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Effect of leachate on the geotechnical properties of soils at Gbagede Dumpsite Ilorin, Kwara State Nigeria

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ABSTRACT

The increasing request for space for private buildings was brought about by the utilization of the previous dumpsites. If the issue of leachate infiltration into the soil isn't legitimately controlled it'll lead to future harm in construction works. The objectives are to compare the geotechnical properties of soil of the contaminated and uncontaminated regions region of the dump site and evaluate if the effect of leachate on the geotechnical properties of soil changes with depth. Laboratory soil tests were conducted on the soil samples obtained and compared the effect of these leachates at the dump site. These methods are Natural water content, Bulk Density, Specific Gravity, Shear strength, and Consolidation tests. The soil samples were obtained from the contaminated region, and the uncontaminated region (i.e. at 100 m away from the dumpsite). All soil samples were obtained at depths 0.5m, 1.0m, and 1.5m below the ground level, to know the effect of leachate on the soil at the dumpsite and also to know if the effects of leachate changes with depth as it goes down the soil. The results obtained show that samples at 0.5m and 1m depth have been affected by leachates but the effects are not so significant at 1.5m depth, thereby making the soil at depths 0.5m and 1m unfit for construction purposes. This result was useful to check the land requirement in urban areas and guide the geotechnical engineers when designing and constructing foundations for buildings and other related structures on these types of soils.

Introduction

Solid waste can be defined as useless, unwanted, or discarded material with insufficient liquid content to be free-flowing (Abu Rukah and Al-Kofahi 2001). Panahpour et al. (2011), defined solid waste as the residual from homes, business centers, and institutions and referred to it as trash, garbage, rubbish, refuse, discards, and throw-away that enter a local system for collection and disposal. This may be in the form of wrappers, papers, tins, cans, plastic containers, junks such as old refrigerators, stores, lanterns, tables, beds, etc. (Glatstein 2010). Generally, solid waste results from a wide range of sources such as community, industrial, commercial, institutional, constructional demolition, and agricultural activities (Celalettin and Orhan 2005).

Civic wastes are commonly known as trash or garbage and as refuse or rubbish consisting of everyday items that are discarded by inhabitants of the community (Morakinyo 2021). As a result of the precipitation process leachate resulting from civic waste is the most hazardous pollutant for the soil underlying and subsequently groundwater (Goswami. and Sarma 2007). According to Chidiebere et al. (2018), municipal solid wastes are solid wastes from single-family and multifamily residences and hotels which consist of residential wastes (garbage, yard wastes, ashes from heating units, and bulky wastes), commercial and institutional wastes (construction and demolition wastes), street refuse, dead animals, abandoned vehicles and so on. Industrial solid waste is solid waste that generally arises from two sources: process wastes remaining after manufacturing a product; and commercial institutional wastes from office activities, cafeterias, laboratories, and the like. Sewage sludge is the sludge left over after treating water or wastewater that must be handled properly to ensure public safety and minimize environmental damage (Nanda 2011; Soliman, and Moustafa 2020). Agricultural wastes include both crop residues that cannot be returned to the soil and manure from animal feeding facilities (Manna et al. 2018). Mining waste is the mining industry produces such large amounts of solid waste that special emphasis should be given to this material (Jeyapriya and Saseetharan 2007).

According to Modak P. (2011), factors considered in evaluating potential sites of solid waste disposal are: (1) Distance from waste generation source and waste type; (2) Depth to groundwater and groundwater quality from observation wells; (3) Distance from residential, religious, and archaeological sites; (4) Site access and capacity; (5) Soil characteristics, clay content, topography, and land slope; (6) Local environmental and climatic conditions; (7) Existing land use pattern and land cost; (8) Distance from airports; (9) Ease of access in any kind of weather to all vehicles expected to use it; (10) Seismic activity.

