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Geotechnical And Geophysical Investigation for The Federal University of Technology Akure (FUTA) Waste Containment Facility

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Abstract- This research focuses on investigation of geological and geotechnical information that will aid the construction of the proposed FUTA waste containment facility (landfill) before the design, development, and construction due to non or inaccurately conducted geological and geotechnical investigation of selected land area used for solid waste disposal. The proposed landfill site is 4,795 m2 of FUTA municipal solid waste. Evaluation of the suitability for the construction of an engineered landfill was determined with geological, geophysical and geotechnical investigation. Geological test was carried out using previous study of the area. The geophysical investigation of Vertical Electrical Sounding and Electrical Resistivity Sounding method were carried out. Disturbed samples were taken at depths of 0.5 and 1.0m respectively with moisture content ranging from 14.20% to 23.40% for 0 – 0.5m depths, 16.20% to 20.40% for 0.5 to 1.0m, specific gravity. The Plastic Index (PI) for samples at depth 0.0-0.5m ranges from 10.9% to 13.2 while the Plastic Index (PI) for samples at depth 0.5-1.0m ranges from 11.1% to 15.3%. The Maximum Dry Density (MDD) for 0.0 – 0.5m depth ranges from 1.68 g/m3 to 1.78 g/m3 and the optimum moisture content ranges from 11.3 g/m3- 15.7g/m3 while the Maximum Dry Density (MDD) for 0.5m - 1.0m depth ranges from 1.68g/m3 to 1.83g/m3 and the optimum moisture content ranges from 13g/m3 to 19g/m3. The coefficient of permeability for 0.0 - 0.5m depth ranges from 2.82E-04 to 4.92E-04 and ranges from 5.43E-04 to 9.11E-04 for 0.5 - 1.0m depth. The soil samples were classified to be A-4 and Silty Clay using AASHTO and USCS methods respectively. The result concluded that proposed area based on the geophysical and geotechnical investigations is suitable for the construction of engineered landfill.

Keywords: Geological Information, Geotechnical Information, Landfill, Vertical Electrical Sounding, Electrical Resistivity Sounding

I. INTRODUCTION

In today's world, the university societies can be viewed as ' mini cities ' with broad territorial reach, diverse human activities, with varying degrees of environmental effects. Universities and colleges are required in all their operations by state and international bodies to adopt sustainable development strategies in order to have a positive impact on their immediate and extended communities ' socio-economic and environmental well-being (Adeniran et al., 2017; Nkululeko et. al., 2025). A part of such development is the practice of waste disposal and management of municipal solid waste. Municipal solid waste (MSW) may be described as solid waste that includes all domestic and non-hazardous waste such as commercial and institutional waste, street sweeping, and building debris (Fajardo et al., 2016). Its main classifications are food waste, paper, plastic, rags, metal, and glass, with some dangerous domestic waste such as electric light bulbs, batteries, and expired drugs.

The increasing growth in numbers of students in universities and colleges has implications in the management of municipal solid waste. The Federal University of Technology, Akure (FUTA) is a federal university located in Akure, is an institution with a growing number of students. In 2010, FUTA had a total population of 24,823 and is estimated to have 49,831 by 2022 (Federal, 2020). This will have effect on the amount of waste generated and without an engineered waste containment facility and a thorough investigated land area for its construction; it will have effect on the environment. Solid waste management problem can be of great hazard to the environment if not accurately managed. The management of municipal solid waste includes the control of the generation, storage, collection, transfer, processing and recycling or disposal of solid waste (Geological and Of, 2015). Disposal is the destination of all waste that has been produced and is the most important part of managing solid municipal waste. There are many approaches that can be used to control and dispose of solid waste, such as biological treatment (composting), thermal treatment (incineration) and waste containment facility (landfill). Landfills remain an important destination in the waste disposal system, despite intensive efforts in other methods of disposal and the implementation of policies on waste reduction and re-use, landfills remain, in the majority of the world, a key part of solid waste management plans (Kingsley et al., 2016).

