed to carryout geotechnical properties of the soil in Ilokun dumpsite to ascertain its suitability to prevent migration of leachate in the surrounding soil.

2. Materials and Methods

2.1. Area Description and Site Location.

The study area was carried out in Ilokun dumpsite located in Ado-Ekiti the state capital of Ekiti-State in Southwestern part of Nigeria. It lies within latitude 7’15°N and longitude 4’51° E respectively and it covers an approximately 6,353 square kilometers of sixteen local government areas (16) in Ekiti-State. The State has a population of 308,621 people residing in Ado. (NPC,2007), making it the most populous local government among others in the state. The climate in the town experiences significant variations in relative humidity and a mean annual temperature of 27°C with annual mean rainfall of 1334mm. The terrain is predominantly undulating, and the weathering characteristics of these crystalline rocks have resulted in the development of clayey and loamy soil. Ado-Ekiti is projected to have a population of 546,676 by 2025 using last 2006 population census (NPC, 2007) at a growth rate of 3.14%. (Popoola.*et al.,* 2025). The google area map of Ilokun dumpsite is shown in Figure 1.

Figure 1 Google Arial Map of Ilokun Dumpsite, Ado Ekiti.

2.2. Site Location

Ilokun dumpsite is located at latitude 7.6667°N and Longitude 5.2333°E along Ekiti-State University Road, off Ado Ekiti, Ifaki- Ekiti Road at approximately Km 10. It is the main dumpsite in Ado Ekiti, supervised by the Ekiti State Waste

Management Board (EKSWMB). The dumpsite has been in existence for over 20 years with an area of approximately 24.7 hectares and is characterized by a highly variable topography with significant changes in elevation. Figure 2a, shows the Map of Nigeria showing States, Cities, Main Road and other Physical features while Figure 2b, shows the Map of Ekiti State showing the Local Government Areas respectively.

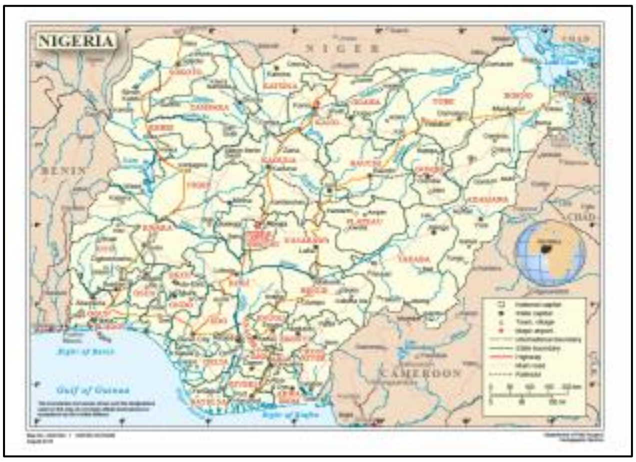

Figure 2a Map of Nigeria showing States, Cities, Main Road and other Physical features (UN, 2014)

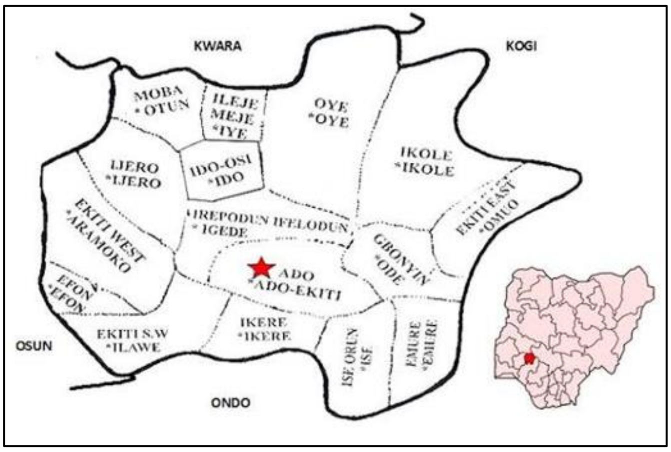

Figure 2b Map of Ekiti State showing the Local Government Area.