The study area is located at Amoyo Ilorin Kwara State Nigeria located on latitude 8°24'N and 8°36'N and longitude 4°10'E and 4°36'E with an area of about 100Km². It is situated at a strategic point between the densely populated south-western and the sparsely populated middle belt of Nigeria. Ilorin is located in the trasitional zone between the deciduous woodland of the south and the dry savanna of the North of Nigeria (Njoku and Tenenbaum 2022). The political economy of Kwara State can be traced to 1967 when it was created. Since then Ilorin has undergone various developmental efforts, mostly initiated by the federal government given the nature of the Nigerian state, a centralized federal system where all development policies and programs originate from the center (Adedeji 2023). Despite its strategic location as the gateway between the southern and northern parts of the country, there are few industries in Kwara State (Odewumi 2002). Figure 1 shows the location of Ilorin on the map of Kwara State and Nigeria. The climate of Ilorin is characterized by both wet and dry seasons (Olubanjo 2019). The temperature of Ilorin ranges from 33°C to 34°C from November to January while from February to April; the value ranges between 34°C to 53°C (Njoku and Tenenbaum 2022). The mean monthly temperatures are very high varying from 25°C to 28.9°C (O. A, A. G, and S. C 2021).

Figure 1. Map of Nigeria showing Kwara State and Ilorin

This research aims to investigate the effect of leachate on the geotechnical properties of the soil. The objectives are as follows: (i) To compare the geotechnical properties of soil of the contaminated and uncontaminated regions region of the dump site; (ii) To evaluate if the effect of leachate on the geotechnical properties of soil changes with depth.

The increasing demand for space for residential buildings to meet up with the country's rapidly increasing population has resulted in the utilization of the former dumpsites within the cities for building purposes (Hinnells, M. 2008). Hence there is a need for this research because if the problem of leachate infiltration into the soil is not properly controlled it will lead to future damage in construction works. In this research, we don't take care of the chemical and biological test of leachate to geotechnical properties of soil at the dump site, and we don't consider the effect of leachate on groundwater quality.

The significance of this study is to investigate the effects of leachate on the geotechnical properties of soil. Carrying out various laboratory tests can help to carry out land development activities to meet the land requirements in urban areas and improve the quality of the suburban environment in the vicinity of the dump yard sites. Also, helps in guiding geotechnical engineers when designing and constructing foundations for buildings and other related structures.

Methods

The soil samples were obtained from the contaminated, and uncontaminated region (i.e. at 100m away from the dumpsite). All soil samples were obtained at depths 0.5m, 1.0m, and 1.5m below the ground level.

Experiments conducted

The procedure of the Natural water content test

- Containers P9 and P14 were weighed;
- Saturated sand was put into the containers of P9 and P14;
- P9 and P14 with saturated sand were weighed;
- Containers P9 and P14 was sun-dried for 48hours;
- After 48 hours, containers P9 and P14 with the dry sand were weighed.

The formula for computing the natural water content test was shown in Equation (1)

Weight of can = m1

Weight of can + wet sample= m2

Weight of can + dry soil sample = m3

$$\text{Water content, m} = \frac{m2-m3}{m3-m1} \quad (1)$$

The result for natural water content is shown in table 1.

The procedure of bulk density test

- We weighed the mold and measured its inner diameter and height;

- We filled the mold with the soil sample in three different layers using twenty blows for each layer;
- We weighed the mold filled with the sample;
- The soil sample was then released into a pan weighed, and dried in the sun for 48 hours;
- After 48 hours the pan and sample were weighed and recorded.

Diameter of mould = 8.0cm
Radius of mould = 4.0cm
Height of mould = 5.0cm
Volume of mould = $\prod r^2 h = \prod * (4)^2 * 5 = 80\prod = 251.4cm^3$
Weight of mould = 204g
The formula for bulk density

$$\text{Bulk density} = \frac{\text{Total weight of wet soil}}{\text{volume of mould}} \quad (2)$$

The results for Bulk density are shown in table 2.

The procedure of the Specific Gravity

We weighed 300g of saturated surface dry sand using a sensitive balance

- Then the sample into a 1000ml measuring cylinder and filled with water.
- We eliminated the air bubbles entrapped in the solution.
- We dried it outside of the measuring cylinder and weighed it [Wsand + Wcylinder + Wwater]
- We dried and weighed the outside of the measuring cylinder [Wwater + Wcylinder]

The specific gravity formula is shown in equation 3.

