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Effects of leachate on geotechnical properties of lateritic soil

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Abstract

The presence of leachate poses a threat to the environment. Soil, water and sometimes air quality are significantly contaminated. This study investigated the effects of leachate contamination on the index properties, compaction and strength characteristics of lateritic soil obtained from Nawfia, Anambra state. Leachate characterization was conducted in the laboratory and its quality documented. Specific gravity, sieve analysis, consistency limits, compaction using British Standard light method (BSL) and unconfined compressive strength (UCS) tests were conducted on the soil samples. From the results, UCS values decreased with increase in leachate content from 229.403 kN/m^3 at 0% leachate to 169.941 kN/m^3 at 20% leachate. A steady decrease was also observed for the cohesive strength of the samples upon contamination with leachate from 114.701 kN/m^3 to 84.97 kN/m^3. Liquid limit values decreased from 48.0% to 40.10% at increasing leachate contents from 0% to 20%. Plastic limit also decreased from control value of 32.05% to 21.70% at 20% leachate contamination. BSL compaction tests revealed that increase in leachate content resulted in decrease of maximum dry unit weight (MDUW) and optimum moisture content (OMC) values. These results indicate that the presence of leachate fluid in the soil negatively impacts the strength and geotechnical properties of sandy-clay soil.

Keywords: *British standard light (BSL), Lateritic soil, Leachate, maximum dry unit weight (MDUW), unconfined compressive strength (UCS)*

1. Introduction

The menace of poor waste handling has adversely affected environmental components; including but not limited to soil, water and air quality. Also, the magnitude of commercialization, industrialization and population expansion of most cities all over the world has also had its attendant adverse effects on the environment (Abur, Oguche & Divuna, 2014; Tariwari, Angaye, Jasper & Abowei, 2017). Dumping of wastes indiscriminately and siting of open dumpsites are some of the major factors affecting the various soil geotechnical properties (Oyediran & Iroegbuchu, 2013). According to Nwankwo (1994); Oyediran and Iroegbuchu (2013), increasing populations, rising incomes, and change in consumption patterns combine to complicate waste management problems in Nigeria. Failure to properly dispose these wastes in properly constructed sanitary landfills presents a threat to groundwater and surface water through contamination by leaching of pollutants generated. During rainy season, the water percolates into the municipal solid waste, which undergoes the decomposition process. During this process contaminant liquid called "leachate" seeps into the soil (Mor, Ravindra, Dahiya & Chandra, 2006). Okeke, Okagu, Okonkwo and Ezeagu (2019) in their study reported that deteriorating soil quality and reduced vegetation are serious consequences of open waste dumping which has led to increased public concern and investigations on the effects on the geotechnical properties of soils.

Harun, Ali-Rahman, Rahum, Lihan and Idris (2013) conducted tests to investigate the effects of leachate on geotechnical properties of sandy clay soil at Selangor, Malaysia. Soil used in their study is a residual soil which originated from in-situ weathering of granitic rock. Results from their study suggested that leachate contamination is capable of modifying some geotechnical properties of the studied residual soil. The impact of leachate on soil properties in a dumpsite was investigated by Praveena and Prasado (2016). The soil samples were later analyzed for soil pH, electrical conductivity (EC), moisture, Nitrogen (N), phosphorous (P) and potassium (K). The results of the contaminated samples were compared with the control soil sample. The results revealed that all the parameters investigated were in high concentration as per the Indian Agricultural Standards which could deteriorate further because of dumping of municipal solid waste thereby increasing the toxic substances in the dump yard soils. Similar studies and findings have also been reported in Yeilagi, Rezapour and Asadzadeh (2021).