Landfill is the site for the disposal of waste materials by burial. It is the oldest form and most common method of waste treatment and disposal in so many places around the world. The widely used type of landfill; the sanitary landfill is a cautiously engineered depression in the ground comprising of a bottom liner, a leachate collection system, a cover, and the natural hydrogeological setting. It is the primary facility for disposal of municipal solid waste. Sanitary landfills as the final disposal sites for municipal solid waste is the environmentally acceptable waste disposal method to prevent environmental pollution (Owusu-Nimo et al., 2019). It is therefore vital that for proper landfill performance, geological and geotechnical investigation is done to ensure optimal use of available landfill facilities to increase its operational life. This is due to the difference in geological and geophysical differences in the terrains selected for the construction.

In the designing, planning and development of constructions with environmentally friendly functions, the importance of the geological and geotechnical basis and foundations is sometimes overlooked, which in turn leads to negative effects on the country's economy, unsatisfactory ecological consequences, and the environmental health if wrong decision is made or in other words, unsuitable area is selected (Mat et al., 2016; Raki et al., 2015). In the design of a waste containment facility certain philosophy are considered which consists of optimization of the landfill site, construction of high-performance liner and capping systems, optimization of the storage of waste, short-term and long-term careful monitoring, and convenient re-use of the landfill after closure (Manassero et al. 2000). (Asante et al, 2018). An evaluation of the suitability of an existing open dump site for the construction of an engineered landfill was determined (Oyediran, 2017). He made an evaluation of a site in southwestern part of Nigeria to investigate geotechnical properties of residual soils for use as isolation barriers and to generate baseline information on soil vulnerability, necessary in assessing site suitability for waste disposal integrated the Electrical Resistivity Tomography (ERT) and Vertical Electrical Soundings (VES) as the geophysical evaluation in testing the suitability of a proposed landfill area (Zeyad and Abu, 2017; Case, et. al., (2017).

Appropriate location and detailed research of a landfill site fulfills the first philosophy of optimization of landfill site. Hence, sanitary landfill cannot be built without the proper information acquired from the geological and geotechnical investigation which is the focus of this study that seeks to investigate the geological and geotechnical properties or information of the proposed site for waste containment facility for FUTA.

II. METHODOLOGY

A. LOCATION SURVEY OF THE SITE

Geographical site investigation map of the study area was carried out using surveying instruments, total station, prism reflector, ranging pole to produce the location map of the study area so as to define the boundary of the site and make soil sampling specific. Figure 2 is the Location Map of the proposed landfill Site. Figure 2 is the location map of the proposed landfill Site.

Figure 2: Proposed landfill Site location

B. Geophysical Investigation

Geophysical methods comprised 2D Electrical Resistivity Tomography (Dipole-Dipole array) and Vertical Electrical Sounding (Schlumberger array) across 5 traverses (TR1–TR5) using a PASI Terrameter and a 12V power supply. Figure 4 is the layout of dipole-dipole traverses across the site.