2.3. Soil sampling

Three (3) Soil samples were randomly selected while samples were collected at 0-0.5 and 0.5-1.0m depth respectively within the dumpsite at different locations using trial pit method, air dried, and sieved using a 2 mm mesh. Each of the pits were dug by hand excavation and samples were collected from the pit of 1.0 X 1.0m, while laboratory tests were conducted on the soil samples. Soil index properties and classification test such as particle size distribution, specific gravity, Atterberg limits and permeability test were performed on the samples. All the tests were conducted according to BS 1377:1990. Figure 3, shows the overview of the dumpsite while the coordinates of the sample collection is shown in Table 1.

Figure 3 General overview of the Dumpsite.

Table 1 Coordinate points of soil samples within the dumpsite

Soil locations	Latitude	Longitude	Mean sea level
A	7°68’83”	5 °26’03”	406.607
B	7 °68’75”	5 °26’04”	404.821
C	7 °68’67”	5 °25’03”	406.745

2.3.1. Soil classification

- **Soil classifications** is the grouping of soils based on shared characteristics, including particle size, origin, and engineering properties, to understand their Behaviour and suitability for various uses.
- **Soil Plasticity** refers to the ability of a soil to undergo deformation without cracking or breaking, when subjected to stress or pressure, and then return to its original shape when the stress is removed. This can be achieved through atterberg limit test.
- **Clay Properties** can be identified manually using Index properties. when it has a higher dry strength, but loose the strength when wetted and can be rolled between finger into 5-mm diameter threads when moist. However, clay is classified according to Unified Soil Classification System as follows: > 12% material passing No 200sieve and the material plots below the A-Line (the equation of which is PL = 0.73(LL-20)

When less than half of fine grained soil retained on No 200 sieve gives a Liquid Limit (LL): <50 = High Plasticity Clay, and >50 = Low Plasticity Clay

iv. **Soil Permeability** refers to the ability of soil to allow movement of water or air through its pores. It affects various processes, such as soil texture, soil structure, soil compaction and water content. According to Venkatramaiah, (2006) soil permeability is the property governing the easy with which a fluid flows through the soil. Allen Hazen prosed an interrelationship between permeability and particle size of a soil as:

$$K = 100D^2_{10}$$

Where, D_{10} (cm) is taken as the maximum particle size of the smallest 10% of the aggregate.

K, (cm/s) is taken as hydraulic conductivity.

Table 2 shows the typical values of soil permeability obtained in literature for different types.

Table 2 Typical values of hydraulic conductivity for various soils

Type of Soil	Hydraulic conductivity, K (cm/sec)	Remarks
Gravel	$K > 1.00\times10^{-01}$	Very High
Coarse Sand, Fine Sand	$1.00\times10^{-03} < K < 1.00\times10^{-01}$	Medium to High
Silty Sand	$1.00\times10^{-05} < K < 1.00\times10^{-03}$	Low
Silt, Silty Clay	$1.00\times10^{-07} < K < 1.00\times10^{-05}$	Very Low
Clay	$K < 1.00\times10^{-07}$	Tends to Impermeable

3. Results and Discussion

3.1. Soil classification Analysis

3.1.1. Particle Size Analysis

From the underlying soil results, it is indicative that the soil is predominantly coarse-grained. Particle size distribution results show that; the percentage fines of the underlying soil samples are predominantly below 50 % except 1B. A standard value of fines greater than 50 % (≥ 50 %) was specified for clay liner material. (CGRM ,2007). However, a percentage fines greater than 30 % (≥ 30 %), clay fraction more than 15 % (≥ 15 %) and percentage gravel less than 10

% (< 10 %) was reported by Mohammed *et al.*, (2024). Material suitable for clay liner should have a standard percentage of clay of ≥ 20 % (Ojuri, 2018; Mohammed *et al.,* 2024). In comparison with the recommended requirement, the sample meet the requirements listed above and can be used as earthen liners.