Nayak, Sunil and Shrihari (2007) reported changes in soil structure after contamination with leachate. They observed an increase in void ratio of soil when pore water was replaced by leachate. Increase in pore fluid and hydraulic conductivity observed was attributed to the dissolution of clay minerals by the leachate. George and Beena (2011) investigated the geotechnical characteristics of leachate contaminated lateritic soil and noted that the municipal solid waste leachate increases the permeability and shear strength of the laterite soil. However, the consistency limits of the soil decreased due to the leachate. Similar results have been reported by Sharma, Gupta and Ganguly (2015) and Serin (2019). Ouria (2019) in his study on the effect of waste leachate on the strength parameters of clay soil observed that the infiltration of leachate into the soil pores leads to decrease in shear strength and increase in settlement values of the soil. He concluded that leachates even in small concentrations have major long-term drawbacks on shear strength and compressibility of soil. Irfan, Chen, Ali, Abrar, Qadri and Bhutta (2018) researched on effluent-contaminated cohesive soils and noted that the clay soil of high plasticity (CH soil) showed a decrease in unconfined compressive strength from 246kPa to 98.66kPa and 90.18kPa for basic and acidic effluents respectively.

In a study conducted on the effect of municipal solid waste (MSW) leachate on the strength of compacted tropical soil for use as landfill liner by Chinade, Yusuf and Osinubi (2017), they obtained leachate sample from a dump site in Bauchi, Nigeria. UCS tests were carried out on specimens and samples were permeated with MSW leachate for periods of 7, 21, 42, 84, and 120 days respectively. Results showed that the UCS of compacted specimens reduced with increase in permeating periods for the different compactive efforts employed (British Standard Heavy, West African Standard and British Standard Light). This observed reduction was attributed to the increase in clay size particles which reduced the frictional resistance between the solid particles at their contact point. The research reported in this paper focused on studying leachate contaminated lateritic soil in a bid to understand the effects of leachate on strength, compaction and index properties of the soil. The leachate was mixed at 0%, 5%, 10% 15% and 20% of dry weight of soil sample. Compaction tests, Atterberg limits, specific gravity and UCS tests were done on both the control soil sample and the contaminated soil sample. The chemical composition of the leachate was also evaluated and proper comparison of control and contaminated soil results are presented with clear and concise graphical illustrations.

2.0 Material and methods

2.1 Materials.

In the study, the leachate sample used was extracted from a refuse dump at Okpuno, Awka after which it was taken to Spring Board Laboratory in Awka for characterization. The soil sample was collected from Nawfia in Njikoka LGA, Anambra State at the coordinates: 6°10′N 7°01′E. The water used in the investigation was potable water, free of contaminants and impurities.

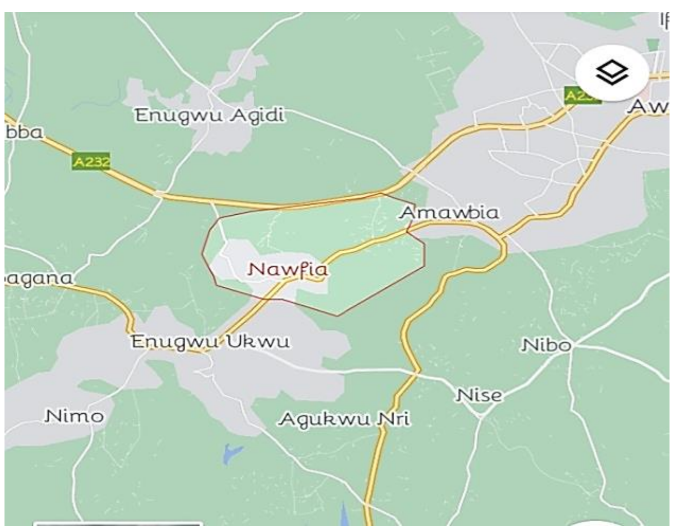

Figure 1: Map Showing Soil sample collection Location

2.2 Sample Preparation and Testing Methods

Leachate contamination was done at 0%, 5%, 10%, 15% and 20%, and was calculated by dry weight of lateritic soil sample. The soil samples were afterwards, preserved at room temperature for seven (7) days. Heavy metal analysis on the leachate sample was conducted using Varian AA240 Atomic Absorption spectrometer according to the method of APHA (1995). The pH was measured by Electrometric Method using Laboratory pH meter Hanna model HI991300 (APHA, 1998). The laboratory soil tests were conducted in accordance with British Standard 1377 i.e., classification tests: compaction tests (British Standard Light), unconfined compressive strength (UCS) test (BS, 1377; ASTM D, 2166)

3.0 Results and Discussions

3.1Leachate characterization

Table (1) shows the result from the laboratory characterization analysis of the leachate sample compared alongside FEPA and SON standards for water quality. The presence of ammonia, zinc, copper, nickel, manganese and chromium is evident from this analysis even though their concentrations vary.