Weight of empty cylinder, $W_1 = w_1$
Weight of empty cylinder + soil sample, $W_2 = w_2$
Weight of empty cylinder + soil sample + water to brim, $W_3 = w_3$
Weight of empty cylinder + water to brim, $W_4 = w_4$

$$\text{Specific gravity} = \frac{w2 - w1}{(w4 - w1) - (w3 - w2)} \quad (3)$$

Typical values of Specific Gravity of Soil Samples between 2.65 – 2.68 is sand, 2.65 – 2.68 is Gravel, between 2.52 – 2.66 is Clay (organic), from 2.68 – 2.68 is Silt (Jeyapriya and M. K. 2007).

Particle size distribution test

- We measured 1kg of the sample using a quartering process;
- We selected the required sieves and dusted them thoroughly;
- We arranged the sieves in descending order by inserting the bottom of one on the top of another;
- We placed the weighed soil into the top of the arranged sieves;
- We shook the sieves thoroughly for about 5 minutes;
- We weighed each sieve and the residue left on each.

$$\text{Coefficient of uniformity (Cu)} = \frac{D60}{D10} \quad (4)$$

$$\text{Coefficient of curvature (Cc)} = \frac{(D30)^2}{D60 \times D10} \quad (5)$$

The result of the particle size distribution test carried out on the soils was presented in figure 2 for the contaminated area at 0.5 m.

Shear strength test

- We screwed the top half and bottom half of the box and placed the first porous stone and toothed perforated brass grid in the box.
- We filled the box with soil and compacted it to the desired density.
- We released the lever arm and loaded the required weight.
- We adjusted the wheel under the shear box machine to balance the loaded weight, the spirit level was observed to be at the center showing that the load was balanced.
- The machine was then switched from neutral mode so that it could be powered by electricity.
- The displacement gauge and the load gauge were set to zero and the machine was turned-on.
- Readings were taken on the load gauge at every revolution on the displacement gauge until the load gauge stopped moving. This process was repeated for different values of mass (i.e. 5Kg, 10Kg, and 15Kg). The shear and normal stress can be computed as given in equations 6 and 7 respectively. Ratio of machine = 10, Effective lever arm weight = 9Kg, Machine constant = 1.733, and Area of box = $36cm^2 = 0.0036m^2$

$$\text{Shear stress } (\tau) = \frac{\text{maximum value on load gauge} \times \text{machine constant}}{Area\ of\ box} \quad (6)$$

$$\tau = c + \sigma \tan \varnothing$$

$$\text{Normal stress } (\sigma) = \frac{weight \times ratio\ of\ machine + weight\ of\ lever\ arm * gravity}{Area\ of\ box} \quad (7)$$

Figure 3 shows the normal stress against the shear stress at the depth of 0.5m for an uncontaminated area.

Consolidation test

- We Weighed 300g of the soil sample and used the value of the moisture content to add water to the soil sample e.g 18% moisture content means 18% of 300g = 54, therefore, 54g of water was added to the sample;
- We stirred the sample properly with the aid of a spatula;
- Then We put some of the samples into the consolidation cell, and fill to the brim manually;
- Then We put the consolidation cell back into the consolidation machine ensured all bolts were properly tightened, and set the load gauge to zero;
- We applied a load of 5kg first and took readings at various time intervals such as 10s,20s 30s, 1min,2min,4min,8min,16min,30min, 1hr, 2hr, 4hr, 6hr, 8hr, and 24hr;
- Then after 24hrs of reading for a 5kg load, continue readings from the initial value at 24hrs for 5kg by increasing the weight to 10kg and take readings for the above time intervals. Repeat the same for 15kg;
- We computed the values at 24 hours for each load, tabulated the values, and plotted the graphs.

Table 4 shows the result of the consolidation test carried out on the soils. for contaminated area at 0.5m depth.