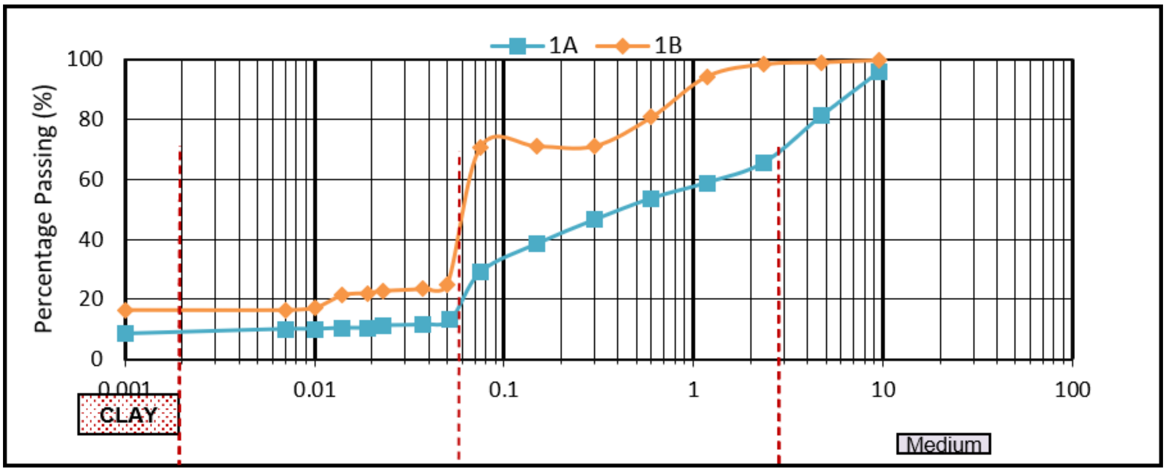

Figure 4 Graduation curve of Location 1

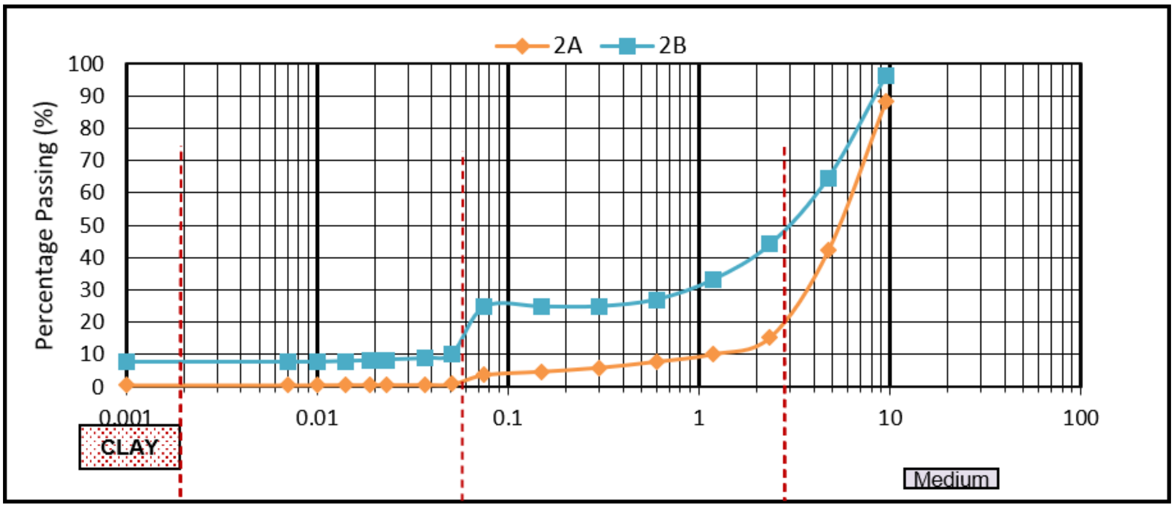

Figure 5 Graduation curve of Location 2

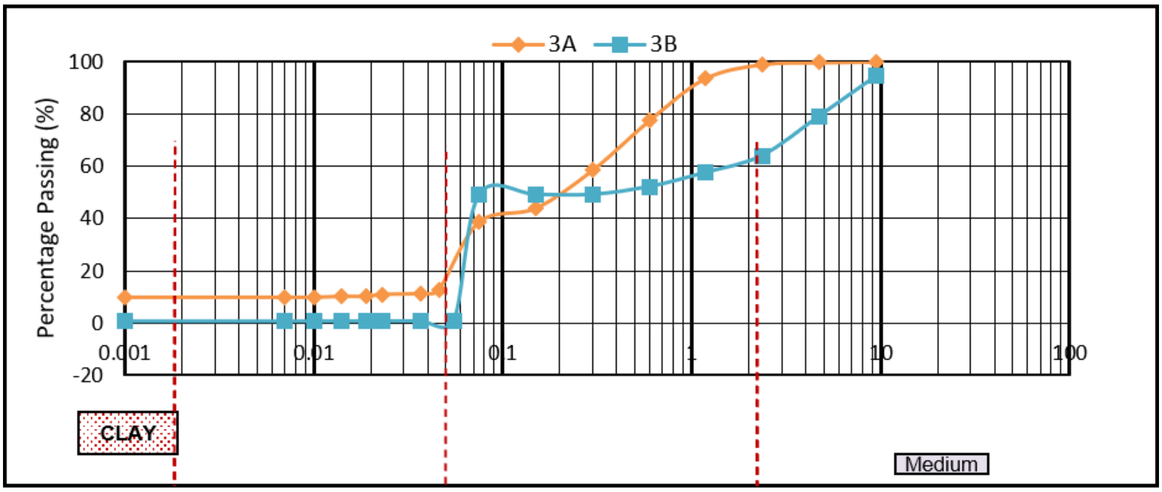

Figure 6 Graduation curve of Location 3

Table 3 Particle size Distribution Analysis of Underline soil at the Dumpsite

LOCATION	% Gravel	% Sand	% Coarse	% Fines	% Clay
1A	18.76	15.63	36.56	29.05	8.00
1B	20.83	21.67	8.36	0.09	16.20
2A	57.57	26.97	11.69	3.77	0.57
2B	1.03	0.06	27.56	70.77	7.67
3A	0.03	0.75	60.30	38.65	9.82
3B	35.26	20.63	19.33	24.78	11.46

3.1.2. Atterberg Limits analysis

Are different types of tests carried out in geotechnical engineering to determine the critical water contents of a soil, which shows the relationship between consistency and moisture content. It comprises of Liquid Limit (LL), Plastic Limit (PL), and Shrinkage Limit (SH). The clay plasticity is measured by Plastic Index (PI). The Atterberg Limit test results of the underline dumpsite soil is shown in Table 4 while the analysis showed that the liquid limit ranged from 19.57 to 27.80, Plastic limits ranged from 10.13 to 24.25 and the Liquid limits ranged from 2.23 to 12.23 respectively. The analysis shows that the Liquid limit of the soil samples are below 30% and Plastic Index of the soil samples are below 20% as given by CGRM (2007).