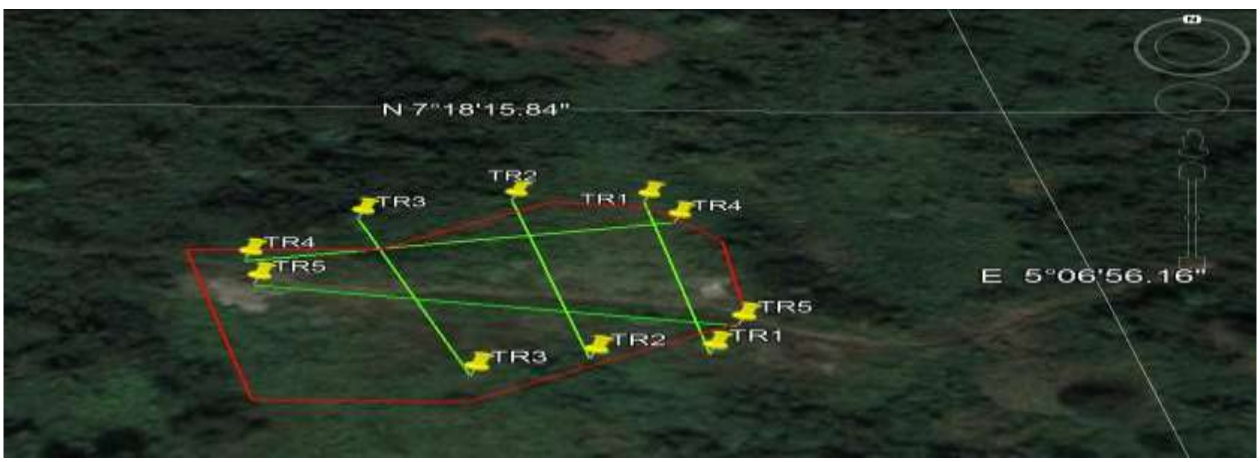

Figure 4: Layout of dipole-dipole traverses across the site

i. 2D Electrical Resistivity Profiling:

Dipole-Dipole measurements used 5m electrode spacing. Data inversion was performed using DIPRO software to generate 2D resistivity structures.

ii. Vertical Electrical Sounding (VES):

5 VES stations (VES 1 to 5) were sounded with current electrode separation (AB/2) ranging from 300 m to 400 m. Data were interpreted using manual partial curve matching with master/auxiliary curves (Bhattacharya and Patra, 1968; Bhattacharya, 2012: Wadhah, 2021) and refined iteratively via WINRESIST software. Geoelectric cross-sections were plotted using AutoCAD. Figures 5 - 6 are the all VES AND combined VES and Transverse section.

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Figure 5: All VES section

Figure 6: Combination of VES and Traverse section

C. Geotechnical Soil Sampling & Testing

Disturbed soil samples were retrieved from 10 trial pits (Sample A–J) at two depth intervals (0.0–0.5 m and 0.5–1.0 m) according to ASTM standards. Figure 7 is the location of Sample/Borrow Pit.

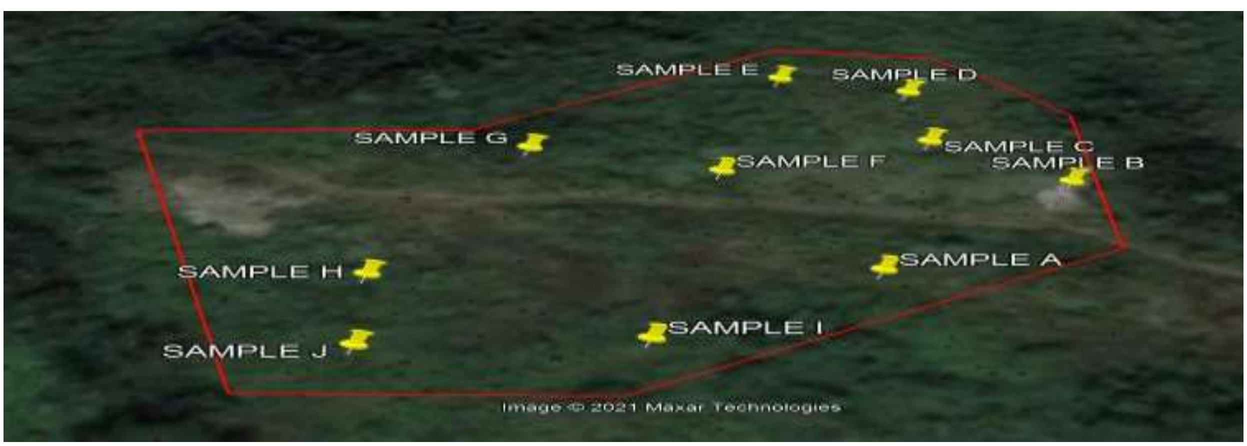

Figure 7: Location of Sample/Borrow Pit

Testing Procedures and Calculations:

i. Natural Moisture Content (WC%): Calculated via oven drying (105°C for 24 hours), using equation (1).

$$W_C\,\% = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad (1)$$

Where W1 is container weight, W2 is wet soil + container, and W3 is dry soil + container

ii. Specific Gravity (G): Measured using a 50mL pycnometer (ASTM D854), using equation (2).