Results and discussion

Table 1. Natural water content test

Contaminated area		
Area	Depth (m)	Result (%)
Contaminated region	0.5	18.0
Contaminated region	1	19.0
Contaminated region	1.5	19.5
Uncontaminated area		
Area	Depth (m)	Result (%)
Uncontaminated region	0.5	17.1
Uncontaminated region	1	18.2
Uncontaminated region	1.5	19.1

The contaminated regions at 0.5m, 1m, and 1.5m have a moisture content of 18%, 19% and 19.5% respectively. The uncontaminated regions at 0.5m, 1m, and 1.5m have a moisture content of 17.1%, 18.2% and 19.1% respectively. Therefore, the natural moisture content increases with depth for each region due to the volume of leachate present respectively.

Table 2. Bulk density test

Contaminated area		
Area	Depth (m)	Result (%)
Contaminated region	0.5	1.40
Contaminated region	1	1.59
Contaminated region	1.5	1.68
Uncontaminated area		
Area	Depth (m)	Result (%)
Uncontaminated region	0.5	1.62
Uncontaminated region	1	1.68
Uncontaminated region	1.5	1.72

For the contaminated region at 0.5m, 1m, and 1.5m they have bulk density 1.40 g/cm^3,1.59 g/cm^3 and 1.68 g/cm^3 respectively. The uncontaminated regions at 0.5m, 1m, and 1.5m have bulk density 1.62 g/cm^3 1.68 g/cm^3, and 1.72 g/cm^3 respectively. This indicated that the bulk density increases with depth for each region.

Table 3. Specific gravity test

Contaminated area		
Area	Depth (m)	Result (%)
Contaminated region	0.5	2.39
Contaminated region	1	2.43
Contaminated region	1.5	2.51
Uncontaminated area		
Area	Depth (m)	Result (%)
Uncontaminated region	0.5	2.55
Uncontaminated region	1	2.57
Uncontaminated region	1.5	2.60

The result of specific gravity analysis for the contaminated region at 0.5m, 1m, and 1.5m had a specific gravity of 2.39, 2.43, and 2.51 respectively. For the uncontaminated region at 0.5m, 1m, and 1.5m they have specific gravity 2.55, 2.57, and 2.60 respectively.