Table 1: Leachate Characterization compared with FEPA and SON standards

Parameters	Leachate	FEPA Standards (1991)	SON (2007)
pH	7.7	6-9	6.5-8.5
TSS (mg/l)	1.10	N/A	-
COD (mg/l)	241.333	75	-
Colour	grey	N/A	None
NH_3 (mg/l)	0.149	0.01	-
Zinc (PPM)	0.013	5.0	3.0
Copper (PPM)	0.029	N/A	1.0
Nickel (PPM)	0.150	0.01	0.02
Manganese (PPM)	0.417	0.05	0.2
Chromium (PPM)	0.003	0.2	0.05

3.2 Specific Gravity and Sieve analysis

The specific gravity of the soil sample was found to be 2.62 documenting a non-organic soil. From the particle size distribution curve presented in Figure (2), the soil was observed to be pre-dominantly sand having clay, sand and gravel contents of 41.95%, 58.043% and 0.068% respectively.

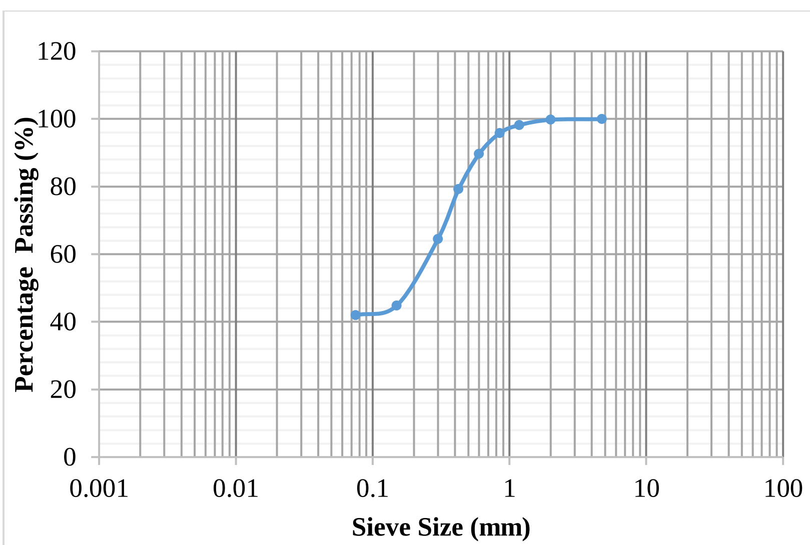

Figure 2: Sieve Analysis graph of Lateritic soil sample

3.3 Atterberg/Consistency Limits

The Atterberg limit is used to identify the soil water content that is related to the behaviour of the soil. The liquid limits of leachate-contaminated soil (see Figure 3) are observed to decrease in value from 48% to 40.1% with the increase of leachate contents between 0% and 20%. This result is in line with (Serin, 2019). Also, the plastic limit results were observed to increase up to 10% leachate contamination after which a decrease in value was observed for 15% and 20% respectively while for plasticity index, the values decreased from the control value of 15.95% to 3.49% at 10% leachate contamination after which an increase in values was observed.