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)} \quad (2)$$

Where M1 is empty bottle, M2 is bottle + dry soil, M3 is bottle + soil + water, and M4 is bottle + water

iii. 3Sieve & Hydrometer Analysis (ASTM D7928 / BS 882): Sieve retention percentages calculated; hydrometer particle diameter (D) computed using equation (3).

$$D = k\sqrt{\frac{L}{t}} \quad (3)$$

Where t is sedimentation time (minutes), L is effective hydrometer depth (cm), and K is a dimensionless constant dependent on soil particle specific gravity (G) and testing temperature.

iv. Atterberg Limits: Plastic Limit (PL), Liquid Limit (LL), and Plasticity Index (PI), using equation 4.

$$PI = LL - PL \quad (4)$$

Where LL is liquid limit, PL is moisture content at which soil transitions from plastic to liquid state measured at 25 drops using Casagrande apparatus, and

v. Compaction (ASTM D698 Standard Proctor): 3 kg soil compacted in 3 layers with 25 blows per layer using a 2.5 kg rammer to determine MDD and OMC.

vi. Falling Head Permeability: Conducted on compacted samples, equation 6.

$$k = 2.303 \times \frac{a \times L}{A \times t} \times \log_{10}\frac{h1}{h2} \quad (6)$$

Where a is standpipe area, A is sample cross-sectional area, L is sample height, h1, h2 is initial and final head over time t.

III. RESULTS AND DISCUSSIONS

A. Geophysical Results and Interpretations

1. 2D Dipole-Dipole Resistivity Pseudosections

The result of profiles delineate topsoil, clay/lateritic clay, weathered basement, and fresh bedrock are presented in Figure 8 -12.

Traverse 1 (Fig. 8): Low surface resistivity (32–97 Ωm) indicates shallow clay down to 5 m depth.

Weathered rock (93–1043 Ωm) dominates intermediate zones, with fresh basement (272–1233 Ωm) emerging below 20 m.

Traverse 2 (Fig. 9): Resistivity ranges from 27–283 Ωm at shallow depths (lateritic clay). At >20 m, resistivity rises to 289–630 Ωm (weathered basement).

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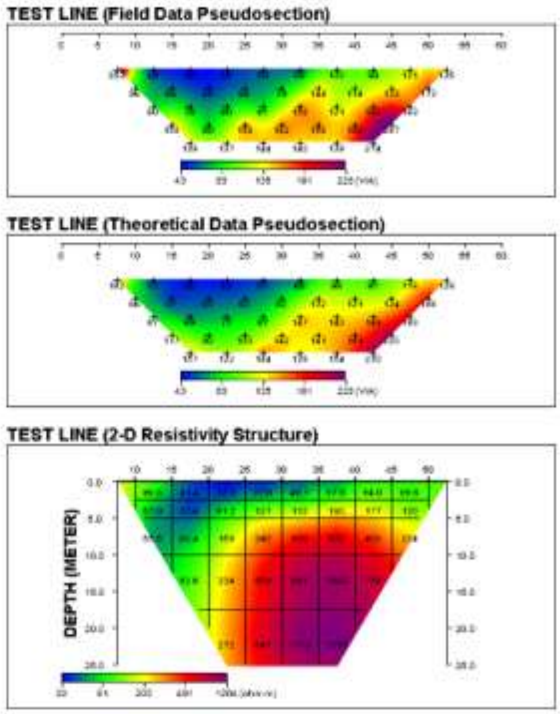