Particle size distribution test

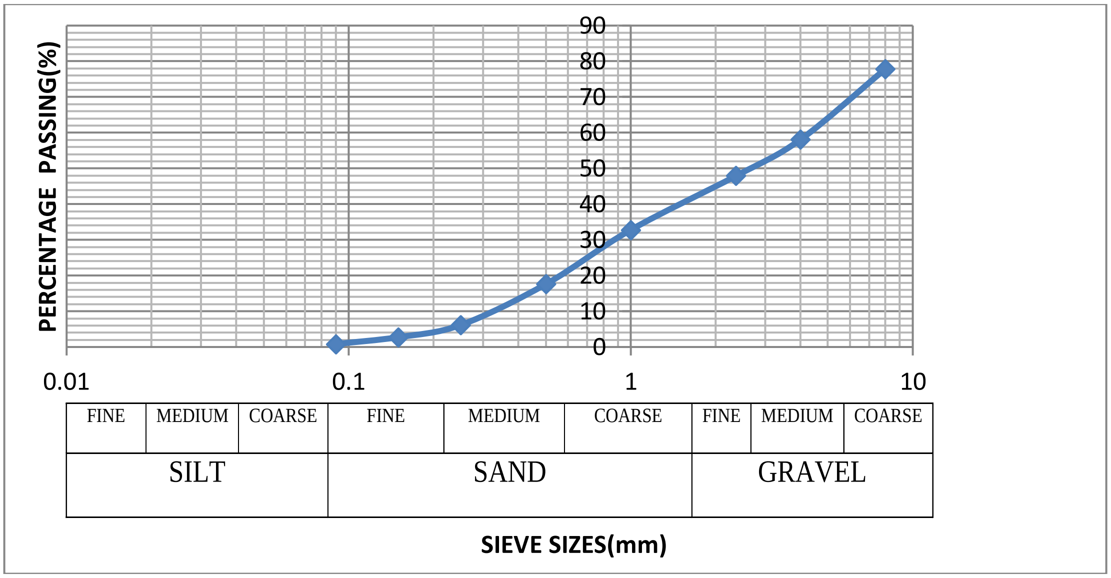

Figure 2. Sieve analysis chart for depth 0.5m of contaminated area

D60 = 4.10, D30 = 0.98, and D10 = 0.30. Therefore, we calculated the Cu = 13.7, Cc = 0.8, Fine gravel% = 55, and Sand% = 45. The results for the particle size distribution test of the soil sample indicated that the soil samples are composed mainly of sand and gravel with gravel having much of the percentage. For the contaminated region at 0.5m, 1m, and 1.5m the co-efficient of uniformity (CU) are 13.7, 9.8, and 11.6, and the Co-efficient of curvature is 0.8, 0.8 and 1.2 % of gravel are 55%, 59%, and 63% while the percentage sand is 45%, 41% and 37% respectively. For the uncontaminated region at 0.5m, 1m, and 1.5m the co-efficient of uniformity (CU) is 11.1, 10.9, and 12.9, and the Co-efficient of curvature is 0.9, 1.0 and 1.2 % gravel are 61%, 60%, and 66% while the percentage of sand are 39%, 40%, and 34% respectively. This indicated that the soil is generally a very sandy GRAVEL soil. Contaminated areas 0.5m and 1m are poorly graded gravel while contaminated 1.5m is well graded gravel. Uncontaminated areas 1m, and 1.5m are well graded while uncontaminated 0.5m is poorly graded.

Shear strength test result

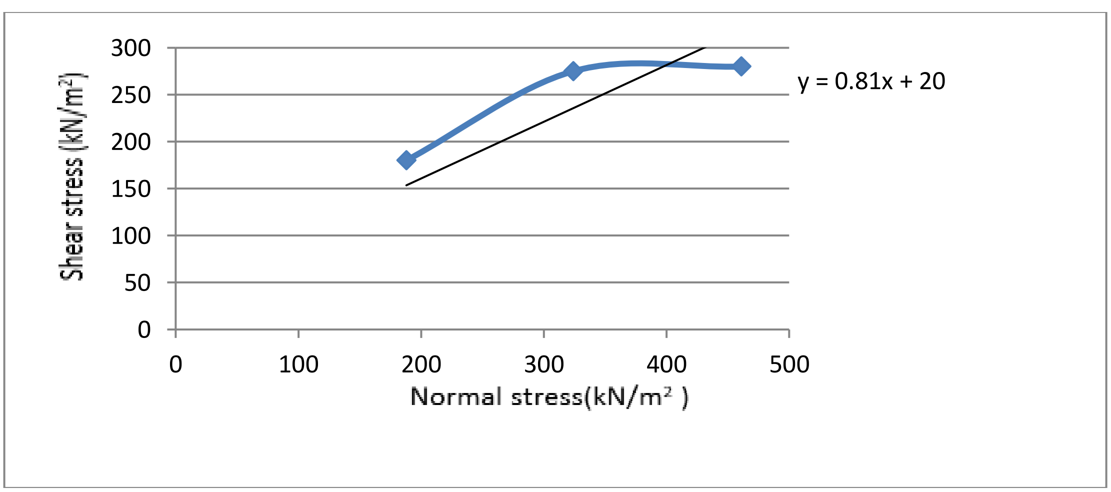

Figure 3. Normal stress against shear stress at depth 0.5m of uncontaminated

For the contaminated region at 0.5m, 1m, and 1.5m the result for the angle of internal friction is 24, 23, 39 while the cohesion(C) are 30,13,20 respectively. For the uncontaminated region at 0.5m, 1m, and 1.5m the result for the angle of internal friction is 39, 33, and 35 while the cohesion(C) is 20, 40, and 40 respectively. Therefore, comparing this value with the table below and according to the Unified soil classification the results obtained from the shear box test are used to classify soils according to their angle of internal friction. A soil having an angle of internal friction less than is classified as soft, between 20- are classified as hard, and above or greater than are classified as stiffs. Based on my practicals the uncontaminated region 0.5m, is classified as stiff soil while that of 1m and 1.5m are classified as hard soil. The contaminated regions 0.5m and 1m are classified as soft soil and that of 1.5m is classified as stiff soil.