Table 4 Atterberg Limit Tests for underlying Dumpsite Soil samples

LOCATION	LL	PL	PI	<0.0075mm
1A (0.5m)	25.70	18.98	6.72	29.06
2B (1.0m)	27.80	24.25	3.55	70.80
2A (0.5m)	19.57	13.79	5.78	3.76
2B (1.0m)	23.82	21.59	2.23	24.75
3A (0.5m)	22.26	10.13	12.13	38.65
3B (1.0m)	26.20	23.78	2.42	49.06

3.1.3. Permeability Analysis

The results of the hydraulic conductivity (K) ranges from 2.3 x 10^{-3} to 5.8 x 10^{-3} cm/sec, which was obtained from falling head permeability test carried out on the soil samples. It was observed that the permeability test of the underlying soil samples shown in Table 5, does not meet the standard threshold of 1.0 x 10^{-7} cm/sec recommended by USEPA (1994) and CGRM (2007).

Table 5 Falling Head Permeability Test of underlying Dumpsite Soil samples

LOCATION	Hydraulic Conductivity, K (cm/sec)
1A (0.5m)	5.8 x10^{-3}
1B (1.0m)	2.7x10^{-3}
2A (0.5m)	2.3 x10^{-3}
2B (1.0m)	4.8x10^{-3}
3A (0.5m)	2.33 x10^{-2}
3B (1.0m)	3.3x10^{-3}

3.2. Dumpsite Soil Properties

The summary of Ilokun dumpsite underlying soil is presented in Table 6. It was observed from the results that the underlying soil at the dumpsite cannot hold movement of toxic pollutants into underground water resources because of the coarseness of the soil particles.