Figure 8: Pseudo-Section along Traverse 1

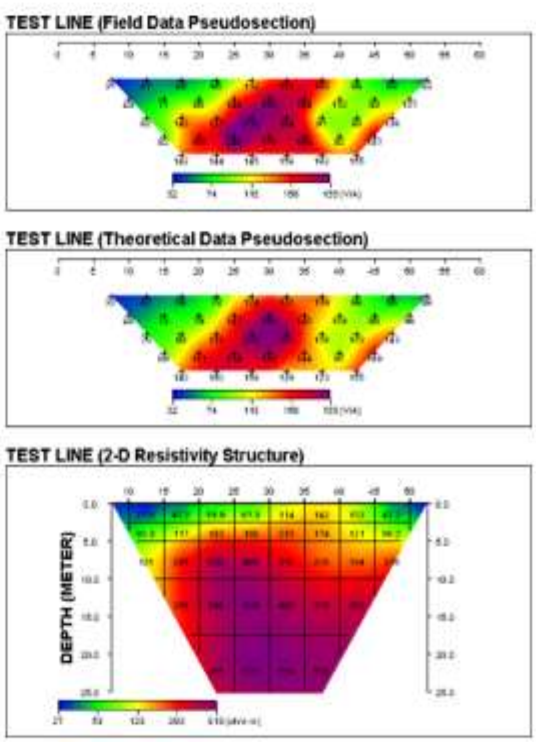

Figure 9: Pseudo-Section along Traverse 2

Traverse 3 (Fig. 8): Surface layer displays 24–276 Ωm. Below 10 m, high values (270–3679 Ωm) reflect resistive crystalline bedrock.

Traverse 4 (Fig. 9): 70 m profile; low topsoil resistivity (32–66 Ωm) underlain by lateritic clay (61–193 Ωm) and bedrock(102–2625 Ωm) below 10 m.

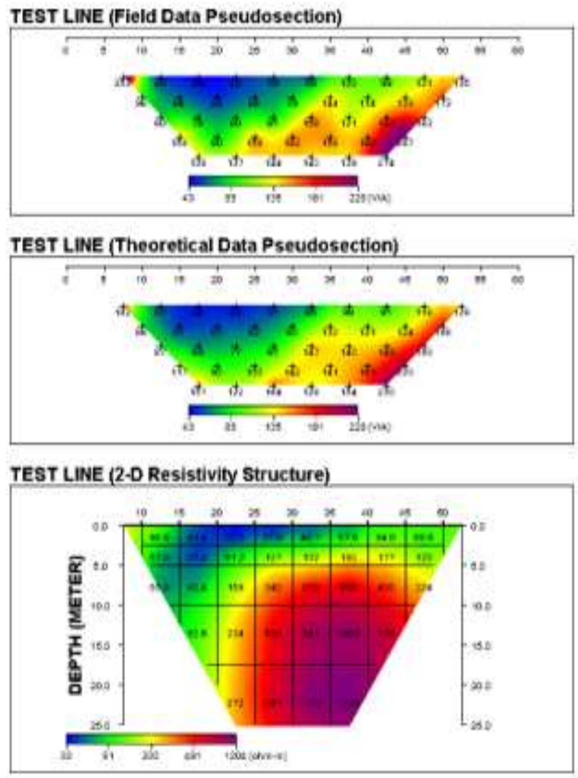

Figure 10: Pseudo-Section along Traverse 3

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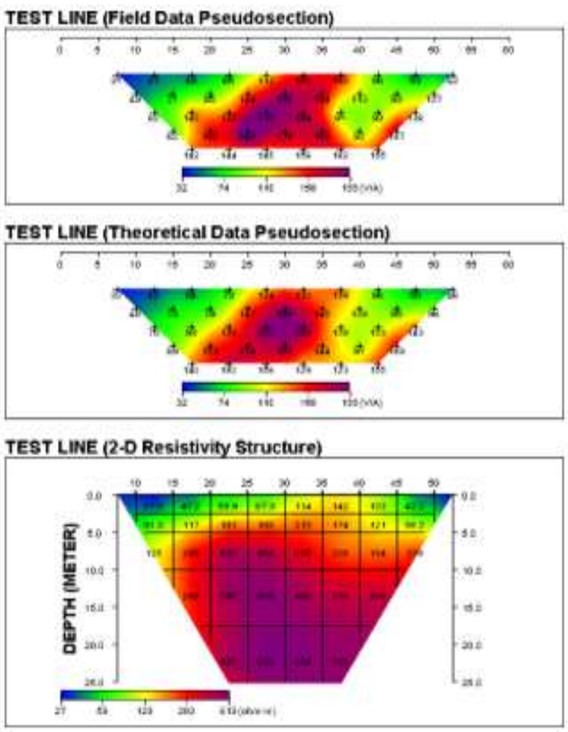