Consolidation test

Table 4. Specific gravity test

5kg load		**10kg load**		**15kg load**	
Time intervals	Penetration reading (mm)	Time intervals	Penetration reading (mm)	Time intervals	Penetration reading (mm)
10s	70	10s	100	10s	110
20s	72	20s	100	20s	110.5
30s	73	30s	100.5	30s	110.5
1min	74.5	1min	101	1min	110.5
2min	85.5	2min	102	2min	110.5
4min	86	4min	102.5	4min	110.5
8min	86.5	8min	103	8min	110.9
16min	87	16min	104	16min	111
30min	87.5	30min	104.8	30min	111.3
1hr	87.8	1hr	105	1hr	112
2hr	87.9	2hr	105.5	2hr	112
4hr	88	4hr	106	4hr	112.8
6hr	-	6hr	106.5	6hr	113.2
8hr	-	8hr	107	8hr	114.5
24hr	88	24hr	109.5	24hr	116.5

For the contaminated region at 0.5m, 1m and 1.5m the values for co-efficient of compressibility are 9×10^{-3}, 4×10^{-3}, 5×10^{-3}. The values for the co-efficient of volume compressibility are 5.96×10^{-3}, 3.7×10^{-3}, 4.63×10^{-3}. The values for the co-efficient of settlement are 5.96, 3.7, and 4.63. For the uncontaminated region at 0.5m, 1m and 1.5m the values for co-efficient of compressibility are 3×10^{-3}, 3×10^{-3}, 4×10^{-3}. The values for the co-efficient of volume compressibility are 2.78×10^{-3}, 2.78×10^{-3}, 3.7×10^{-3}. The values for the co-efficient of settlement are 2.8, 2.79, and 3.7.

The result of the bearing capacity and average shear strength shows that the bearing capacity for the contaminated region for depths 0.5m, and 1m are very low except that of depth 1.5m and this shows that a larger footing will be required for both depth 0.5m and 1m and it also shows that the of effect leachate doesn't have a significant effect on depth 1.5m. Compared to the uncontaminated region where the bearing capacity is high. Therefore, this shows the rate at which the leachate substance affects the bearing capacity of the soil for the design of a strip footing. For the average shear strength which indicates the strength of the soil, the uncontaminated region is also higher than that of the contaminated region except for depth 1.5m, which also shows a lesser effect of the leachate substance in that region (contaminated 1.5m).

Conclusions

1. The result also shows that the bearing capacity based on the assumed strip footing for the contaminated region is low and will require a larger footing size during the strip footing foundation. Only the bearing capacity for 1.5m depth is high which shows that the quality of the soil at depths 1m and 0.5m has been reduced by the effect of the leachate substances; 2. The effect of leachate on the geotechnical properties of the soil changes with depth. Based on the laboratory test it is recommended that if any construction

work is to be done on depths 0.5m and 1m certain engineering corrections (repairs) are to be made to the soil like Soil Stabilization. We recommended that the entire dump yard should be excavated to a depth of 1.5m (i.e. areas with low bearing capacity should be excavated to a point with those of high bearing capacity) before any foundation work can take place.

This result will be useful for carrying out land development activities to meet the land requirement in urban areas and improving the quality of the suburban environment in the vicinity of the dump yard sites, it will also help in guiding geotechnical engineers when designing and constructing foundations for buildings and other related structures on these types of soils.

We recommended that: (1) Further research should take care of chemical tests and biological tests of leachate to have an idea of the mechanism through which the leachate affects the soil and the reactions that take place; (2) Appropriate design of sanitary landfill should be done to prevent the contamination of the groundwater and underlying soil; (3) Further research should be done to know the effect on groundwater e.g. nearby boreholes to determine the direction of the flow of the leachate substance in the dumpsite.

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Author(s) contribution

Usman Musa Ibrahim contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

Mujittafa Sariyyu contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

Ali Rabi'u Anwar contribute to methodology, supervision, and validation.

Hassan Opeoluwa Ayoku contribute to methodology, supervision, and validation.

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