Table 6 Summarized range of Ilokun dumpsite soil properties

SAMPLE CODE	ATTERBERG LIMITS			PARTICLE SIZE DISTRIBUTION					CLASS
	LL	PL	PI	4.75mm	2.00mm	0.425mm	0.075mm	%Clay	USCS
1A	25.70	18.98	6.72	81.21	63.00	50.00	29.06	8.00	SC
1B	27.80	24.25	3.55	99.00	98.00	76.00	70.80	16.20	ML
2A	19.60	13.79	5.81	42.33	12.00	6.50	3.76	0.57	GP
2B	23.80	21.59	2.21	64.74	40.50	25.50	24.75	7.67	SM
3A	22.20	10.13	12.07	99.70	98.00	68.00	38.65	9.82	SC
3B	26.20	23.78	2.42	79.17	62.00	51.00	49.06	11.46	SM

3.3. Statistical Interpretation of Particle Size Distribution

The statistical results (mean, Standard deviation and Coefficient of Variation) give insight into Variability, Sorting and dispositional characteristics of the soil both depths. A CV greater than 50% indicates high variability (poor sorting), CV less than 35% suggest better sorting (uniform). The summary showing the Mean, Standard Deviation and the Coefficient of Deviation for Particle Size Distribution at 0.5m and 1.0m depth is shown in Table 7 to 8 and Figure 7 to 8.

CV of soil parameters at 0.5m depths show gravel with 57.6%, sand (54.6%), coarse (57.7%) which suggest very high variability, indicating poorly sorted sediments. Clay (51.3%) also indicate considerable variability, suggesting inconsistent in fine particles. Fine (46.3%) is slightly lower but still indicate moderate to high variability.

CV of soil parameters at 1.0m depth indicate gravel (54.4%), sand (57.4%), fine (57.8%) which indicate high variability, suggesting continuous poor sorting. Coarse (30.8%), clay (20.6%) show low CV, indicating a better sorting and a more uniform distribution. This results suggest that deeper layers (1.0m) have undergone more stable or selective disposition, especially for coarse and clay fractions.

The SD indicate the spread of parameters. Higher SD value (Fine at 1.0m), 20.46, indicate a wide spread of particle size, indicating variable condition during deposition. Lower SD (2.46) value of Clay at 1.0m depth, indicate more consistent particle size. The mean values indicate dominant particle size. Higher mean value (Fine at 1.0m) with 35.43 indicate dominance of that fraction in the distribution range. Lower mean value (Clay at 0.5m) with 5.20 suggest less dominance or finer material particles.

Table 7 Table showing the distribution of particles across the locations

Depth	Location	Gravel	Sand	Coarse	Fines	Clay
0.5m	1A	18.76	15.63	36.56	29.05	8.00
	2A	57.57	26.97	11.69	3.17	0.57
	3A	0.03	0.75	60.30	38.65	9.82
1.0m						
	1B	20.83	21.67	8.36	0.09	16.20
	2B	1.03	0.06	27.56	70.77	7.67
	3B	35.26	20.63	19.37	24.78	11.46

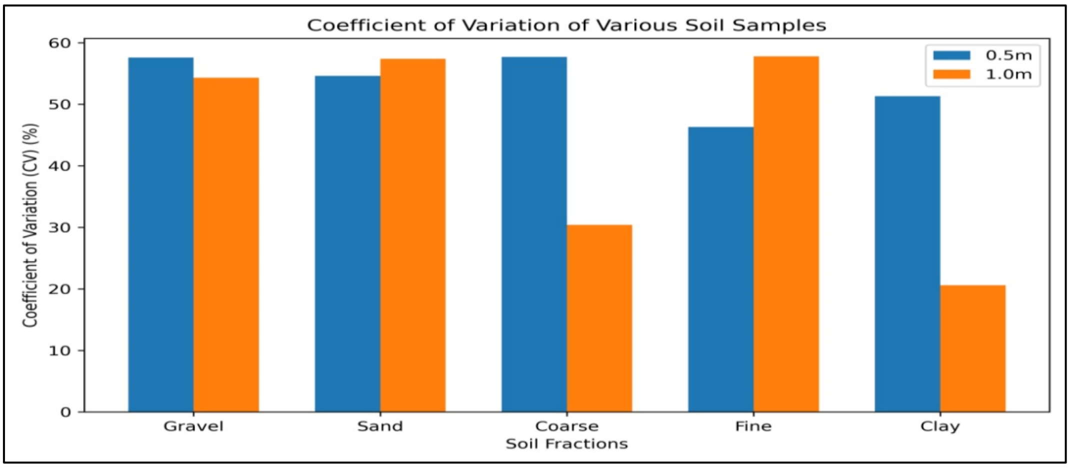

Figure 7 Coefficient of variation of various underlying soil samples at 0.5m and 1.0m depth

Table 8 Summary of Particle Size Distribution at 0.5m and 1.0m depth.