Figure 11: Pseudo-Section along Traverse 4

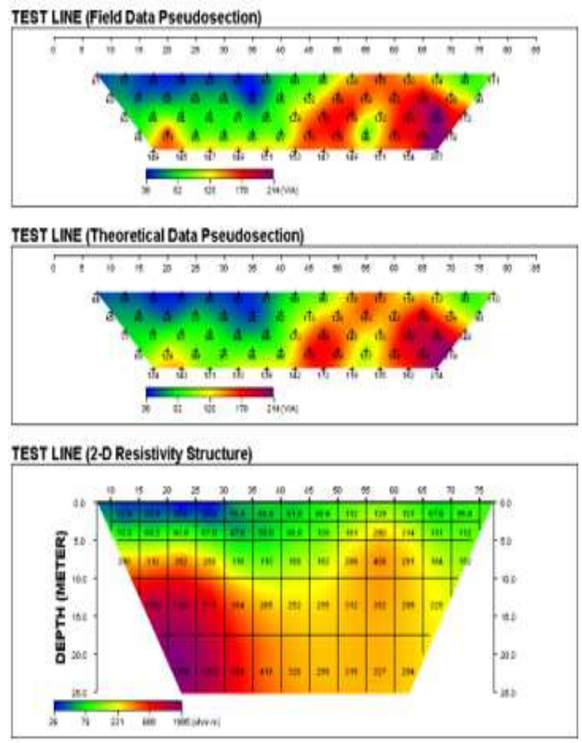

Figure 12: Pseudo-Section along Traverse 5

Traverse 5 (Fig. 12): Clay zone (48–129 Ωm) observed down to 5 m. Resistivity increases gradually deeper down (110–1986 Ωm).

2. The result of dipole-dipole Interpretation Results is presented in Table 1.

Table 1: Summary of dipole-dipole Interpretation Results

Traverse	Layer	Apparent Resistivity (Ωm)	Inferred Lithology
TR1	1–5	32 – 1233	Topsoil → Clay/laterite →Clay/Weathered basement → Weathered/Fresh Basement
TR2	1–5	28 – 630	Topsoil → Clay/laterite → Weathered Basement
TR3	1–5	24 – 3679	Topsoil → Clay/Laterite → Weathered/Fresh Basement
TR4	1–5	32 – 2625	Topsoil → Clay/laterite → Fresh Basement
TR5	1–5	26 – 1986	Topsoil → Clay/Laterite → Weathered/Fresh Basement

Vertical Electrical Sounding (VES)
The summary result of VES Interpretation Results is presented in Table 2.

Curves were classified into H-type ($\rho1 > \rho2 < \rho3$) and A-type ($\rho1 < \rho2 < \rho3$).

Table 2: Summary of VES Interpretation Results

VES No.	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve Type	Lithology
1	3	151.6 / 45.7 / 4072.6	1.0 / 2.7 / -	1.0 / 3.7 / ∞	H	Topsoil / Clay / Fresh Basement
2	3	46.1 / 48.9 / 4278.6	1.3 / 3.4 / -	1.3 / 4.7 / ∞	A	Topsoil / Clay / Fresh Basement
3	3	99.3 / 124.7 / 1955.0	1.4 / 5.4 / -	1.4 / 6.8 / ∞	A	Topsoil / Sandy Clay / Fresh Basement
4	3	80.3 / 92.0 / 5715.0	1.1 / 3.7 / -	1.1 / 4.8 / ∞	A	Topsoil / Clay / Fresh Basement
5	3	66.4 / 30.0 / 2688.0	0.9 / 2.1 / -	0.9 / 3.0 / ∞	H	Topsoil / Clay / Fresh Basement

B. Geotechnical Results & Interpretations

1. Classification of Soil Sample

Soil samples were classified using the American Association of State Highway and Transportation Officials (AASHTO) classification system and Unified Soil Classification System (USCS). The soil samples were classified to be A-4 and Silty Clay using AASHTO and USCS methods respectively. The combined result for test on soil sampled in Table 9 and Classification of soil samples is presented in Table 10.