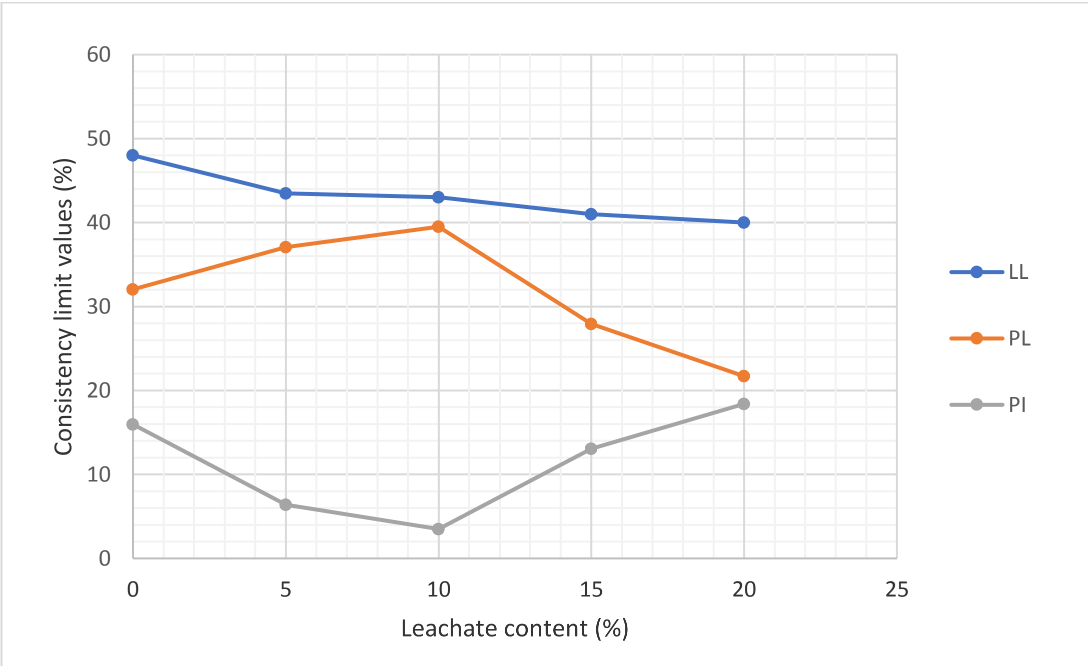

Figure 3: Summary of Consistency Limit Results

This behaviour, may be attributed to the nature of water at microstructure level of clay minerals and the constituents of the leachate. Changes in geotechnical behaviour of fine-grained soils under the influence of ionic concentrations and pH depends on the chemistry of the soil constituents and the pore fluid chemistry. Generally, clay particles surface is negatively charged while its edges are positively charged. To preserve electrical neutrality the negative charge of the clay particle is balanced by the attraction of cations which are held between the layers, and on the surface of the particles i.e., the charged clay surface together with the counter–ions in the pore water at the diffuse double layer (Sen, Dixit and Chitra, 2016). According to Gouy Chapman theory by increasing the ion concentration i.e., cations the thickness of diffuse double layer decreases which leads to flocculation of the clay particles eventually resulting in decrease in liquid limit values.

3.4 Compaction characteristics

The compaction results indicated that the maximum dry unit weight and optimum moisture content decreased with the increase of liquid leachate at all percentages of leachate contamination as portrayed in Figure (4). When moisture is added, the soil becomes easily kneaded, can bear compaction and produce higher dry density. However, at high moisture content, dry density decreases with increasing moisture content of the bulk soil volume when filled with water. The presence of liquid in the soil leachate increases the saturation of the soil and this has resulted in the reduction of the maximum dry unit weight and optimum moisture content of soil. Similar findings have been reported in Harun et al. (2013).