Depth	Fraction	Min	Max	Mean + SD	CV
0.5m	Gravel	0.03	18.75	9.40+ 5.41	57.6
	Sand	0.75	26.97	13.86 + 7.57	54.6
	Coarse	0.03	36.56	18.30 + 10.56	57.7
	Fine	3.17	28.65	15.91 + 7.36	46.3
	Clay	0.57	9.82	5.20 + 2.67	51.3
1.0m					
	Gravel	1.03	35.26	18.15 + 9.88	54.3
	Sand	0.06	21.26	10.87 + 6.34	57.4
	Coarse	8.36	27.56	17.98 + 5.54	30.4
	Fine	0.09	70.77	35.43 + 20.46	57.8
	Clay	7.67	16.20	11.94 + 2.46	20.6

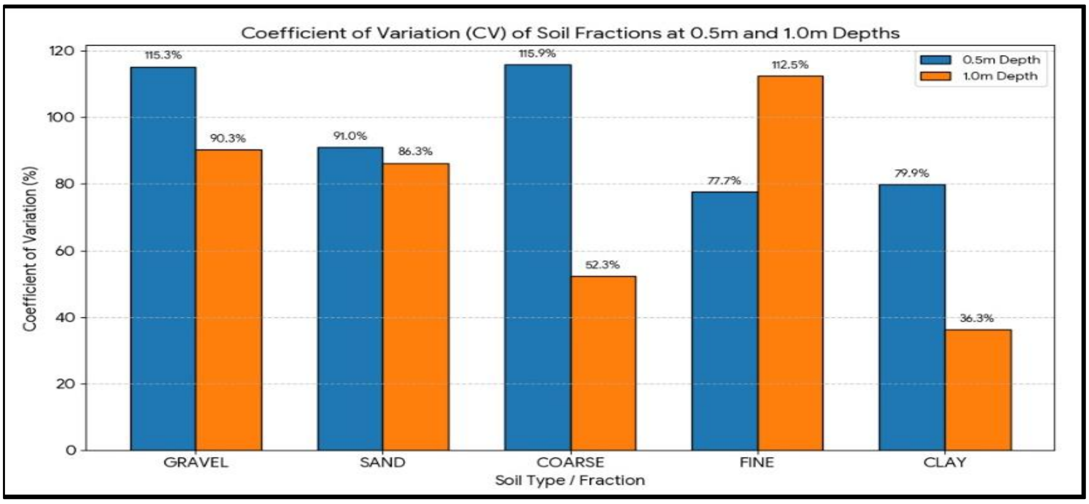

Figure 8 Coefficient of variation of soil fractions at 0.5 and 1.0m depth

4. Conclusions

i. The leachate produced by the waste fill has affected the geotechnical properties of the underlying soil as a result of infiltration and percolation of the high level of organic matter and heavy materials in the leachate. (Popoola *et al*., 2025, Akinro *et al*., 2022)

ii. The underlying soil results is indicative that the soil is **predominantly coarse-grained**. This is according to Unified Soil Classification System (USCS) that soil that have less than 50 % of their particle pass through 75μm (#200) sieve are coarse-grained soil.

iii. Particle size distribution results show that; the percentage fines of the underlying soil samples are predominantly below 50 % except 1B. A standard value of fines greater than 50 % (≥ 50 %) was specified for clay liner material as reported by CGRM (2007). However, a percentage fines greater than 30 % (≥ 30 %), clay fraction more than 15 % (≥ 15 %) and percentage gravel less than 10 % (< 10 %) was reported by Mohammed et al., (2024). Material suitable for clay liner should have a standard percentage of clay of ≥ 20 % (Ojuri, 2018; Mohammed *et al*., 2024).

iv. The values of the Liquid limit of the underlying soil ranged from 19.57 to 27.80, Plastic limits ranged from 10.13 to 24.25 and the Plastic Index ranged from 2.23 to 12.23 respectively. The analysis shows that the Liquid limit of the soil samples are below 30% and Plastic Index of the soil samples are below 20% as given by CGRM (2007)

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest regarding this paper.

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