Table 9: Combined result for test on soil sample

Sample ID	Depth (m)	Specific gravity	Natural moisture content (%)	Particle Size Distribution			Consistency Limits			Compaction	
				Passing No 200 (%)	Silt content (%)	Clay content (%)	LL (%)	PL (%)	PI (%)	MDD (g/cm-3)	OMC (%)
Sample F	0.5	2.32	21.30%	49.8	42.4	7.4	41.3	27.6	13.7	1.73	15.7
	1	2.11	20.40%	54.7	45.7	9	43.7	28.8	14.9	1.64	19
Sample G	0.5	2.3	23.40%	68.2	66	2.2	35.4	24.5	10.9	1.68	15.5
	1	2.4	16.20%	52.3	46.3	6	33.2	17.9	15.3	1.83	13
Sample H	0.5	2.67	17.10%	54.6	52.9	1.7	38	25.7	12.3	1.69	11.4
	1	2.65	16.90%	54.6	50.1	4.5	34	22.9	11.1	1.63	17
Sample I	0.5	2.52	21.80%	58.1	49.1	9	41.2	28	13.2	1.78	12
	1	2.44	19.60%	63	46.3	16.7	38	26.1	11.9	1.7	15
Sample J	0.5	2.55	14.20%	60.5	52.6	7.9	33.7	21	12.7	1.67	11.3
	1	2.67	18.20%	48	41.68	6.32	38.8	25.7	13.1	1.73	13.4

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Table 10: Classification of soil samples

Sample Location	Sample Depth (m)	MDD (g/cm^{-3})	Subgrade Rating	Group Index		AASHTO CLASS	USCS CLASS	
				Value	Rating			
Sample F	0.5	1.73	Fair	4	Fair	A-4	Silty sand (ML)	
	1	1.64	Fair	4	Fair	A-4	Silt Sand (ML)	
Sample G	0.5	1.68	Fair	4	Fair	A-4	Silty (SM)	sand
	1	1.83	Fair	4	Fair	A-4	Silty (SM)	sand
Sample H	0.5	1.69	Fair	4	Fair	A-4	Silty (SM)	sand
	1	1.63	Fair	4	Fair	A-4	Sandy (ML)	silt
Sample I	0.5	1.78	Fair	4	Fair	A-4	Silty (SM)	sand
	1	1.7	Fair	4	Fair	A-4	Silty (SM)	sand
Sample J	0.5	1.67	Fair	4	Fair	A-4	Silty (SM)	sand
	1	1.73	Fair	4	Fair	A-4	Silty (SM)	sand

2. Site Suitability Analysis

Geological Suitability: Crystalline bedrock provides structural support.

Geophysical Suitability: Bedrock depths of 3.0 – 6.8 m protect underlying aquifers when paired with engineered liners.

Geotechnical Suitability: High fines content and fair subgrade rating (A-4 / SM) support structural foundation
needs.

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

Geological, geophysical, and geotechnical investigations confirm the proposed 4,795 m² site is suitable for an engineered sanitary landfill. Bedrock occurs at depths of 3.0 – 6.8 m, providing a stable foundation. Natural soils classify as A-4 (AASHTO) and Silty Sand/Silt (USCS) with high fine-grained fractions. Field compaction is required to lower permeability to regulatory containment standards (10^{-9} m/s).

B. Recommendations

This research recommends to perform soil chemical testing to evaluate ion exchange capabilities; conduct detailed structural mapping to identify potential joint/fault networks; execute Environmental and Socio-Economic Impact

Assessments (ESIAs); install monitoring wells to track local groundwater depths and baseline quality.and construct heavy-duty access roads for waste transport vehicles.

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