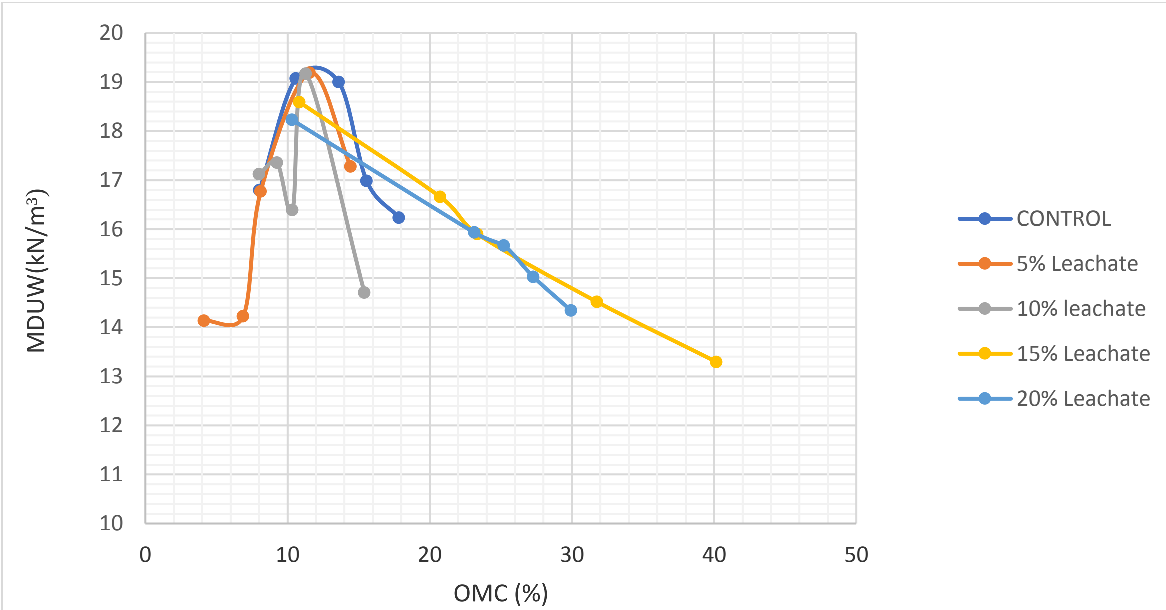

Figure 4: Deductions from Compaction Tests

The decrease in maximum dry unit weight reflects the effect caused by chemical reaction (due to change in the nature of the pore fluid) between the leachate and the soil as shown in figure (5). At 15% and 20% leachate concentration, a significant amount of leachate was already present in soil which led to the ability of the soil to absorb increased amount of moisture from compaction. This resulted in the subsequent drop in the maximum dry unit weight values after the initial rise of 18.59kN/m³ and 18.23kN/m³ at moisture content values of 10.54% and 10.33% for 15% and 20 % leachate contamination respectively.

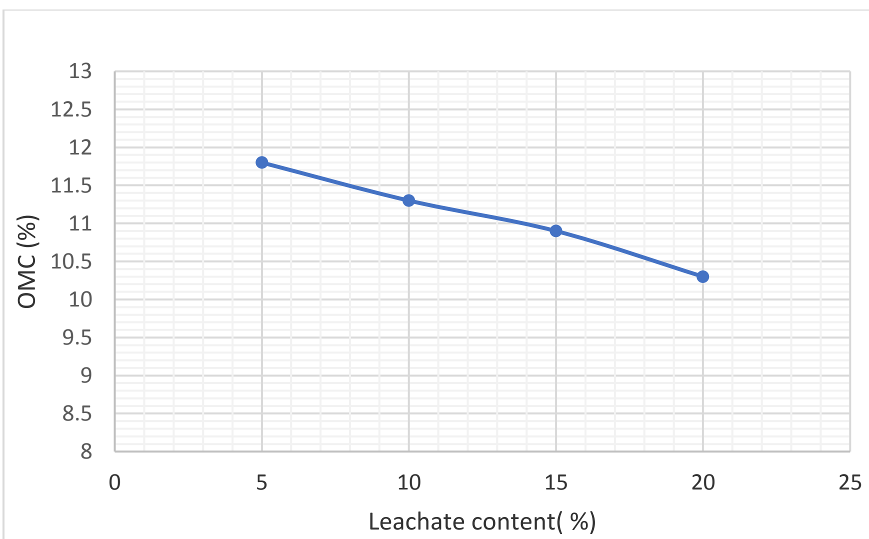

Figure 5: Graph of OMC against leachate contents

3.5 Unconfined compressive strength

From the results obtained from the unconfined compressive strength test, the maximum value of the unconfined compressive strength reduced from 229.401kN/m^3 to 169.94185kN/m^3 as leachate sample was increased from 0% to 20% as shown in Figure (6). Also, as the leachate sample was increased, the cohesive strength of the soil reduced from 114.701kN/m^3 to 84.97kN/m^3.

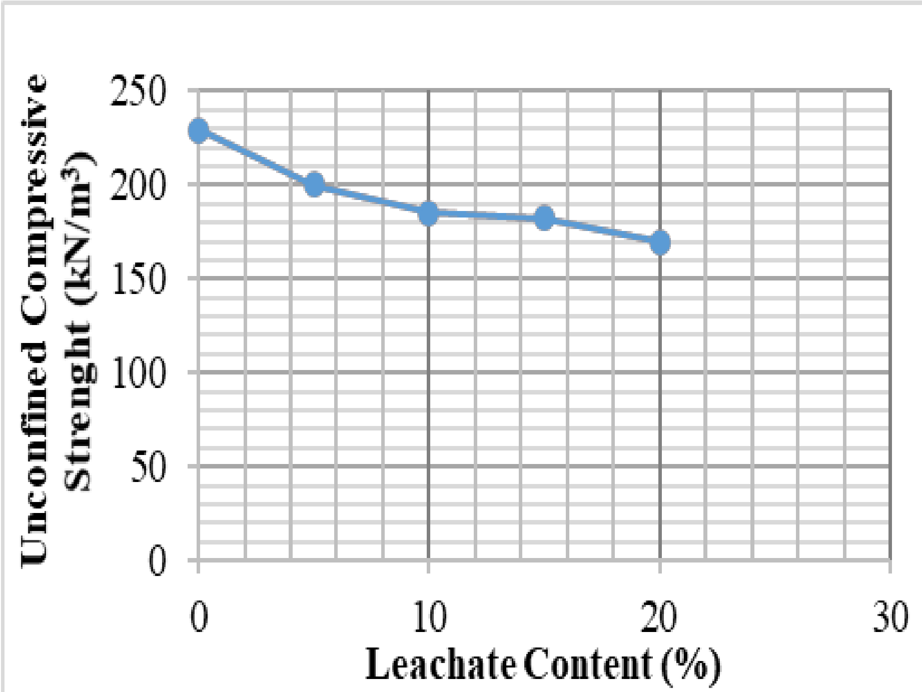

Figure 6: Graph of Leachate content against unconfined compressive strength

The summary result of unconfined strength property has been plotted graphically. From the graph presented above, it can be deduced that the value of unconfined compressive strength of the soil decreased as leachate percentage contamination was increased. Hence, it can be seen that presence of leachate in soils have negative impacts on the cohesive and unconfined compressive strength properties. Irfan et al. (2018) reported similar results stating almost 60% decrease in unconfined compressive strength of the clay soil with high plasticity for both basic and acidic effluents. They attributed the decrease to possible breakage of internal bonds as investigated by Umesha, Dinesh and Savapullaiah (2012).

4.0 Conclusion

Leachates have effects on strength and geotechnical properties of soils. Soil-leachate interactions can affect liquid limit, plastic limit, compaction characteristics, and strength properties of soils. The adverse modification of these soil properties can lead to various geotechnical problems such as landslides, ground subsidence, erosion, which affects underground structural stability because the polluted water attacks foundation structures. This study indicates that the value of plastic limit, liquid limit and plastic index were decreased with increasing leachate contamination in the soil. The increasing of leachate contamination also negatively affects soil compressive strength. The value of UCS decreased when the leachate content increased. The cohesive strength of the soil was also decreased by 25.92% when compared with the control value of 114.701kN/m^3. Maximum dry unit weight and optimum moisture content also decreased with the increase of leachate content. Based on this study, the presence of leachate fluid in the soil brings negative impact to the strength and geotechnical properties of lateritic sandy-clayey soil.

5.0 Recommendation

Based on the conclusion drawn above, it is recommended that:

i. Soil-leachate contamination must be recovered before any construction is done. Stabilization method for treatment of such soils has been recommended in literature.
ii. The effect of leachate on other test properties of different soil types should be investigated.
iii. Also, leachate samples with higher concentrations of contaminants can be investigated.

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